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Application Fields of Flexible Production Systems and Their Impact on Agile Product Creation

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Abstract

Agility is a central instrument for reacting appropriately to dynamic influences and enabling innovation capability. However, rigid production systems can no longer meet the requirements of agile product development and innovation processes. Flexible production systems like the 'Value Stream Kinematics' provide benefits for producing companies. In this research effort, the 'Persona-method' has been used to derive typical individuals who are influenced by a socio-technical system, specifically by a flexible production system. Based on these results holistic use cases of flexible production systems for the product development process and production system development were identified and described as well as discussed in detail. The comparison of agility barriers within industrial companies and the identified specific use cases of a flexible production system shows that agility barriers in product and production system development can be overcome by utilizing a flexible production system.

Keywords: Flexible Production Systems; Adaptable Production Systems; Value Stream Kinematics; Product-Production-CoDesign; Agility; Agile Product Development

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 creation process (Fettig et al. 2018). Agility is a central instrument for reacting appropriately to dynamic influences and enabling innovation capability (Förster and Wendler 2012). Agile methods originated and are already widespread in software development but given the advantages and their potential for the innovation capability of organizations, their application in the product development of mechatronic products is also increasingly in the interest of industrial companies (Albers et al. 2019; R. G. Cooper 2014; Schoeck, Batora et. al. 2023).

Flexible production systems serve as the counterpart on the production side to agile product development. It is however necessary to analyze how the ability of production systems to react flexibly to the requirements of the respective product to be manufactured can already be anchored in early product development in order to maximize the respective synergies.

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 and

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contributes to the sustaining and adaptation of global value chains. (Kimmig et al. 2021; Mühlbeier et al. 2021)

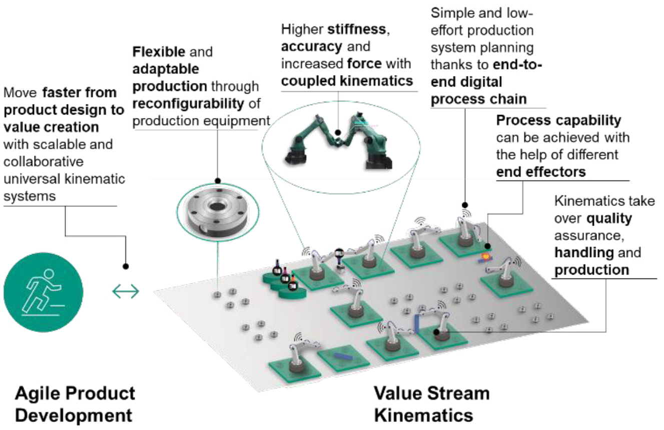

Figure 1.1: Vision of the flexible production system 'Value Stream Kinematics' (Mühlbeier et al. 2020)

2. Research Gap and Target

The aim of this research study is to identify holistic use cases of flexible production systems for the product development process. Specifically, such a use case describes an application where flexible production systems deliver an advantage over conventional production systems in product creation and production system development. Further, the potentials of these use cases are analyzed for their potential to support agility in product development and innovation management.

To achieve this goal, this research effort intends to answer the following research questions:

1. What are personas in product creation that are affected by the use of flexible production systems?
2. What are specific use cases for the implementation and application of flexible production systems in the product creation process?
3. Which of these use cases show the highest benefit for agile product creation?

The research project thus contributes to the codesign of products and related production systems, agile product creation, and innovation management.

3. Research Design

In order to identify the targeted use cases for flexible production systems according to the research gap in a methodologically supported manner, the 'Persona-Method' has been used (Hanington and Martin 2012; A. Cooper 2006). The persona method aims to identify specific personas, i.e., typical individuals who are e.g. influenced by a socio-technical system. While a persona corresponds to a fictitious character, all existing information, and knowledge is being taken into consideration when designing the personas. Such archetypal characters offer the opportunity to focus a group on certain characteristics of users while offering a more creative way of working and at the same time making the characters something visual and alive.

During a cross-domain workshop of 23 renowned experts in product development and production system development from research institutes as well as industry representatives from a broad range of companies, selective personas were defined. Based on these personas using cross-referencing of the information, ten specific use cases could be derived.

4. Personas of a flexible production system

The Persona method was carried out following five steps – from identifying stakeholder groups and attributes to the creation of specific profiles (See Figure 4.1).

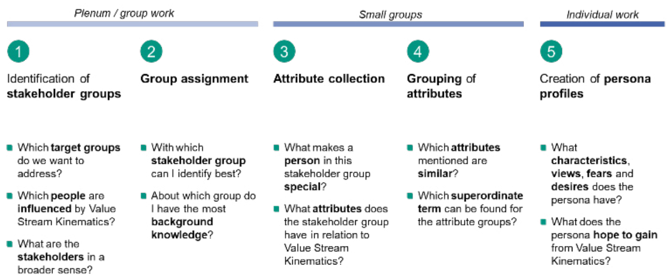

Figure 4.1: Five steps of the conducted Persona-workshop and relevant questions

As a first step, stakeholder clusters were identified by the group of workshop participants. A stakeholder is influenced by the Value Stream Kinematics and/or represents a potential target group. To generate valid information the participants were assigned to the stakeholder cluster with which they could relate best in the second step. In the third step, typical attributes of the respective stakeholders were collected within the small subgroup of participants and then clustered according to superordinate terms (step four). In the fifth step, each participant worked individually to create a persona profile. In this profile, the persona's attributes, views, and experiences with conventional production systems were stated, and the fears, wishes, and hopes for Value Stream Kinematics have been detailed. After completion of the workshop, the profiles were analyzed. Since different stakeholder groups have similar characteristics and requirements for Value Stream Kinematics, the personas were again clustered into the following three groups:

a. *Manufacturing and Collaboration:* this group consists of individual personas and organizations involved in the manufacturing of the Value Stream Kinematics production system itself. It covers personas, such as researchers and developers of the flexible production system, manufacturers of conventional machines, tool manufacturers for the end effectors, and AI startups

b. *Decision Maker:* the persona group of decision-makers consists of the general manager of the organizations that are interested in acquiring flexible production systems like Value Stream Kinematics. The analysis of the profiles suggests that the size of the companies has an impact on their requirements for Value Stream Kinematics.

c. *User:* this group consists of the heterogeneous persona group of employees in an organization, who work with Value Stream Kinematics. These include data engineers, factory planners, production managers, product developers, and manufacturing mechanics, among others.

Figure 4.2 shows the identified personas along the three groups. Additionally, further overarching or infrastructure-related personas could be identified.

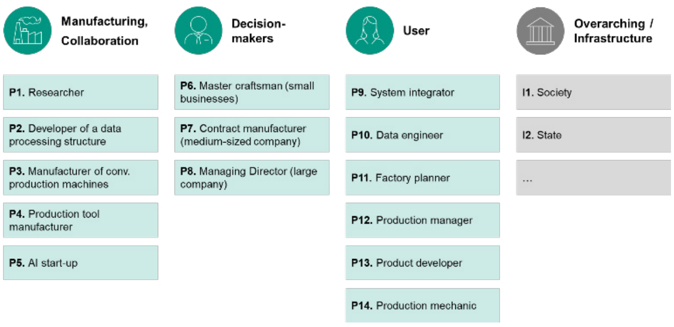

Figure 4.2: Overview on generated Personas

5. Translating Personas into use cases

A use case describes a use situation where flexible production systems like Value Stream Kinematics deliver an advantage over competing, conventional production systems. The personas were now used for a cross-referencing approach: First, similarities (in terms of information on, requirements of, or challenges in conventional production systems) in the different persona profiles were collected. Those similarities were then clustered and initial hypotheses on the current state and potentials of the Value Stream Kinematics were formed. These hypotheses were checked against all personas and were thus validated. Systematically, the advantages that Value Stream Kinematics offers were assigned, and use cases were formed. With the help of this cross-referencing approach, ten use cases specific to flexible production systems like the Value Stream Kinematics could be derived. For a better understanding of each use case, they are represented by the following three elements:

As-is / current state	*Measure*	*Result*
The as-is state describes the disadvantages or challenges of a conventional production system.	The measure in the context of the use of Value Stream Kinematics can resolve certain challenges.	The result shows the advantages and tangible benefits that arise from the use of Value Stream Kinematics.

The identified use cases can be classified into three groups: Production system - related, product-related, and process-related. An overview of all identified use cases can be found in Figure 5.1.

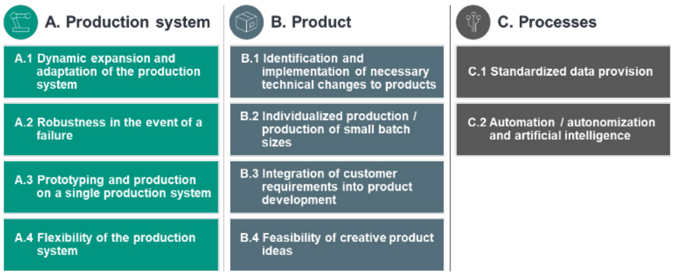

Figure 5.1: Use cases of a flexible production system

A - Production system-related use cases: The production system-related use cases represent how flexible production systems benefit the production or manufacturing of mechatronic products.

A1: Dynamic expansion and adaptation of the production system

Current state: Conventional production systems are usually rigid and can only be expanded at great expense. If a company nevertheless decides to expand, it usually incurs high initial investments that must be amortized over many years. This increases the financial risk and the danger that the machine can no longer meet the changing process requirements before its depreciation period. In addition, it is often difficult for fast-growing companies to define the appropriate level of investment. A large investment implies high financial risk, while a small investment could quickly fail to meet production requirements in the future. (Cadet et al. 2017)

Measure: The use of Value Stream Kinematics means that the production system can be dynamically adapted and expanded. It is possible for a company to initially acquire a starting base of a few kinematics and then gradually expand or adapt it in the future.

Result: Dynamic expansion means that investments can be made in line with the order situation. This minimizes the financial risk and favors the company's solvency. If the requirements for the production system change, the production system can be suitably adapted to meet the requirements.

A2: Robustness in case of failure

Current state: In conventional production systems, processes are designed sequentially. If a machine malfunctions the production flow is interrupted. Repairing the failed machine can result in long waiting times.

Measure: In the event of a failure of one of the standardized kinematics, its function can be replaced by a kinematic that is still functioning. In addition, the failed kinematics can be replaced quickly.

Result: Due to the use of standard kinematics, the Value Stream Kinematics is very robust in the event of a failure. Performance is only reduced minimally as a result with no interruption of production flow.

A3: Prototyping and production on one production system

Current state: Prototyping is usually carried out outside the productive production system or in a separate workshop. The prototyping results are collected, analyzed, and insights are then transferred to the product and the production system. This transformation typically involves an effort. (Lindermann et al. 2003).

Measure: The flexibility and especially the reconfigurability of Value Stream Kinematics allows for the production of small batch sizes (e.g. batch size = 1) on the productive production system. This enables, e.g., the production of prototypes and the production of regular products on the same production system.

Result: Knowledge gained through prototyping can be applied immediately to improve the product design according to the requirements of the final production system and process. No separate workshop and no transformation of the production system are necessary. This use case can thus save effort and costs while optimizing the quality of the processes.

A4: Different products on one production system

Current state: Due to highly specialized machines in conventional production systems, the production of different products on only one production system is a challenge; in the most extreme case, a production system can only depict one product (Cadet et al. 2017). Therefore, the development of a broad and variant-rich product portfolio is typically limited.

Measure: Standard kinematics of Value Stream Kinematics can use different end-effectors to perform various activities. This implies a changeover time of the production system within seconds, enabling the manufacturing of a variety of entirely different products.

Result: Value Stream Kinematics enables efficient production of a broad and variant-rich product portfolio. Only one production system can be used for all products produced, which saves space, time, and thus costs. The high variance of the products offers the possibility to bring completely different and highly individualized products to the market, which represents a competitive advantage.

B - Product-related use cases: The identified product-related use cases contribute to increasing the quality, individualization, and customer acceptance in the product creation process of the products produced.

B1: Implementation of technical changes right before the start of production

Current state: In production on conventional production systems, late technical changes have far-reaching effects on all departments involved. The product may have to be redesigned and the production process adapted. Tools may have to be replaced and new negotiations may have to be conducted with suppliers depending on the production processes. This is time and cost-consuming.

Measure: Simulation and virtual ramp-up of the Value Stream Kinematics allows technical changes to be identified at an early stage. At the same time, the short changeover time of the kinematics enables the technical change to be implemented quickly compared to conventional production systems.

Result: Knowledge of possible technical changes is available earlier so that the affected departments can adapt, and resources are thus saved. The principle of interchangeable end-effectors allows a short changeover time.

B2: Production of small batches / individualized production

This use case is a consequence of use case A4: "Different products on one production system".

Current state: The individualization of products is difficult to implement on conventional production systems because the production of small lot sizes on highly specialized machines is uneconomical (Bogner, Löwen, and Franke 2017).

Measure: Due to the flexibility of the production system, small batch sizes can be produced in an economically profitable way and individualized products can be brought to the market.

Result: Customers ask for increasingly unique, individually tailored products. The production of small batch sizes also offers the opportunity to test product ideas with uncertain demand on the market with a comparably small investment required. This minimizes financial risk and allows customer feedback to be obtained at an early stage.

B3: Integration of customer requirements in product development

This use case is a consequence of use case A1: "Dynamic expansion and adaptation of the production system".

Current state: In plan-driven product development processes, customer requirements are usually integrated into an early stage of product development. Companies often develop a product based on e.g., an initial market and target group analysis and later consideration of feedback from customers is usually difficult to realize - given the constraints of conventional production systems.

Measure: The Value Stream Kinematics can be dynamically adapted to changing requirements given their e.g., flexibility and easy reconfigurability. If the product developer modifies a product, these changes can be reflected easily even after the start of production.

Result: Customer feedback can be optimally integrated into the product development process at any time and consequently mapped in production. This is of enormous advantage, as products can be continuously adapted to current trends and customer requirements. If the customer's wishes are realized, the customer feels perceived and can better identify with the product.

B4: Implement creative but daring product ideas

Current state: Highly specialized production on conventional production systems often means that few different products can be manufactured (Cadet et al. 2017). As a result, product requirements are set to appeal to a large mass of customers. If a product developer has a creative but daring product idea, it usually remains an idea because the risk of commercial failure is too great.

Measure: Value Stream Kinematics can map small batch sizes and be adapted quickly. Wrong decisions can be reversed quickly.

Result: 'Trial & Error' can be lived and agile production methods benefit from the fast validation iterations. If a product developer has a creative idea, it is possible to implement it on a small scale, prototype it, and test it on the market. This can boost the motivation and creativity of product developers and ensures that product ideas that would have been discarded in companies with a conventional production system are realized.

C - Process-related use cases: Realization of process optimizations

C1: Standardized data acquisition

Current state: Individual machines often use different data processing structures. As a result, data may be stored incompletely or inconsistently. If at all possible, a complicated preparation of the incoherent data is necessary for the analysis.

Measure: In Value Stream Kinematics, standard kinematics with a uniform data processing structure are used.

Result: Due to the uniform kinematics, standardized data can be recorded for the entire production. These are available in a uniform data set and can thus be analyzed optimally. Process information is transparent and accessible so that processes can be optimized on this basis.

C2: Basis for artificial intelligence

Current state: To date, there have been isolated industrial applications of artificial intelligence. However, the more heterogeneous the production plant, the less applicable AI models become.

Measure: Value Stream Kinematics with the use of homogenous kinematics enable the application of AI models.

Result: By standardizing kinematics, AI can be used for data-based optimization of process performance and thus laying the foundation for further innovation through AI.

The identified use cases of flexible production systems serve as a basis to further develop flexible production systems as well as incorporate those into product development and production system development processes.

In previous research work by the authors, 16 holistic barriers for the implementation of agility in product creation were identified - whereas seven were classified as decisive or very decisive agility barriers (Schoeck et al. 2022). By systematically comparing agility barriers and use cases of flexible production systems, potentials for the codesign of products and related production systems could be determined. It can be shown that the use cases of flexible production systems have the potential to completely dissolve four of the previously identified agility barriers. For two others, they can at least help to overcome the challenges (see Figure 5.2 and Schoeck et al. 2022 for further details).

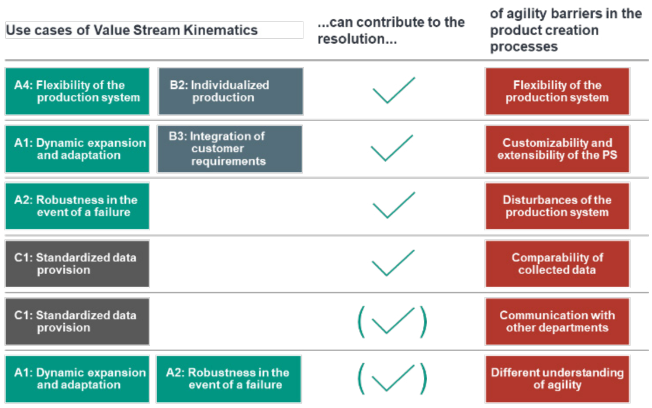

Figure 5.2: Use cases of flexible production systems and their implications on agile product development (Schoeck et al. 2022)

6. Conclusion and Outlook

This result emphasizes the significance of the contribution of a flexible production system to the implementation and use of agility in product and production system development. In particular, the flexibility and dynamic extensibility, and adaptability of a production system make it possible to overcome the challenges of increasing complexity of the entire product creation process. In this context, ten specific use cases of flexible production systems exemplified by the Value Stream Kinematics have been identified and described as well as discussed in detail. 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.

7. Acknowledgments

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8. References

Albers, Albert, Jonas Heimicke, Markus Spadinger, Nicolas Reiß, Jan Breitschuh, Thilo Richter, Nikola Bursac, and Florian Marthaler. 2019. "Eine Systematik zur situationsadäquaten Mechatroniksystementwicklung durch ASD - Agile Systems Design.".

Bogner, Eva, Ulrich Löwen, and Jörg Franke. 2017. "Bedeutung der zukünftigen Produktion kundenindividueller Produkte in Losgröße 1." In *Interdisziplinäre Perspektiven Zur Zukunft der Wertschöpfung*, edited by Tobias Redlich, Manuel Moritz, and Jens P. Wulfsberg, 63–75. Wiesbaden: Gabler.

Cadet, Marcel, Chantal Sinnwell, Jan Fischer, and Nicole Stephan. 2017. "Kernelemente für die Zusammenarbeit von CTP-Entwicklung und CTPS-Planung." In *Modellbasierter Entwicklungsprozess cybertronischer Systeme: Der PLM-unterstützte Referenzentwicklungsprozess für Produkte und Produktionssysteme*, edited by Martin Eigner, Walter Koch, and Christian Muggeo, 93–101. Berlin: Springer Vieweg.

Cooper, Alan. 2006. *The Inmates Are Running the Asylum: Why High-Tech Products Drive Us Crazy and How to Restore the Sanity.* 6. [print.]. Indianapolis, Ind. Sams.

Cooper, Robert G. 2014. "What's Next? After Stage-Gate." *Research-Technology Management* 57 (1): 20–31. doi:10.5437/08956308X5606963.

Fettig, Katrin, Tamara Gacic, Aykut Koskal, Ansgar Kuhn, and Fabienne Stuber. 2018. "Impact of Industry 4.0 on Organizational Structures." *2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC).* doi:10.1109/ICE.2018.8436284.

Förster, Kerstin, and Roy Wendler. 2012. *Theorien Und Konzepte Zu Agilität in Organisationen.* DRESDNER BEITRÄGE ZUR WIRTSCHAFTSINFORMATIK NR. 63/12. Dresden.

Hanington, Bruce, and Bella Martin. 2012. *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions.* Beverly: Rockport Publishers.

Kimmig, Andreas, Moritz Schoeck, Edgar Mühlbeier, Florian Oexle, and Jürgen Fleischer. 2021. "Wertstromkinematik – Produktionssysteme Neu Gedacht." *Zeitschrift für wirtschaftlichen Fabrikbetrieb* 116 (12): 935–39. doi:10.1515/zwf-2021-0207.

Linderman, Kevin, Roger G. Schroeder, Srilata Zaheer, and Adrian S. Choo. "Six Sigma: A Goal-Theoretic Perspective." Journal of Operations Management 21, no. 2 (2003): 193-203. https://doi.org/10.1016/S0272-6963(02)00087-6

Mühlbeier, Edgar, Philipp Gönnheimer, Ludiwg Hausmann, and Jürgen Fleischer. 2020. "Value Stream Kinematics." In *Production at the Leading Edge of Technology*, edited by Bernd-Arno Behrens, Alexander Brosius, Wolfgang Hintze, Steffen Ihlenfeldt, and Jens P. Wulfsberg, 409–18. Lecture Notes in Production Engineering: Springer-Verlag Berlin.

Mühlbeier, Edgar, Florian Oexle, Philipp Gönnheimer, and Jürgen Fleischer. 2021. "Wertstromkinematik – Produktionssysteme Neu Gedacht." *Zeitschrift für wirtschaftlichen Fabrikbetrieb* 116 (11): 847–51. doi:10.1515/zwf-2021-0179.

Schoeck, Moritz, David Voss, Simon Rapp, and Albert Albers. 2022. "Interaction of Agility and Flexible Production Systems in Innovation." *XXXIII ISPIM Innovation Conference "Innovating in a Digital World".*

Schoeck, Moritz, Mona Batora, Johannes Mueller, Nikola Bursac, and Albert Albers. 2023. "Influence of Agility on the Innovation Capability of Organizations – A Systematic Review of Influencing Factors." *33rd CIRP Design Conference "Grand Challenges for Engineering Design".*