Concept for Increasing the Resilience of Manufacturing Companies

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Abstract. In the context of sustainable management, organizational resilience is gaining importance. Manufacturing companies are increasingly exposed to external disturbances. Crisis-resistant product development is of particular importance, as innovative products offer a promising opportunity to create competitive advantages and thus secure the company's existence or even enable a company to increase its market share in the event of a crisis. At the same time, corporate functions today are usually geared towards efficient execution. In this context, the paper presents a concept for the alignment of product development in the conflict between efficient goal achievement and the prevention of the impacts of disturbances. For this purpose, the design elements, goals and relevant disturbances of product development are taken into account. Based on the interdependencies of these elements, a methodological approach for a company-specific determination of the target characteristics of the design elements is presented, in order to enable an alignment in the conflict between efficient goal achievement and resilience. The concept is designed to the alignment of product development, but can be transferred to other corporate functions and corporate divisions.

Keywords: Resilience · Product development · Efficiency

1 Introduction

Modern value chains are usually organized towards efficiency and productivity. However, the effects of the Corona pandemic exemplarily illustrate the vulnerability of these value chains to disturbances and crises. There is a conflict between the efficient achievement of corporate goals and the prevention of the impacts of disturbances. Efficiency-oriented companies perform better than resilience-oriented companies do in times of no crisis. In the event of a crisis, however, the performance of efficiency-oriented companies decreases rapidly and their existence may be threatened. Science, politics and industry have recognized the need for action. [1, 2] The goal of a resilient design of value chains has emerged [3]. In particular the corporate function of product development plays a decisive role here. Innovative products that meet the market requirements better than competitor products enable competitive advantages [4] and thus ensure the probability of survival or even enable a company to increase its market share in the event of a crisis.

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M. Liewald et al. (Eds.): WGP 2022, LNPE, pp. 761–770, 2023.
https://doi.org/10.1007/978-3-031-18318-8_75

This paper defines organizational resilience as a company's ability to anticipate, deal with and adapt in the aftermath of disturbances [5, 6]. Crises are typically the result of a combination of multiple disturbances [7]. Disturbances are more frequent and more difficult to predict and deal with in volatile, uncertain, complex and ambiguous times [8]. Product development, as with the entire company, is under the influence of external and internal disturbances. Examples of disturbances can be the extreme situation of the Corona crisis, but weaker disturbances such as new regulations or emerging technologies of competitor companies can also have a disruptive influence. [6]

Both a sufficient level of efficiency and resilience must be ensured. Within product development, there is usually a reactive, short-term handling of the impacts of disturbances [9], which must be replaced by a preventive approach. For this reason, answering the following question promises relevant information: How can product development be aligned within the conflict of efficient goal achievement and prevention of the impacts of disturbances? The concept presented in this paper is intended to present answers to this question and enable companies in the manufacturing industry to position themselves at the desired level of resilience through the alignment of product development. The concept is based on [6] but includes relevant changes and concretizations in all submodels.

2 Fundamentals

The purpose of this section is to provide relevant basics and definitions of resilience, crisis management and product development. According to [5], organizational resilience describes the company's ability to anticipate, deal with and adapt in the aftermath of disturbances. Organizational resilience can therefore also be interpreted as the ability of a system to withstand crises. Resilience makes a system more capable of acting in crises, but it is not meant to overcome all negative influences of a crisis. Accordingly, the added value of a resilient organization is particularly advantageous in times of crisis, but is often neglected in times of abundance [2, 6]. Corporate crises are unplanned, undesirable and temporary processes with ambivalent results, which can threaten the existence of a company in the long term [10]. Three categories can be distingusted. Strategic crises, success crises and liquidity crises are usually passed through in sequence and increase in their negative effects [11]. The extent of the threat and the need for action increases continuously and the scope for action for the company decreases gradually with each category [12].

The corporate function of product development focuses on the design of products and variants for specific customers or the anonymous market based on requirements, applications and specifications using available technology [13]. Product development is an interdisciplinary corporate function with multiple interfaces. A distinction is made between two viewpoints on product development. On the one hand, product development controls the processes of development activities and the actions of the associated employees and teams. [14] A distinction can be made between classical, plan-oriented, sequential, iterative and hybrid processes. On the other hand, product development is an organizational unit, which describes the structure of the necessary workspace, the allocation of the unit into subsystems and the assignment of subtasks to the respective subsystems [15]. [6, 16]. The concept follows the presented basics and definitions.

3 Related Work

The following section discusses existing approaches to organizational resilience in the context of product development.

Fundamental principles of organizational resilience and related attributes is provided by ISO 22316 [17]. The norm provides generally applicable principles for organizations regardless of size, industry or sector. Due to the general approach, the norm does not provide concrete approaches for an implementation and does not go into details of different business functions.

DIN ISO 31000 [18] provides guidelines for successful risk management in organizations regardless of the nature of the risk. The norm provides principles for organizations regardless of size, industry or sector. Risk management is presented as a multi-phase process consisting of communication and consultation, context setting, risk identification, analysis, assessment and treatment, as well as monitoring and review. In [19], literature regarding risk management in product development is reviewed using the framework of DIN ISO 31000 [18]. This shows that the applicability of the norm is given, but there are shortcomings in the implementation.

A practical approach is taken in [20]. In the paper, an exploratory study of crises in product development is conducted with designers from industrial practice. It included 15 examples of crises in product development to develop a total of 9 contextual factors to characterize product development crises and 56 success factors for managing crises.

Reference [21] provides an overview of resilient technology strategies in volatile environments by deriving requirements for long-term strategic positioning in VUCA times. It is stated that a successful technology strategy in VUCA environments requires context-adaptive technology planning through clear and consistent strategic goals.

In summary, the approaches presented emphasize the importance of organizational resilience. However, the trade-off between efficient goal achievement and resilience is not adequately addressed. Additionally, it has to be noted that none of the approaches simultaneously considers product development and its contribution to the resilience of the overall company. This paper aims to address the identified weaknesses in the aforementioned literature.

4 Methodology

This paper presents a concept for increasing the resilience of manufacturing companies through the alignment of product development in the conflict between efficient goal achievement and prevention of the impacts of disturbances. The concept is divided into five submodels (see Fig. 1). In submodel one, the procedure for deriving goals of product development from corporate goals is presented. Submodel two describes the procedure for the determination of relevant disturbances for product development. The approach for developing a morphology of the design elements of product development results from submodel three. In submodel four, a procedure for explaining interdependencies between goals, disturbances and design elements are determined. Submodel five presents a methodical approach for a company-specific determination of the target characteristics of the design elements of product development, in order to enable an alignment in the conflict between efficient goal achievement and resilience. The concept is geared to the sensible alignment of product development, but can in principle be transferred to other corporate functions and corporate divisions.

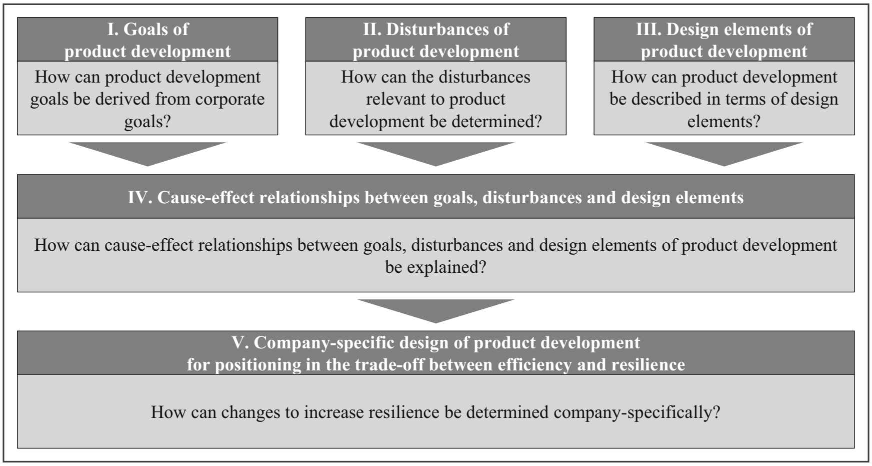

Fig. 1. Concept for the alignment of product development in the conflict between efficient goal achievement and the prevention of the impacts of disturbances

4.1 I. Derivation of Product Development Goals from Corporate Goals

A resilient company strives to achieve its goals in the best possible way even in times of crises. The subject of the first submodel is therefore to derive product development goals from overall corporate goals for the manufacturing industry. This is a prerequisite for the explanation of the cause-effect relationships between goals, disturbances and design elements of product development in the fourth submodel.

The first step is to describe and hierarchize corporate goals. With the help of an analytical deductive analysis of existing approaches in the scientific literature and an empirical inductive analysis of case studies of manufacturing companies, the relevant goals of companies in the manufacturing industry are elaborated. Subsequently, the identified corporate goals are arranged in a hierarchical structure. Financial, environmental, social and regulatory corporate goals such as productivity, environmental performance and workplace safety must be taken into account.

The second step is to describe and hierarchize product development goals. Analogous to the derivation of corporate goals, relevant product development goals are elaborated with the help of an analytical deductive analysis of existing approaches in the scientific literature and an empirical inductive analysis of case studies. This is followed by their hierarchization, taking into account both the result-side and the cost-side goals of product development.

Finally, an assignment of corporate goals and product development goals is made based on evaluation criteria, which enable an examination of possible correlations between the respective lowest levels of corporate and product development goals. The result of submodel one is a model for describing product development goals based on corporate goals.

4.2 II. Derivation of Disturbances Relevant to Product Development from Corporate Disturbances

The subject of submodel two is the derivation of disturbances that are relevant to product development. This is a prerequisite for the explanation of the cause-effect relationships between goals, disturbances and design elements of product development in the fourth submodel. The description here is limited to exogenous disturbances, which by definition cannot be influenced by a company. Endogenous disturbances can be influenced by the company and are therefore interpreted as potential design elements in the third submodel.

The first steps are a literature review and expert interviews on exogenous disturbances. For this purpose, first an analytical deductive analysis of existing approaches in the scientific literature and an empirical inductive analysis of case studies of manufacturing companies are conducted. Redundancies are then eliminated. This is followed by further consolidation using a design structure matrix. Substitution technology, entry of new competitors, change in legislation and esource scarcity are examples for disturbances.

In the second step, the disturbances relevant to product development are selected. The concept is focused on the corporate function of product development. Therefore, the total amount of exogenous disturbances has to be reduced to the subset of disturbances relevant for product development. For this purpose, suitable criteria for assessing the product development relevance of exogenous company disturbances are defined and applied to the total set of disturbances.

In the third step, the effect-relevant disturbances are selected. The totality of exogenous disturbances can be divided into cause-related disturbances and effect-related disturbances. Relevant, however, are the effect-related disturbances, which can become apparent due to the impact at the company and must be addressed. For this purpose, an effect network is constructed, which sorts the elaborated disturbances into the cause level or the effect level. From the effect network, conclusions can be drawn about the concatenation of the disturbances. The result of submodel two is a model for describing the disturbances relevant to product development.

4.3 III. Description of Product Development Based on Design Elements and Characteristics

Submodel three describes the corporate function of product development based on design elements as well as their possible characteristics. It represents a further prerequisite for the explanation of the cause-effect relationships between goals, disturbances and design elements of product development in the fourth submodel. The design elements are the parameters for aligning product development with the conflicting goals of efficient goal achievement and prevention of the impacts of disturbances.

The first step is a collection of design elements of the corporate function product development. The design elements are derived analytically deductively from existing approaches and models in the scientific literature. For example, publications such as VDI Norm 2221 [14] are used to describe the product development process. Other relevant publications describe the object area of product development, the product development organization and culture. The collection is supplemented by empirically inductively derived design elements from industry projects as well as structured expert interviews with participants of industry working groups of the authors.

In the next step, the design elements are consolidated by eliminating redundancies and by means of a design structure matrix. To structure the design elements in a meaningful way, superordinate dimensions are formed in which the design elements can be classified. In this way, a systematic presentation can be ensured.

Finally, the design elements of product development are operationalized by defining potential characterisitcs for every design element. For this purpose, the results of the scientific literature and the industry exchange are used. The result of submodel three is a model for the morphological description of product development (see Fig. 2).

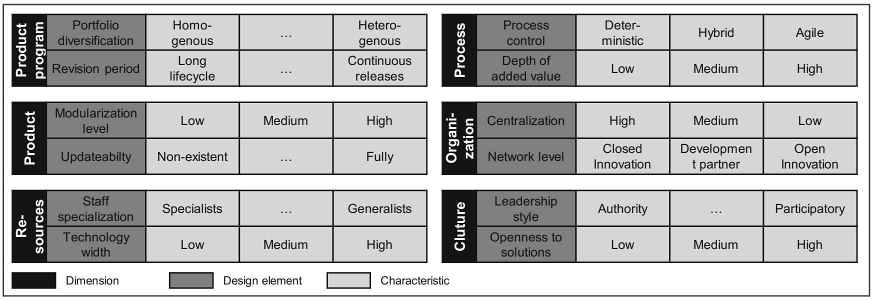

Fig. 2. Description of product development based on exemplary design elements and characteristics

4.4 IV. Explanation of the Cause-Effect Relationships Between Goals, Disturbances and Design Elements of Product Development

Submodel four explains the cause-effect relationships between design elements and goals, design elements and disturbance, and within design elements of product development. It has to be noted that no direct cause-effect relationships between goals and disturbances of product development are considered, since goals cannot influence exogenous disturbances. Although disturbances have an influence on the subsequent achievement of goals, they do not effect the initial definition of the goals.

A conformity matrix is created from the characteristics of the design elements and the goals of product development. For each cell of this matrix, the following question has to be answered: "How well is the characteristic of the design element separately suited for achieving the goal?" An additional conformity matrix is formed from the characteristics of the design elements and the disturbances of product development. For each cell of this matrix, the following question has to be answered: "How well is the characteristic of the design element separately suited for the prevention of the impact of the disturbance?" In addition, an influence matrix is created in which the characteristics of the design elements of product development are compared. For each cell of the matrix, the following question is to be answered: "How does a horizontal characteristic of the design elements influence a vertical characteristic of the design elements? Decisive prerequisites for reliable answers to the formulated questions are the precise and comprehensible formulation of the design elements including their characteristics, goals, as well as disturbances of product development. In addition, a Likert scale that is understood uniformly by all interview partners is constructed.

In the next step, the cause-effect relationships are logically derived through expert interviews and literature research. In the course of preparing the interviews, the interview guidelines are developed and tested in advance. In addition, managers and experts in product development are selected as suitable interview partners. For this purpose, the network of scientists and participants of the authors' industry working groups are used. This is followed by a structured and recorded interview process and systematic interview evaluation.

Based on the results, both goal-related and disturbance-related conformity sums can be calculated for the characteristics of the design elements. Thus, it becomes clear which characteristics positively influence the achievement of goals and which characteristics positively influence the prevention of the impacts of disturbances. In the influence matrix of the design elements, active and passive sums can be determined for each characteristic of the design elements. This shows which characteristics of a design element positively influence or are influenced by other characteristics of other design elements. The result of submodel four is a model for explaining the interdependencies between goals, disturbances and design elements of product development. Figure 3 shows the matrices with exemplary design elements, goals and disturbances.

4.5 V. Company-Specific Design of Product Development for Positioning in the Trade-off Between Efficiency and Resilience

Submodel five defines the company-specific changes for positioning in the trade-off between efficiency and resilience. From the totality of disturbances relevant to product development, one company specifically chooses the disturbances relevant for the company. For handling these relevant disturbances, an adjustment of the characteristics of the design elements is to be examined. Potential negative effects of an adjustment on the goal achievement in times without disturbances are to be accepted. This results in an increase of the company's resilience.

First, the company-specific product development goals and disturbances are derived, prioritized and weighted. To determine the relevant goals and disturbances, the company applies the results from submodels one and two and weights these elements.

Subsequently, the conformity matrices are reduced accordingly by deleting the rows with goals and disturbances that are not relevant for the company. After checking the numerical values from submodel four for the specific use case of the company, the specific goal-related and disturbance-related conformity sums can be determined for each design element characteristic. Both sums are connected with each other via the risk affinity factor. The risk affinity factor is the ratio of the specific weighting of goals to the prevention of impacts of disturbances. This results in the company-specific, combined conformity sum for each characteristic of the design elements. These values are used to weight the numerical values of the influence matrix of the design elements from

Goal: **Goal-related** design of product development

		PD design elements						
		Inno. deg		Net. deg		Proc. ctrl.		…
		Incremental	Disruptive	Closed Innovation	Open Innovation	Deterministic	Agile	…
PD goals	Incremental portfolio expansion	5	0	3	2	3	0	…
	Reduction Time-to-Market	2	2	1	5	1	4	…
	MC reduction through modularization	0	0	4	1	4	2	…
	…	…	…	…	…	…	…	…
CS_G		20	5	12	30	30	17	…

Goal: **Disturbance-related** design of product development

		PD design elements						
		Inno. deg		Net. deg		Proc. ctrl.		…
		Incremental	Disruptive	Closed Innovation	Open Innovation	Deterministic	Agile	…
Disturbances	Substitution technology	1	5	2	5	2	4	…
	Skills shortage	2	2	1	4	1	1	…
	Change in customer requirements	1	2	2	5	1	5	…
	…	…	…	…	…	…	…	…
CS_D		8	14	9	42	14	29	…

CS_G: Goal-related conformity sum
CS_D: Disturbance-related conformity sum
0: No conformity between characteristic and goal/disturbance
1: Very weak conformity
2: Weak conformity
3: Medium conformity
4: Strong conformity
5: Very strong conformity

Goal: **Sensible** design of product development

			PD design elements								
			Inno. deg.		Net. deg		Proc. ctrl.		…		
			Incremental	Disruptive	Closed Innovation	Open Innovation	Deterministic	Agile	…	AS	|AS|
PE design elements	Inno.	Incremental			1	-1	1	0	…	0	10
		Disruptive			0	1	0	1	…	1	6
	Net.	Closed Innovation	1	0			0	-1	…	0	4
		Open Innovation	0	1			0	1	…	2	5
	Proc.	Deterministic	1	0	0	0			…	0	0
		Agile	0	1	0	1			…	4	8
	…	…	…	….	…	…	…	…		…	…
PS			3	2	-1	2	0	-1	…		
|PS|			8	6	9	9	6	8	…		

1: Positive influence
0: No influence
-1: Negative influence
AS: Active sum
PS: Passive sum

Fig. 3. Cause-effect relationships between goals, disturbances and design elements of product development

submodel four. Therefore, the results are the conformity sum-specific active and passive sums per design element characteristic.

In the last step, the adaptation measures are determined, taking into account the conformity of the overall system. For this purpose, a portfolio is created in which the characteristics of the design elements are classified according to their respective conformity sum-specific active and passive sums. Based on the calculated sums, critical, active, inert and reactive characteristics can be distinguished. The structure of the portfolio is based on the method of networked thinking [22]. The relationships shown in the portfolio can be used to derive optimization approaches for the company-specific positioning in the trade-off between efficient goal achievement and prevention of impacts of disturbances. Taking into account the current characteristics of each design element in the company and estimating the required time and financial transformation effort, target characteristics can be defined for each design element. The result of submodel four is a model for the company-specific definition of the characteristics of the design elements.

5 Conclusion

The manufacturing industry faces major challenges. Exogenous, combined disturbances are gaining in importance. The presented concept enables the positioning of corporate functions and corporate divisions in the area of conflict between the efficient achievement of goals and the prevention of the impacts of disturbances. On the one hand, the paper is targeted at researchers in the fields of product development and organizational resilience.

However, the methodology is transferable to other corporate functions and divisions. On the other hand, the paper is aimed at managers of manufacturing companies who want to make their company resilient to disturbances.

Based on the derivation of product development goals from corporate goals, the derivation of product development relevant disturbances from corporate disturbances, and the description of product development based on design elements and characteristics, the cause-effect relationships between goals, disturbances and design elements of product development are explained. This allows the design elements of product development to be configured company-specifically, thus enabling the positioning in the trade-off between efficiency and resilience.

The presented topic is currently being researched as part of a dissertation at the Chair of Production Engineering of the Laboratory for Machine Tools and Production Engineering WZL at RWTH Aachen University. It will be applied in consulting projects and industry working groups to ensure its feasibility in industrial applications.

Acknowledgment. Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy — EXC-2023 Internet of Production — 390621612.

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