Chapter 10
Integration of Mechatronic Product Development Methods in an Agile Development Area

Kristin Goevert, Maximilian Brombeiss and Udo Lindemann

Abstract Currently, a lot of companies transfer their product development processes from a phase-oriented to an agile process. This paper describes our research on the integration of mechatronic product development methods into the agile development process. The integration of the methods supports agile product development of mechatronic products with the goal to develop better products and increase the success of agile development processes in non-IT areas. For the analysis of product development methods for agile development, a process model with six steps is required. The result is a model, which integrates agile steps with mechatronic tasks and usable product development methods.

10.1 Introduction

Many changes occur in our world and the direction of the development of trends, politics, customer, and project partner is unpredictable. Thus, agility is more important than ever before. To solve the connected challenges in the area of product development, companies try to integrate agile development methods from the software product development to the mechatronic product development [1]. Most of the mechatronic product development processes are structured into different development phases [2, 3]. In contrast to that agile methods help to design a flexible and adaptable product development environment, which supports a shorter reaction time in uncertain situations [4]. Combined to the transfer, a lot of challenges are related to it. One of these challenges is that a lot of agile methods support the project management or are specifically for the software product development and

K. Goevert (✉) · M. Brombeiss · U. Lindemann
Technical University of Munich, Munich, Germany
e-mail: kristin.goevert@tum.de

M. Brombeiss
e-mail: maximilian.brombeiss@tum.de

U. Lindemann
e-mail: udo.lindemann@tum.de

A. Chakrabarti (ed.), *Research into Design for a Connected World*,
Smart Innovation, Systems and Technologies 135,
https://doi.org/10.1007/978-981-13-5977-4_10

not transformable. Scrum is an agile method, which supports project management and is not as much IT specific than other methods. Hence, it is the most transferred agile method [5]. The management methods provide no support on the level of product development. Based on this current situation, our goal was derived to develop an integrated process of agile project elements and mechatronic product development elements. Elements could be methods, principles, roles, processes, and artifacts.

10.2 Research Methodology and Process

The research project follows the Design Research Methodology (DRM) of Blessing and Chakrabarti [6]. The methodology structures the research in four phases [6].

The first phase is the research clarification. A first literature study helps to identify the research gap and goal of the research [6]. This phase represents Sects. 1 and 3.3 in this paper. This phase is followed by the descriptive study 1. This phase conducts a detailed literature study [6]. This research project focuses the analysis on agile and mechatronic processes, principles, and methods. Based on this phase, the prescriptive study is conducted. This phase supports the concretization of requirements, analysis, and solutions [6]. In this phase, the six-step research process shown in Fig. 10.1 was applied. Section 3 shows the steps of this research process in detail.

The last phase of the DRM is called descriptive study 2. This phase evaluates the results of the prescriptive study [6]. The phase evaluates the fulfillment of the defined requirements on the developed model. Therefore, the model is discussed with two experts (Sect. 5).

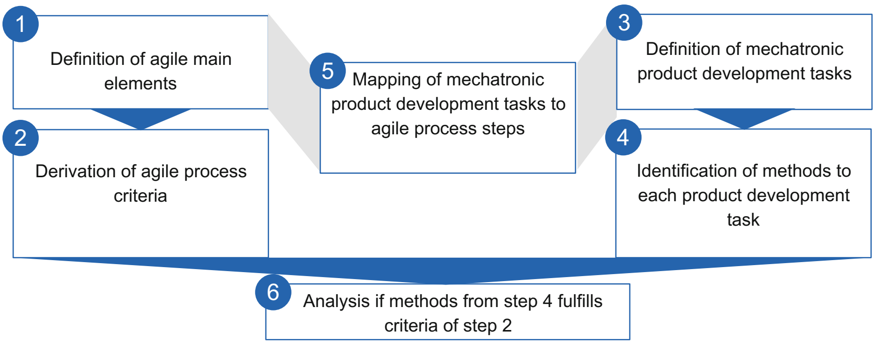

Fig. 10.1 Research process of the prescriptive study

10.3 Literature Background

This section focuses on the literature background of the research: agile processes, mechatronic product development processes, and methods. At the end of the section, the research gap and questions are derived from the results of the literature research and the current situation.

10.3.1 Agile Processes

Agile processes are processes that design a flexible, adaptable product development environment, which supports a shorter reaction time in uncertain situations [4]. The agile manifesto describes twelve agile principles and four agile values [7]. In [3], it is transferred from the software development into the mechatronic product development. The manifesto defines for example that a working product is more important than documentation or that reacting to changes is more important than following a plan [7].

Based on these principles, a lot of methods or processes can be assigned to the agile product development, e.g., Scrum, Extreme Programming, Lean Startup, Design Thinking, and the Agile Hybrid Model [8]. Most of them are iterative processes, which are focusing on continuous improvements and working prototypes [8]. Furthermore, some are some hybrid models already exist. These models like the Agile Hybrid Model are focusing on mechatronic products but only on the project management level.

Hence, it has to be distinguished if these processes/methods support the project management or the product development. Project management defines planning, monitoring, coordinating, and controlling of the project working steps [9]. Product development defines design of subjects, corresponding elaborations, integration of specific design, and the designing of complete solutions [10]. Most of the referred processes and methods are focusing on project management or software specific product development.

10.3.2 Mechatronic Product Development Processes and Methods

Mechatronic product development defines a development of a product, which combines software/information technology, electronic, and mechanical elements [11]. To develop this type of product, different processes exist like the V-model, waterfall model, incremental prototyping, stage gate process, or the spiral model [11–13]. They are different in their sequence but all of them combine similar product development phases like requirements definition, design of the elements, or testing.

Based on the different phases of the mechatronic processes, different method collections for product development exist (e.g., [14–17]). For example, TRIZ focuses on different problem solution and idea generation methods [17]. Other examples are the functional modeling or creative methods like 635-Method [15]. Many further methods exist and are described in the referred method collections.

10.3.3 Research Gap and Questions

On the one hand, the parts of the literature background show the agile point of view and on the other hand, the mechatronic point of view. Existing agile processes and methods are transferred to the mechatronic product development, e.g., Scrum. But all transferred methods are part of the project management. With these agile methods, the developers get only support on the project management level and not on the development level. Based on these findings, the following research question can be derived.

How can the agile mechatronic product development be supported by existing methods of product development without losing agility?

Based on the research gap and questions, the requirements and boundary conditions on the solution approach are defined. The following nine requirements and boundary conditions are derived from literature study, the current situation, and assumptions. They are structured in content (c), modeling (mo), methods (me), realization (r), and assumptions (a):

1. Combination of agile project management and mechatronic development methods (c)
2. No limitations on agility due to the methods (me)
3. General description of the model (c)
4. Relations between the different process modules (mo) [18]
5. Upgradeable model (mo) [18]
6. Applicability in different industries (r)
7. Suitability for Mechatronic product (a)
8. No resource bottlenecks (a)
9. Product increment could be developed from less than nine persons (a).

10.4 Integration of Mechatronic Product Development Methods

This section shows the details of the different steps from the research process (see Sect. 2). At the end, the final model is shown.

10.4.1 Definition of Agile Main Elements

The first step of the research process identifies the agile main elements. The result of this step is shown in Fig. 10.2 and explained below.

Three different types of elements structure the model: principles, roles, and process steps. The agile process is based on four principles and the process is structured in four iterative process steps. It starts with planning of the development sprint followed by the development step. After the development, a workshop to get product or product increment feedback and a workshop to improve the development process and methods are the further steps. The different roles support these agile process steps. One person is responsible for the product, one for the methods and processes, and the other are team members for the development of the product.

The four principles were derived from the twelve principles of the agile manifesto (Sect. 4.1). First, nine different keywords were extracted from the twelve principles and after these keywords were combined and summarized to the main principles. The keywords are: continuous process, self-organized team, customer contact, continuous group work, early delivery, change of requirements, feedback, simplicity, and working product increment. The process steps were derived from the analysis of scrum as the main transferred agile project management method. This process steps are for example also part of the TAFagile framework [19], the Hybrid Agile Model [20], or the Agile Stage Gate Model [12] for example. The process steps are named differently in the different frameworks and are combined in some models. The roles were derived the same way as the main process steps of the agile process.

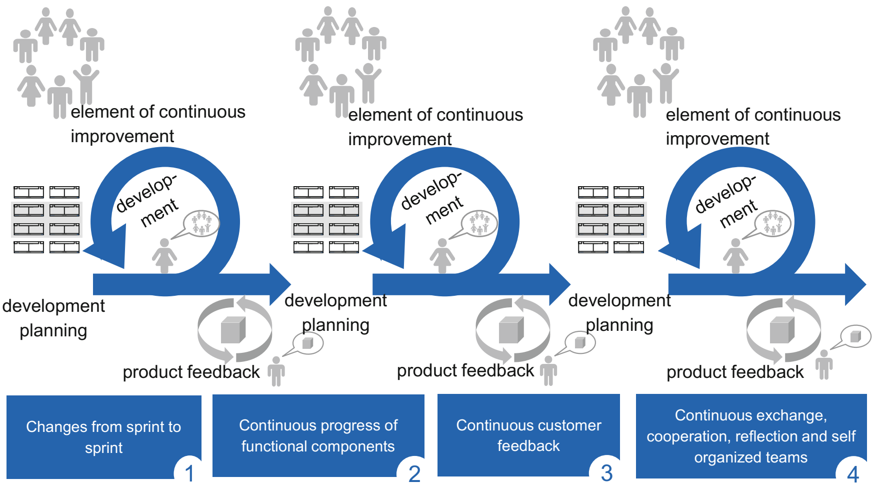

Fig. 10.2 Agile main elements

10.4.2 Derivation of Agile Process Criteria

Based on the identified key elements of agile processes and literature, criteria which describe the key elements were identified (see Table 10.1).

The criteria are clustered into general criteria and criteria for each agile process step. The general criteria were derived from the four main principles (see Sect. 4.1). The criteria for each agile step were derived from the official scrum guide [21].

Table 10.1 Criteria of each agile key element

No.	Criteria	Source
Agile process—general criteria		
1	Change of requirements	Principle 1
2	Focus on working product increment	Principle 2
3	Continuous process	Principle 2
4	Customer feedback	Principle 3
5	Self-organized team	Principle 4
6	Continuous group work	Principle 4
Development planning		
7	Definition of goals	Scrum guide
8	Definition/identification of tasks	Scrum guide
9	Selection of tasks	Scrum guide
Development		
10	Development of products	Scrum guide
11	Focus on development goals	Scrum guide
12	Concretization of the area of consideration	Scrum guide
13	Timeboxing	Scrum guide
Product feedback		
14	Continuous exchange	Principle 4; scrum guide
15	Reflection	Principle 4; scrum guide
16	Result presentation	Scrum guide
17	Feedback on product level	Scrum guide
18	Adaption of tasks	Scrum guide
19	Integration of market impact	Scrum guide
20	Time and budget consideration	Scrum guide
Element of continuous improvement		
21	Continuous exchange	Principle 4; scrum guide
22	Reflection	Principle 4; scrum guide
23	Feedback on process level	Scrum guide
24	Development of process improvements	Scrum guide
25	Planning of improvement implementation	Scrum guide

10.4.3 Definition of Mechatronic Product Development Tasks

The definition of the product development task is based on an analysis of the five different mechatronic product development models (models see Sect. 4.2). Each phase of the models represents one task. The different tasks were compared to each other and summarized in one task-collection. The task-collection includes the following nine elements: system analysis, system design, requirements management, implementation, testing, ideation, integration, risk assessment, and acceptance.

10.4.4 Identification of Methods for Each Product Development Task

After the different mechatronic product development tasks were defined, methods of each task were identified. The identification of the different methods is based on a literature research. 41 methods were identified within the literature research and were mapped to the different mechatronic product development tasks. Table 10.2 represents one example method and how the method collection is structured. For each of the 41 methods, a short description, a mapped task, and a source exist.

10.4.5 Mapping Mechatronic Product Development Tasks to Agile Process Steps

The fifth step is the first step, which combines agile aspects with mechatronic aspects. In this step, the mechatronic tasks are mapped to the agile process elements. The mapping is based on a comparison between the literature definitions of each agile element and the mechatronic tasks. The result of this comparison is shown in Table 10.3.

If the mapping shows an “×,” the task is part of the agile process step. If the mapping shows an “(×),” the task is not directly part of the process step, but the task partially influences the step. The table also shows that no task of the

Table 10.2 Example of a mechatronic product development method

No.	Method name	Short description	Task	Source
1	Functional modeling	Graphic representation of product functions and their relations depending on the point of view (user-oriented, volume-oriented, relation-oriented)	System analysis	Lindemann [15]

Table 10.3 Mapping mechatronic product development tasks to agile process steps

	System analysis	System design	Ideation	Requirements management	Implementation	Risk assessment	Acceptance	Integration	Testing
Development planning				×					
Development	×	×	×		×	×	×	×	×
Product feedback	(×)		(×)	×			×		
Element of continuous improvement									

mechatronic product development is part of the agile element of "continuous improvement." For this process step, existing agile methods should be used or an analysis of further areas has to be conducted.

10.5 Analysis if Methods from Step 4 Fulfill the Criteria of Step 2

This section focuses on the mechatronic product development methods (Sect. 4.4) and their compatibility with agile processes (Sect. 4.2). This analysis is supported by an assessment scheme. The methods were evaluated on their influence on the agile criteria. The methods can influence the criteria in a positive (+), neutral (0), or negative (−) way. The general criteria (see Table 10.1) have to be influenced in a positive or at least neutral way. The methods may not influence the general criteria in a negative way, as this would reduce the agility. Furthermore, the methods were mapped to the tasks and the tasks to an agile process step. Moreover, each agile process step has additional criteria (see Table 10.1). These criteria must be influenced in a positive or neutral way as well, and at least, one of these criteria must be influenced positively. Otherwise, there are no advantages of this method. Table 10.4 represents a detailed view of the analysis. The FMEA, for example, influences two of the general agile criteria in a negative way. Thus, the FMEA is not usable in mechatronic product development process. For example, the requirements list, functional modeling, Method-635, and the Zwicky box influence the general criteria in a neutral or positive way and at least one or more of the specific criteria in a positive way. Hence, these four methods are usable in a mechatronic agile product development.

Based on the analysis and the steps before, an agile model with integrated mechatronic tasks and methods was derived. Figure 10.3 shows one process, the task, and some examples of linked methods. The process can be iterated any number of times. It depends on the development situation and the complexity of the project. Furthermore, the focus on the different tasks depends on the development situation as well and can be redefined in each development planning.

10.5.1 Discussion and Evaluation

This chapter discusses and evaluates the research process and the results. The research process has a strong focus on literature research. Nevertheless, the research process and results were discussed with two experts from the industry. Both work in companies in Scrum teams, which develop different mechatronic products. The feedback from both of them was positive and they said a combination of agile methods and mechatronic product development methods is really useful. Another

Table 10.4 Detailed view of the method—agile criteria analysis

	Agile process—general criteria						Development planning			Development			
	Change of requirements	Focus on working product increment	Continuous process	Customer feedback	Self-organized team	Continuous group work	Definition of goals	Definition/identification of tasks	Selection of tasks	Development of products	Focus on development goals	Concretization of the area of consideration	Timeboxing
ABC analysis	0	0	0	0	0	0							
Requirements list	0	+	0	0	0	0	+	0	0				
FMEA	–	+	–	+	0	0							
Function modeling	0	+	0	0	0	0				+	+	+	0
Method 635	0	0	0	0	0	+				+	0	0	+
Zwicky box	0	0	0	+	0	0				+	0	0	0

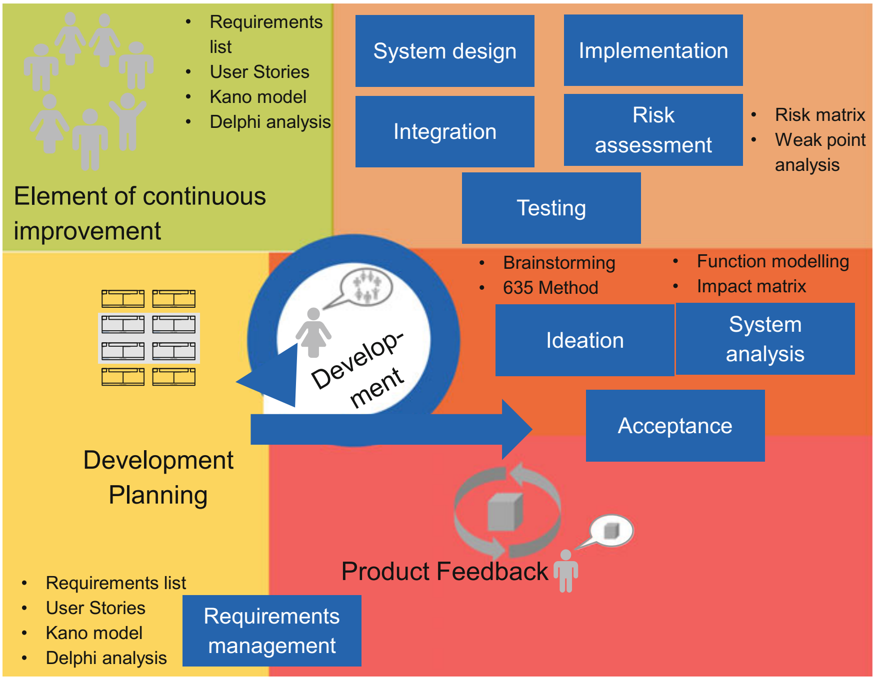

Fig. 10.3 Overview of agile process steps, mapped mechatronic tasks, and example methods

feedback was that the model can be extended to different scenarios. The different scenarios can help to get a better focus in the different sprints to specific task and useful methods. Furthermore, for each method a short description can be integrated with advantages, disadvantages the process, and so on to get a better overview. Nevertheless, the current research is a base, which has to be implemented in an industrial use case as a next step.

In addition to the expert discussion, the requirements from Sect. 4.3 were evaluated (see Table 10.5). The first requirement is fulfilled with the analysis, which mechatronic product development methods links to the agile process steps. The second requirement is mostly fulfilled. The analysis helps to identify that methods which limit the agility and can be excluded from the model. Yet, only an industrial use case can reliability identify agile limitations. Thus, requirement six is only partly fulfilled. The requirements three to five are fulfilled: The model is a general description, is upgradeable, and relations between the different process modules exist.

Table 10.5 Evaluation of the requirements

Requirements	Evaluation
1. Combination agile project management and mechatronic development methods (c)	●
2. No limitations on agility due to the methods (me)	◕
3. General description of the model (c)	●
4. Relations between the different process modules (mo) [18]	●
5. Upgradeable model (mo) [18]	●
6. Applicable in industry (r)	◑

10.6 Conclusion

This paper describes a research process to develop a model, which combines agile process elements with mechatronic product development tasks and methods. With this model agile product development in mechatronic, areas are supported. The research process is a process of six steps. First, agile elements are identified. The elements are four agile principles, three roles, and four agile steps. After that, agile criteria are identified on the level of general principles and for each agile step. At the same time, five different mechatronic development processes are analyzed regarding to the different tasks. For each mechatronic task, methods are identified. In total, 41 methods are identified. After that, the tasks are mapped to the agile process steps and the methods are analyzed with regard to limitations on agility.

This research is a first step and additional research has to conduct. The model will be applied in an industrial use case and new findings have to be integrated. Furthermore, methods for the continuous improvement of methods and processes have to be included as well as different scenarios.

References

1. Komus, A., Kuberg, M.: Status Quo Agile (2017)
2. Berg, B., Knott, P., Sandhaus, G.: Hybride Softwareentwicklung. Springer, Berlin, Heidelberg (2014)
3. Gövert, K., Baumgartner, M., Lindemann, U.: The Agile Toolbox—Adapting of Agile MPPs to the Mechatronic Development Process. In: 21st International Conference on Engineering Design, ICED’17 (2017)
4. Hofert, S.: Agiler Führen. Springer, Wiesbaden (2016)
5. Goevert, K., Lindner, M., Lindemann, U.: Survey on agile methods and processes in physical product development. In: Bitran, I., Conn, S., Huizingh, E., Kokshagina, O., Torkkeli, M., Tynnhammar, M. (eds.) ISPIM Innovation Forum: The Innovation Game: Base Hits, Not Home Runs (2018)
6. Blessing, L.T., Chakrabarti, A.: DRM, a Design Research Methodology. Springer, London (2009)

7. Beck, K., Beedle M., van Bennekum, A., Cockburn, A., Cunningham, W., Fowler, M., et al.: Manifesto for Agile Software Development (2001) https://www.agilealliance.org/agile101/the-agile-manifesto/
8. Goevert, K., Lindemann, U.: Further development of an agile technique toolbox for mechatronic product development. In: Marjanović, D., Storga, M., Skec, S., Bojcetic, N., Pavkovic, N. (eds.) 15th International Design Conference, pp. 2015–2026. Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia, The Design Society, Glasgow, UK, 21–24 May 2018. https://doi.org/10.21278/idc.2018.0204
9. Kuster, J.: Handbuch Projektmanagement. Springer, Dordrecht (2011)
10. Gausemeier, J., Plass, C.: Zukunftsorientierte Unternehmensgestaltung: Strategien, Geschäftsprozesse und IT-Systeme für die Produktion von Morgen, 2nd edn. Hanser, München (2014)
11. Gausemeier, J., Moehringer, S.: VDI 2206—A New Guideline for the Design of Mechatronic Systems. IFAC Proc. Vol. **35**, 785–790 (2002). https://doi.org/10.1016/S1474-6670(17)34035-1
12. Cooper, R.G., Sommer, A.F.: The agile-stage-gate hybrid model: a promising new approach and a new research opportunity. J. Prod. Innov. Manag. **33**, 513–526 (2016). https://doi.org/10.1111/jpim.12314
13. Goll, J.: Ausprägungen von Vorgehensmodellen. In: Goll, J. (ed.) Methoden und Architekturen der Softwaretechnik, 1st edn, pp. 81–128. Vieweg + Teubner, Wiesbaden (2011). https://doi.org/10.1007/978-3-8348-8164-9_3
14. Albers, A., Reiß, N., Bursac, N., Walter, B., Gladysz, B.: InnoFox—Situationsspezifische Methodenempfehlung im Produktentstehungsprozess. In: Binz, H. (ed.) Stuttgarter Symposium für Produktentwicklung (SSP). Fraunhofer, Stuttgart (2015)
15. Lindemann, U.: Methodische Entwicklung Technischer Produkte, 3rd edn. Springer, Berlin (2009)
16. Haberfellner, R. (ed.): Systems Engineering: Grundlagen und Anwendung, 13th edn. Zürich, Orell Füssli (2015)
17. Chechurin, L.: Research and Practice on the Theory of Inventive Problem Solving (TRIZ). Springer International Publishing, Cham (2016)
18. Jansen, S.: Eine Methodik zur Modellbasierten Partitionierung Mechatronischer Systeme. Shaker, Aachen (2007)
19. Böhmer A.I., Kosiol, M., Lindemann, U.: Agile Mechatronics—Innovation Strategy for Cross-Functional Teams in the Age of Uncertainty. In: ISPIM (ed.) XXVIII ISPIM Conference: Composing the Innovation Symphony (2017)
20. Schröder, A.: Agile Produktentwicklung: Schneller zur Innovation—Erfolgreicher am Markt. Hanser, München (2017)
21. Sutherland, J., Schwaber, K.: The Scrum Guide—The Definitive Guide to Scrum: The Rules of the Game (2017)