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Interaction of Agility and Flexible Production Systems in Innovation

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Abstract: Agility is already widespread in software development, but not yet in the product development of mechatronic products. However, agile companies have a competitive advantage in dynamic markets as they can react quickly and appropriately to changing circumstances. In this scientific research effort, the challenges industrial companies face when implementing agility in product creation were investigated. With the help of an empirical study with industry representatives, agility barriers were identified. Flexible production systems like the 'Value Stream Kinematics' provide benefits for producing companies through their specific use-cases. The synthesis of the results - i.e. the comparison of the agility barriers within industrial companies and the specific use cases of a flexible production system - shows that agility barriers in product development and innovation management can be overcome by utilizing a flexible production system.

Keywords: Agility, Agile Product Development, Innovation Management, Flexible Production Systems, Value-Stream-Kinematics, Product-Production-CoDesign

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1. Motivation & State-of-the-art

Increasing customer requirements, shorter product life cycles and more and more stringent legal guidelines lead to increasing complexity and dynamics of the entire product development process (Fettig, Gacic, Koskal, Kuhn & Stuber, 2018). Agility is a central instrument for being able to react appropriately to dynamic influences and to enable innovation capability (Förster & Wendler, 2012). Agile methods originated and are already widespread in software development but given the advantages their application in the product development of mechatronic products is also increasingly in the interest of industrial companies (Albers et al., 2019; Cooper, 2014). However, rigid, and inflexible production systems can no longer meet the requirements of agile product development and innovation processes.

It is therefore necessary to analyze how agility barriers in the innovation process can be dissolved making use of flexible production systems that can react flexibly to production system-related requirements of the respective product to be manufactured.

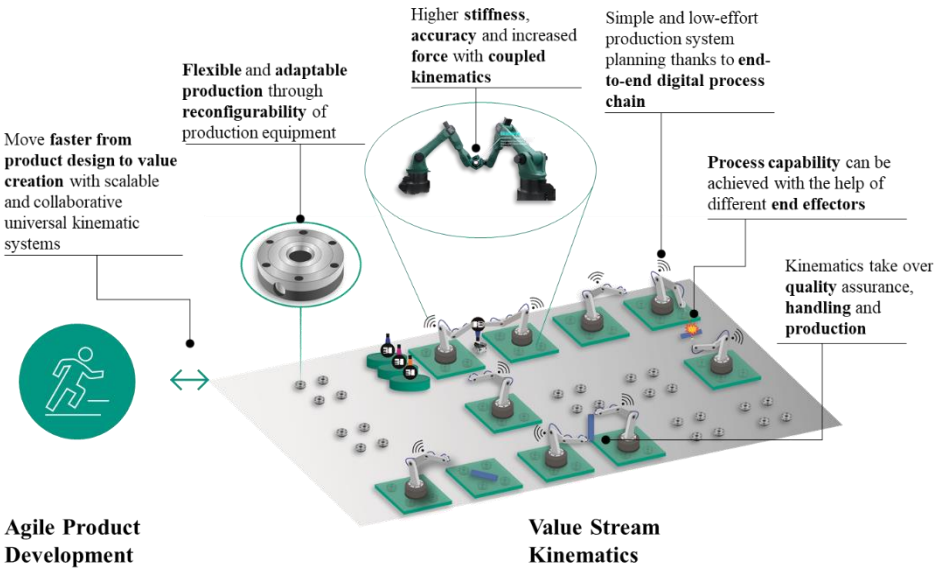

Figure 1.1: Vision of the flexible production system 'Value Stream Kinematics' (Mühlbeier, Gönnheimer, Hausmann & Fleischer, 2020)

This research effort is based on the flexible production system 'Value Stream Kinematics'. The novel production concept envisions the design of

entire productions based on the interlinking of numerous machines of identical, robot-like kinematics. The production system created in this way has a mutability that enables the full potential of Industry 4.0 to be exploited and contributes to the sustaining and adaptation of global value chains. (Kimmig, Schöck, Mühlbeier, Oexle & Fleischer, 2021; Mühlbeier, Oexle, Gönnheimer & Fleischer, 2021).
The goal of this analysis is to identify potentials for the product creation process through the interaction of agility and flexible production systems. The analysis is based on the integrated approach of Product-Production-CoDesign. Product-Production-CoDesign are highly collaborative and parallelized activities i.e. the iterative planning, development and realization of products and the associated production system (Schäfer, Burkhardt, Kuhnle & Lanza, 2021).

2. Research Profile

The aim of this scientific work is to identify potentials that arise from the interaction of agility in product development and flexible production systems for the product creation process. Specifically, potentials for agility arise in this context, when use cases of flexible production systems increase the usability of agility in innovation and product creation processes and thus increase the innovation capability of industrial companies and their dynamic reaction to changes.

To achieve these goals, this paper is structured around the following research questions:

1. What barriers exist in implementation and application of agility in the product creation process?
2. Which of these barriers can be resolved utilizing flexible production systems?
3. Which use cases of a flexible production system show a high benefit for agile product creation?

The research project thus contributes to the understanding of agile product creation and innovation management.

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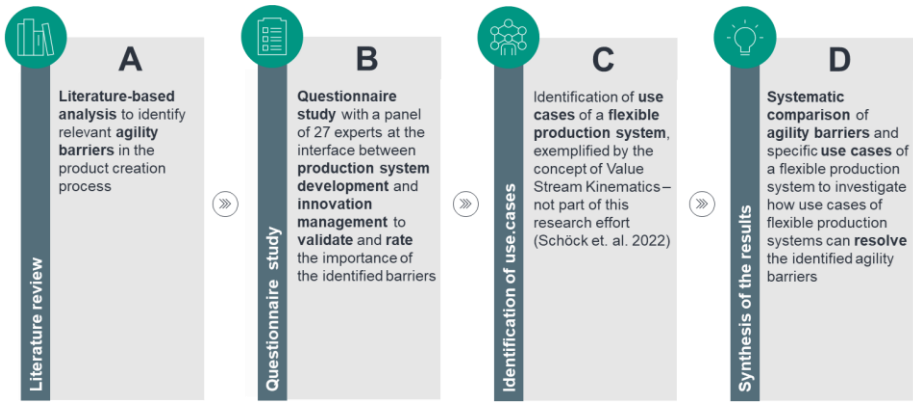

Figure 2.1: Research design

The research design follows the principles of the Design Research Methodology (Blessing & Chakrabarti, 2009). In a first step and to answer research question 1, literature research has been conducted in order to identify relevant agility barriers in the product creation process. Based on these barriers, a questionnaire study with a panel of 27 experts at the interface between production system development and innovation management has been consequently used as key empirical research method to validate and rate the importance of the identified barriers. Face and content validity of the survey have been secured by independent reviewers. Based on these results, the identified barriers were then categorized and prioritized to identify the most critical barriers.

Subsequently and to answer research question 2 and 3, it was investigated how use cases of flexible production systems (see Schoeck, Hahn, Rapp & Albers, 2022) can consequently resolve the identified agility barriers. The Value Stream Kinematics has been used as an example for flexible production systems. Identified agility barriers and the specific use cases of a flexible production system were systematically compared. By resolving agility barriers, agile approaches can be further anchored in product development and innovation management processes.

3. Determination of Agility Barriers in Product Development

In a first stage, agility factors that represent a potential challenge in the implementation of agility in product creation were identified based on a literature research effort (following Albers, Heimicke, Trost & Spadinger, 2020, Appendix A). The factors were clustered into 16 agility factors and can be subdivided into the categories management, staff, characteristics of

mechatronic products, communication and cooperation as well as production system (see Figure 3.1).

Production System	Communication & Cooperation	Staff	Management	Characteristics of mech. prod.
1 Highly integrated subsystems in production systems	1 Decentralized or distributed teams	1 Motivation of the staff to increase agility in product development	1 Agile culture lived out by the management	1 External dependencies
2 Disturbances of the production system	2 Existence and functionality of a central knowledge database	2 Knowledge and qualifications of the staff for the implementation of agility in PD	2 Knowledge and qualifications of mgmt. for the implementation of agility in PD	
3 Comparability of collected data on product creation processes	3 Communication and cooperation with other teams and/or departments	3 Different understanding of agility in the company	3 Fear of loss of control	
4 Adaptability and expandability of the production system				
5 Flexibility of the production system				
6 Degree of automation of the production system				

Figure 3.1: Clustered agility barriers

These barriers were subsequently reviewed in a bipartite survey of industry representatives. The target group for the survey were experts at the interface of product development or innovation management and production system development covering a broad cross-section of 27 industry representatives of different responsibilities and ages from companies of all sizes and a wide range of industries involved in the development of mechatronic products. The aim was to identify which of the factors pose a particular challenge when it comes to implementing agility in product creation and innovation management processes.
In the first part of the survey, the identified factors were listed and weighted by the respondents according to their general influence on agility in product development. In the second part, the respondents were then asked about the extent to which the individual factors were relevant to the respective industrial company – given the individual boundary conditions for the

implementation of agility in their respective industrial company. The respondents rated the factors according to their importance, and then revealed how maturely the individual factors are implemented in their company. Accordingly, a factor that is simultaneously relevant for the general application of agility in the product creation process and insufficiently implemented in the company represents a barrier to the implementation of agility in product creation. The two components "*relevance*" and "*relevance in the company regarding implementation*" were made quantifiable with the aid of a Likert scale and were given equal linear weighting. The evaluation of the survey resulted in a matrix in which the two characteristic values were mapped against each other.

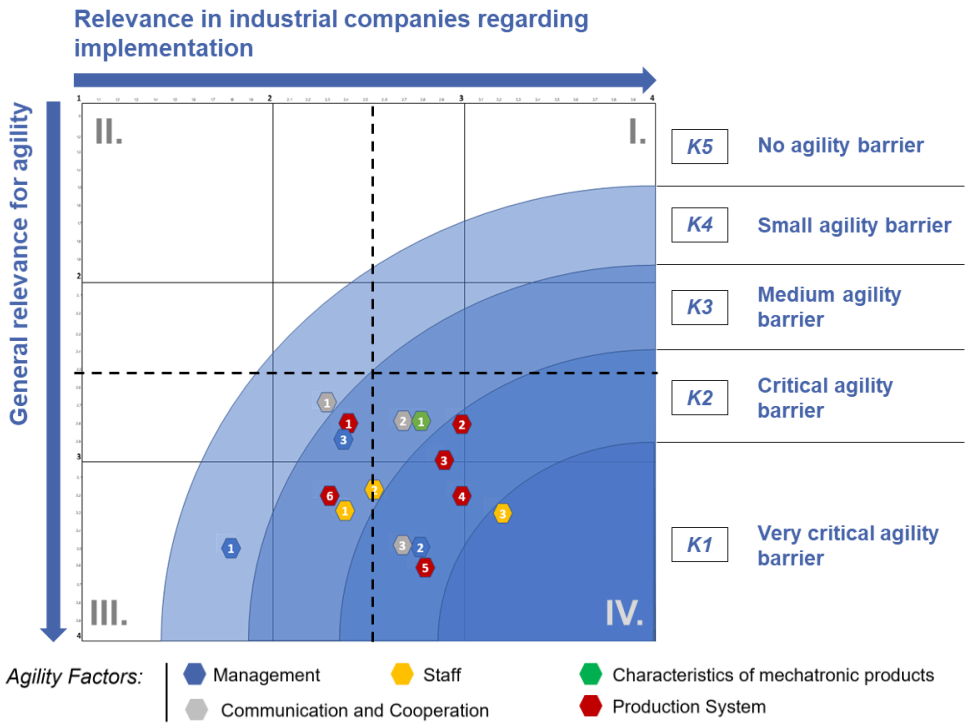

Figure 3.2: Agility barriers classified according to general relevance in product-creation processes and relevance in industrial companies (categories 1-4)

The matrix was divided into five categories:
Factors in **category 5** (K5) have no influence on the implementation of agility and/or are already optimally implemented in the company and therefore do not represent a barrier. None of the factors resulted to be categorized as being in category 5, so none of the factors is considered

unimportant or already optimally implemented in the company. This confirms that all 16 factors represent a barrier to the implementation of agility in product development and innovation management.

The factors in **category 4** (K4) represent a small barrier to the implementation of agility according to the presented evaluation logic. The factor "*agile culture lived out by the management*" (#1 blue in Figure 3.2) can be interpreted as an outlier from the field of other factors. The industry representatives rate this factor as very important but think that the agile culture is already well exemplified by the management in their respective industrial company. The agile culture therefore has a great influence on the implementation of agility in product development but does not represent a critical barrier because it is already well developed in industrial companies. The factors "*Highly integrated subsystems in production systems*" (#1 red), "*Motivation of the staff to increase agility in product development*"(#1 yellow), "*Knowledge and qualifications of the staff for the implementation of agility in product development*" (#2 yellow) and "*Degree of automation of the production system*" (#6 red) are rated in **category 3** (K3) and thus can be interpreted as a medium barrier.

Factors in **categories 1** and **2** (K1/K2) were rated as having more than a medium influence on agility and/or as being poorly implemented in the company. Thus, such a factor, which is characterized equally by a high relevance and an insufficient implementation in the company, represents a critical barrier. Seven of the 16 barriers could be classified as "*critical*" or "*very critical*". The factors "*disturbances of the production system*" (#2 red), "*comparability of collected data on product creation processes*" (#3 red) and "*adaptability and expandability of the production system*" (#4 red) were each rated as having a medium to high influence on agility. At the same time, these factors are among the four least implemented factors in a company. This means that there is a great need for improvement here, which is why they represent a critical barrier. The factor "*flexibility of the production system*" (#5 red), meaning the possibility to produce different products using a single production system, is marginally better implemented in the company compared to the previous three factors. However, it is weighted with a very high influence on agility - the highest of all identified factors. Therefore, the "*flexibility of the production system*" with its large impact on the implementation of agility is equally a critical barrier. The factors "*communication and cooperation with other teams and/or departments*" (#3 grey) and "*knowledge and qualifications of management for the implementation of agility in product creation*" (#2 blue) can also be interpreted as posing a critical barrier. The only factor located in category 1

"*different understanding of agility in the company*" (#3 yellow) represents a very critical barrier.

In summary, seven of the 16 agility barriers could be classified as "critical" or “very critical”. It is striking that four of the seven critical barriers are production system-related factors. The characteristics of the production system could therefore be regarded as having an important influence on the implementation of agility in product development.

4. Resolving Agility Barriers utilizing Flexible Production Systems

The second stage of this scientific work examined how the identified critical agility barriers can be overcome with the help of specific use cases of flexible production systems. A particular focus was on overcoming the critical agility barriers in category 1 and 2.
A use case describes a use situation in which flexible production systems provide an advantage over rigid production systems. With the help of a persona workshop on the topic of flexible production systems using the example of Value-Stream-Kinematics, ten use cases were identified clustered along three categories (Schoeck et al., 2022).

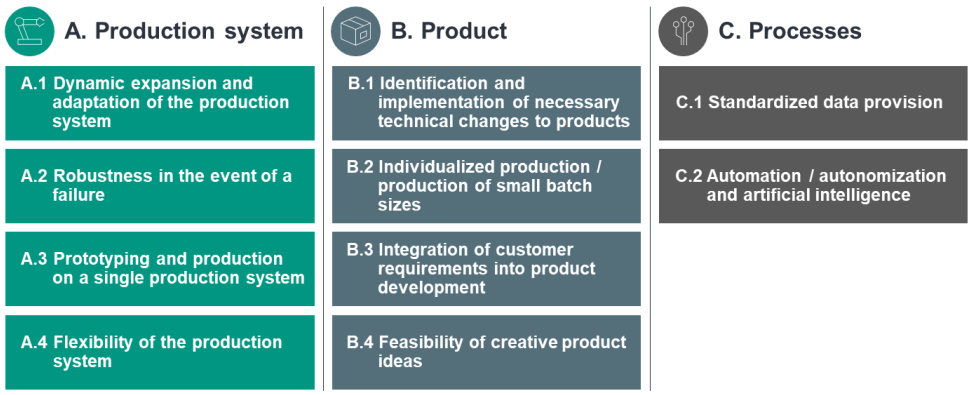

Figure 4.1: Use-cases of a flexible production system (Schoeck et al., 2022)

If a critical agility barrier can be dissolved with the help of a use case of a flexible production system, a potential for agile product development and innovation management could be identified. In Figure 4.2 shows the results of a systematic comparison between the identified agility barriers (see chapter 3) and the use cases of Value Stream Kinematics as a flexible production system.

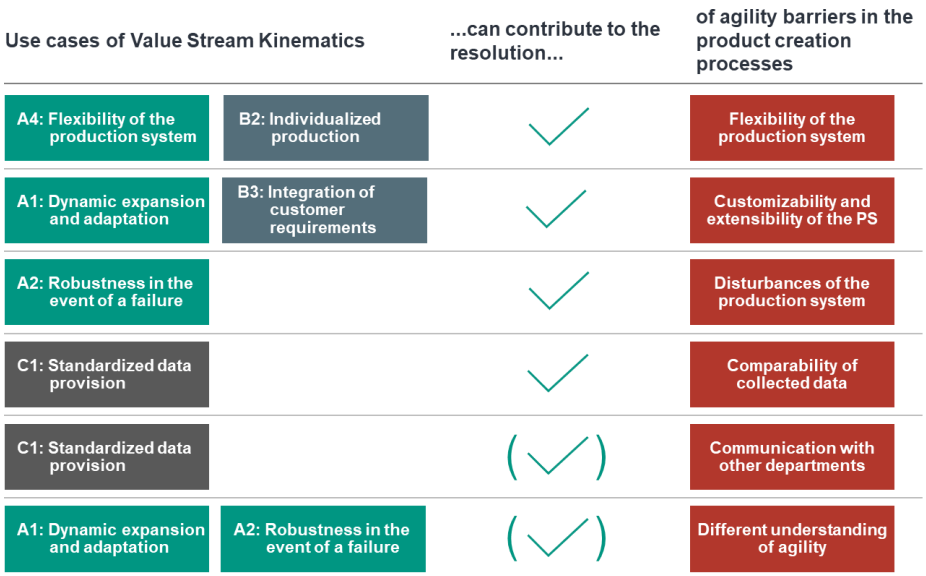

Figure 4.2: Systematic comparison of identified agility barriers and use cases of Value Stream Kinematics

The critical barrier "*knowledge and qualifications of management for the implementation of agility in product creation*" cannot be influenced by the use of flexible production systems, nor can flexible production systems completely dissolve the barrier of "*communication and collaboration with other teams and/or departments*". However, process data can be stored uniformly and made transparently accessible using flexible production systems. In this way, employees from different departments can access data e.g. via a common platform, which can facilitate collaboration between the teams. The use case "*standardized data provision*" could bring true added value in this context. Also, this use case contributes overcoming lack of "*comparability of collected data on the processes of product creation*". Another important use case of flexible production systems is the "*robustness in case of disruptions*". It can help overcoming the critical agility barrier of "*disturbances of the production system*". The lack of "*adaptability and expandability of the production system*" is another critical barrier to the implementation of agility in product creation. If product requirements change or production quantities need to be scaled, this is mostly not feasible with a rigid and inflexible production system. The use case "*dynamic expansion and adaptation of the production system*" can support to completely dissolve this barrier. A lack of "*flexibility of the*

production system" prevents the production of different products on one production system. This prevents the production of small batch sizes in particular, as these often cannot be produced profitably. By using flexible production systems, different variants of a product and even entirely different products can be mapped on one production system. Thus, the barrier of the missing "*flexibility of the production system*" is obsolete given the use case "*flexibility of the production system*".
The very critical agility barrier "*different understanding of agility in the company*" concerns human understanding and consequently cannot be completely resolved by a production system. However, it is conceivable that the use of flexible production systems can support the company in forming a common understanding of agility. It can be argued that e.g. the "*adaptability and expandability of the production system*" exemplifies the benefits of agility to the employees, so the agile production process of flexible production systems can lead to a better idea of the broad concept of agility.

5. Lessons Learned

It is undisputed that agile methods have a large potential for product creation and innovation management. Based on a deep literature research, 16 agility barriers for companies were identified. Seven of these 16 barriers were rated as "critical" by a panel of experts from companies using a questionnaire study. Thus, companies have difficulty implementing agility in product creation and as a result, are not able to fully leverage the potential of agility. The use cases of a flexible production system have the potential to completely dissolve four of the seven critical barriers. For two others, they can at least support to overcome them.
This result emphasizes the significance of the contribution of a flexible production system to the implementation and use of agility in product creation and innovation management. Overcoming the barriers creates potentials in terms of an integrated approach according to Product-Production-CoDesign for agile product creation. In particular, the flexibility and the dynamic extensibility and adaptability of a production system make it possible to overcome the challenges of an increasing complexity of the entire product creation process.
To what extent the impact and success of the developed insights can be confirmed and measured in industrial practice is part of our future research.

6. Acknowledgments

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