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Introducing Agility into the Processes of Manufacturing Companies: A Method for Evaluating Success, Support and Applicability

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Abstract

Agile approaches are increasingly being used in appropriate use cases for the development of mechatronic systems.In the process of implementing agile elements in the development processes, the question of the success of the transformation often arises. In order to support the agile transition in measuring process improvement, a framework was developed that evaluates the success of the implementation process by means of interviews at 4 maturity levels in the transformation. The method was evaluated in 3 use cases. On this basis, continuous adaptations can be made to the implementation process.

Keywords: agile development, agility, evaluation, agile systems design, advanced systems engineering

1. Introduction

Numerous companies are currently increasingly expanding their product portfolios in the area of service integration, so that the share of services in company sales is becoming larger and larger (Dumitrescu *et al.*, 2021). Vorwerk, for example, sells the Thermomix® product and also offers the online recipe book *Cookidoo*®, which can be subscribed to for a fee (Kindermann, 2018). This development away from pure mechatronic system development towards complex systems as part of a higher-level system of systems (Keating *et al.*, 2003) with a high proportion of networking and autonomous functions requires further development of competencies in the development teams (Albers *et al.* , 2018; Dumitrescu *et al.* , 2021). The resulting interdisciplinarity of these teams requires an extension of existing approaches in companies to respond to the new challenges and a dynamic development context (Atzberger *et al.*, 2020). Some of these especially agile approaches, e.g. Scrum and Design Thinking are already used very successfully in software development, where development is driven by short cycles and rapidly changing requirements (Atzberger *et al.*, 2020; Heimicke *et al.*, 2021b). Therefore, agility is also increasingly used in mechatronic system development (Goevert *et al.*, 2019a). However, the approaches cannot be easily introduced in manufacturing companies and challenges arise (Dikert *et al.* , 2016; Ovesen, 2012). One major challenge is that the culture in manufacturing companies is counter to the principles of agile development. Processes have evolved, in some cases over decades, and are ingrained in the minds of the workforce (Boehm and Turner, 2005). To this end, the physical characteristics of the product often prevent short-cycle development from being implemented. These include the more complex development of the validation system and the consideration of production efforts (Albers et al., 2016; Schuh *et al.*, 2016). To avoid these challenges, it has been shown that the introduction of agility is a tailoring and follows a problem-solving process to integrate agility into development processes according to the situation and needs and does not follow a fixed pattern (Albers *et al.*, 2020b; Schuh *et al.*, 2018). There are already methods that support this implementation process, but there is currently

still no systematic to evaluate the success of the implementation process of agile elements into the development processes of mechatronic systems (Heimicke *et al.*, 2021a).

2. State of the art

2.1. Agility in Product Development Processes

Since its publication in the agile manifesto, agility has become widespread in software development and beyond. The development process takes place in a dynamic environment, and with it great uncertainties with regard to requirements and features or functions, especially at the beginning of the development. (Atzberger *et al.*, 2020; Heimicke *et al.*, 2021b) These challenges are met with close collaboration with the customer and users, early continuous validation, short-cycle planning, and continuous improvement to increase responsiveness to the changes described earlier. In addition, agile approaches lead to more ownership and autonomy in the development team. (Schwaber and Sutherland, 2020; Gloger, 2017) However, due to the differences in the development context (Gericke *et al.*, 2013; Heimicke *et al.*, 2019) between pure software development and mechatronic system development, agile approaches cannot be easily adopted in the processes of manufacturing companies (Schmidt *et al.*, 2017).

An important point is the fear of the management to lose responsibility. Since the development team has more personal responsibility and autonomy through agile working methods, this responsibility is lost elsewhere. Conflicts arise over the decision-making power with regard to the release of development results. But also the employees often feel overstrained by the introduction of agile working methods. (Atzberger *et al.* , 2020) Further challenges also always occur where agile departments collaborate with non-agile departments. Responsibilities are unclear, result cycles differ and interfaces are developed differently (Gregory *et al.* , 2015; Dikert *et al.* , 2016). To meet these challenges, the ASD - Agile Systems Design approach was developed to support the introduction of agility into the mechatronic system development. The approach is based on 9 fundamental principles (Albers *et al.* , 2020a).

- *The developer is the center of product development*
- *Each product development process is unique and individual*
- *Agile, situation- and demand-oriented combination of structuring and flexible elements*
- *Each process element can be located in the system triple and each activity is based on the fundamental operators analysis and synthesis*
- *All activities in product engineering are to be understood as a problem-solving process.*
- *Each product is developed on the basis of references*
- *Product profiles, invention and business model are necessary within the innovation process*
- *Early and continuous validation serves the purpose of continuous comparison between the problem and its solution*
- *For a situation- and demand-oriented support in every development project, methods and processes must be scalable, fractal and adaptable*

The realization of these basic principles through specific methodological elements supports the combination of structuring and flexible elements at different project levels according to the situation and requirements. (Albers *et al.* , 2019, Goevert et al. 2019b) For this purpose, a method for introducing suitable agile and process-oriented elements into the product development process was developed (see Figure 1). Based on a collection of process models and methods from agile and plan-driven use cases, a use case-specific process solution is developed in 7 steps to support and further develop collaboration and development activities in the respective context and iteratively introduced into the application context. In order to identify the appropriate methods, process model and frameworks, a problem-solving process (see steps **A**, **L**, **T** in Figure 1) (Heimicke et al., 2021a) is used to first select a set of factors from a catalogue that describe the agile capabilities of the respective organizational unit (see steps **S**, **P** in Figure 1). The process solution developed through this as a combination of agile and plan-driven elements is then introduced in an iterative process and continuously evaluated and adapted in terms of its support performance (see steps **E**, **N** in Figure 1). (Heimicke et al., 2021c) This method is investigated within this contribution. By applying this individual problem-solving process when introducing agile elements,

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the acceptance and perceived added value of agility in the development of mechatronic systems should be improved. A complete list of criteria can be found in (Heimicke et al., 2021b).

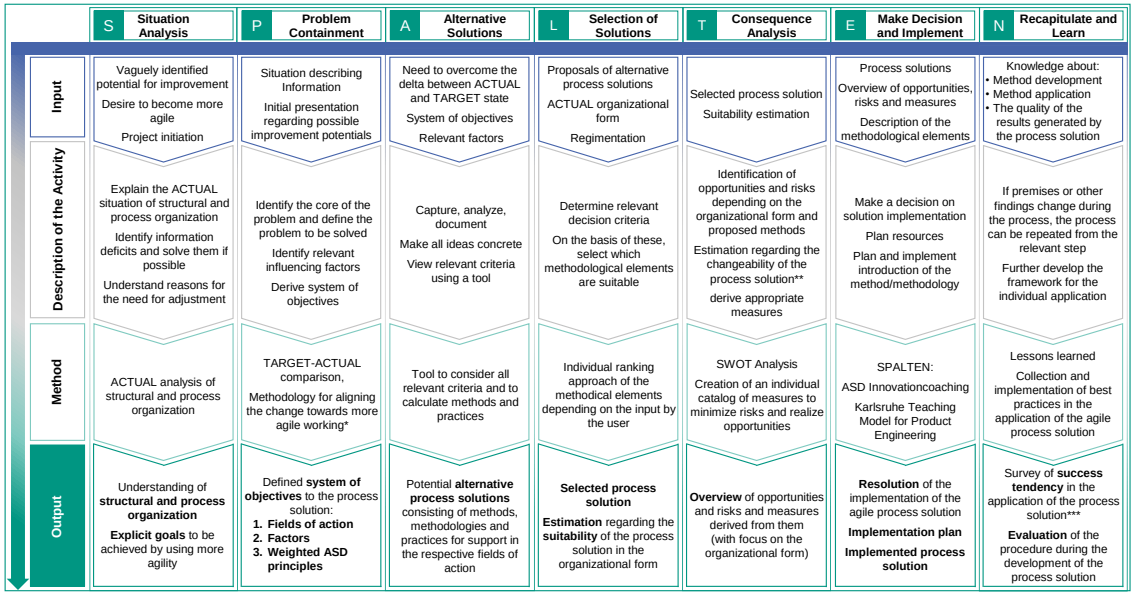

Figure 1. Method to implement agile elements into processes of mechatronic systems development (Heimicke et al., 2021c).

2.2. Design Research Methodology - Evaluation of Support

In order to validate the results in the area of product development research, already defined research methodologies with a focus on this area of research are available. An established and often used methodology is the *Design Research Methodology - DRM* (Blessing and Chakrabarti, 2009) The DRM is divided into 4 superordinate stages: *Research Clarification*, *Descriptive Study I*, *Prescriptive Study* and *Descriptive Study II*. In Research Clarification, the main objective of the research is identified and factors are defined to quantify the success. In the DSI, the understanding of the problem is further developed and then this understanding is used to identify factors that need to be adjusted in the PS and how this adjustment is carried out. In this paper, the focus is on Descriptive Study II, which is used to evaluate developed methods independently of their underlying specific problems to ensure that the method can be applied to previously unknown problems. For this purpose, three different types of evaluation are distinguished and applied in the DRM. Application Evaluation: This type of evaluation checks whether the method can solve the problems for which it was developed and whether it influences the key factors (KPIs) to the right extent. Thus, the focus of this first approach is mainly on usability and applicability. The second type of evaluation is called Success Evaluation. Its focus is mainly on whether the use of the method is useful. It looks at whether the use of the method has the desired outcome, i.e. whether the overarching goal is realised and no side effects occur and no problems are caused elsewhere. Finally, there is the support evaluation. In its course, it is checked whether the support provided by the method meets the requirements for it. (Blessing and Chakrabarti, 2009, 13ff.)

Eckert et al. (2003) also see the need to systematically evaluate research results. Similar to Blessing and Chakrabarti, they foresee two steps for this. Evaluation of tools and procedures: This involves active testing by users in the thematic environment of the method. For the final validation, however, the second step is still missing: Introduction of tools and procedures. Here the method is tested in a real industrial environment and the process is observed. (Eckert *et al.* , 2003) Another method for validating success is the Validation Square by Pedersen et al. (2000). It tests the validity of development methods with regard to four aspects. Theoretical Structural Validity and Empirical Structural Validity. These two points describe whether the method is effective in solving the intended problem. The other side of the Validation Square, consisting of Theoretical Performance Validity and Empirical Performance Validity describes whether the method is efficient in its use. According to this model, only if the method is effective, efficient and fulfils its purpose, it is successfully validated. (Pedersen *et al.* , 2000)

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Marxen summarizes the ideas of the previously described approaches in his framework. Thus, he also leaves two steps for method validation. The first step describes the application of the method in a test environment that the researcher can control. To do this, he must first determine which aspects can be controlled and which will be observed. If the method fulfils its purpose in this environment, it can then be tested in a real environment comparable to Eckert. The main thing to observe is how the results of the observations develop in comparison to the controlled environment. (Marxen, 2014)

3. Research Approach

More than 80% of companies developing physical products develop with plan-driven approaches (Stage-Gate International, 2019) and face the challenge of a rapidly changing environment and need to act flexibly. In order to successfully implement agile approaches in the field of mechatronic product development, a variety of factors and influences of the specific development context, organizational structure, and individual company goals need to be considered (Heimicke *et al.* , 2021c). A solution for companies seeking active support in the process of agile transformation is offered by the method of introducing ASD - Agile System Design - according to the situation and needs. This is based on the systematic understanding and narrowing down of the use case through the targeted selection of context levels, fields of action and factors that are to be improved in the company's use case through the use of agile elements. Subsequently, the agile methods and frameworks that correlate most strongly with the user's selection are suggested to the user based on an algorithm, with the goal of then incorporating them into the agile transformation of the organizational unit. (Heimicke *et al.* , 2021a) In order to validate this approach in the categories of appropriateness, applicability and success, a systematic approach is necessary that enables a reproducible evaluation of the methodology according to Heimicke et al. (2021a) in different use cases. For this purpose, the following research questions are answered in the article:

- *How should a systematic be designed that evaluates the method for introducing agile elements analogous to the agility concept of the ASD - Agile Systems Design into the processes of mechatronic system development?*
- *Which statements can be made regarding success, support and application of the method for the situation- and demand-oriented introduction of agility following the developed evaluation?*

In order to evaluate the method, the three evaluation types according to Blessing and Chakrabarti (2009) were used to structure the measurement categories. The validation methodology was set up through an iterative procedure within the research environment of a student development project within an in-service Master's programme. By creating questionnaires that were applied at different measuring points during the implementation of the method as can be seen in Figure 2, not only an iterative improvement process could be started, but also tools that should support the user in the implementation of the method were developed. The validation methodology was subsequently tested in two practical use cases at manufacturing companies during the implementation of the method for the situation- and demand-oriented introduction of ASD - Agile System Design. In the course of this, the foundation was laid for a database that can map a result profile that is constantly gaining in significance and thus correlating improvement measures for the method of agile transformation.

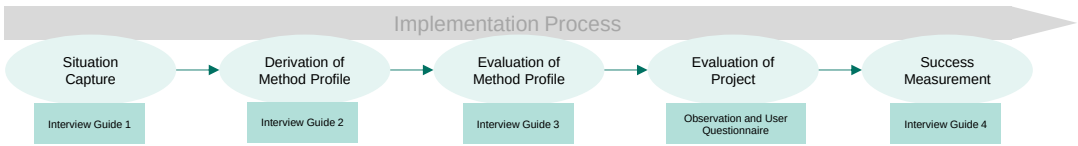

Figure 2. Association of the questionnaires with the individual steps in the implementation process

4. Results

4.1. Systematics for Evaluation of the Methodology for Introduction of Agility

The basic requirement for the validation methodology is that it answers the question of whether the method for introducing ASD - Agile System Design in line with the situation and requirements supports

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the user in the agile transformation with regard to his use case. This is done based on the generic evaluation categories of success, applicability and support measurement according to Blessing and Chakrabarti (2009), which is to examine the research procedure of the method design through the four development stages of Clarification of Research Intent, Descriptive Study I, Prescriptive Study and Descriptive Study II. By means of the support measurement, the question is to be answered to what extent the method is actively used to solve the problems in the introduction of agile elements into the processes of the development of mechatronic systems. The measurement of applicability aims to find out whether the supports provided for the tasks are used and directly influence the user. Thus, the focus of the criterion is on usability and suitability. The category success intends to answer the question of the actual impact through the use of the method regarding acceptance and perceived added value.

In order to assess the contribution of the method in the process of introducing agile elements into the product development processes, questions were formulated that correlate with these criteria and are specifically applied via the questionnaires at the various measurement points (see Figure 2) (see Appendix). The perceived value and acceptance criteria (Heimicke et al. 2021b) were used to measure success. Examples of acceptance criteria are *coordination effort*, *suitability*, *method complexity*, *satisfaction* and *fun*. Criteria for measuring the perceived added value include *productivity*, *scope of action*, *responsiveness*, *improved quality*, and *customer integration*. Criteria defined for usability measurement include the extent to which the available tools can support the user in making a conscious decision or prevent misunderstandings. In the category of support measurement, criteria were established such as the *quality of the realistic representation of the user's situation*, *the degree of understanding of the transformation process* or the *suitability of the proposed solutions of the method*. The validation method, within which the corresponding criteria are recorded, was developed as a process running parallel to the method for the situation- and demand-oriented introduction of ASD - Agile System Design, which takes up the method steps and successively reveals a more defined picture of the qualities as well as potentials and weaknesses of the method in the individual measurement categories by the user. The interlocking of the processes of the two methods is shown in Figure 3 described in the following. The validation method is divided into five phases that are visualized in Figure 3 and explained in the following section.

Situation Capture: In the first steps of the method for the situation and needs-based introduction of ASD, the situation analysis (S) takes place, as well as the problem containment (P) is started. For this, the user receives questions concerning the environment to be transformed. He first selects a context level (individual, project, management, company) on which the process improvement is to take place and, based on this, 6 fields of action (e.g. team, project management, use of methods, etc.) in order to further narrow down the field of action for the improvement. For this selection, he is supported with the tool *Pairwise comparison of the fields of action.* In this first phase, the questionnaire from the validation method contains questions for recording the status quo of the success criteria, which serve as a reference for later measurements, for applicability related to the selection process, and for support measurement in reference to the realistic depiction of the user's situation by the selected fields of action.

Derivation of the method profile: In the second phase of the validation method, one is still in the process step of problem containment (P). In the following, the user is to select 20 factors which, from his point of view, have a significant influence on his project situation and should be improved. The user is supported in this task by the *Selection of Factors* tool. At the end, the user is presented with an overview that shows the results of his selection so far in the process - the method profile. At this point, the validation method examines the applicability and support measurement categories. For this purpose, the focus of the investigation at this point is on the tool, as well as the presentation of the results.

Evaluation of the method profile: The third step of the validation method measures the user's perception and insights related to the selection options determined by the mapping algorithm. Based on the input from the previous steps, the mapping algorithm suggests suitable frameworks and methodological elements to the individual application context. Based on this input, the method statement is created. In the process of introducing agile elements, this represents the *Alternative Solutions* (A) step, which is followed by *Selection of Solutions* (L). The user now selects a framework and a maximum of 10 methodological elements. In the following validation measurement by the third interview guide, the success

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of the suitability of the proposals, applicability of the selection process of framework and methodological elements, feedback on missing proposals, as well as support of the selected overall framework in the agile transformation are evaluated.

Evaluation of the project: After the selection of the solution and the construction of the specific process solution on the basis of the generic proposals in the method profile, the consequences analysis (T) follows, after which the implementation strategy is developed. From a validation perspective, the *introduction of* methodological elements and the framework (E) is not only interesting from the point of view of project experts who have had the opportunity to continuously observe the project, but also from that of the actual user within the project. The observer first evaluates acceptance criteria such as method discipline, understanding, fun and meaningfulness. Later, he is asked questions to measure success, e.g. whether the introduced agile elements increase the team's room for maneuver, improve the handling of complexity and lead to a faster reaction time. In addition, he should give feedback on the further development of the method. The user's daily work with the provided frameworks and methodological elements is in the foreground. In addition to general questions, he should examine the categories similar to those of the observer and assess them from the user's point of view.

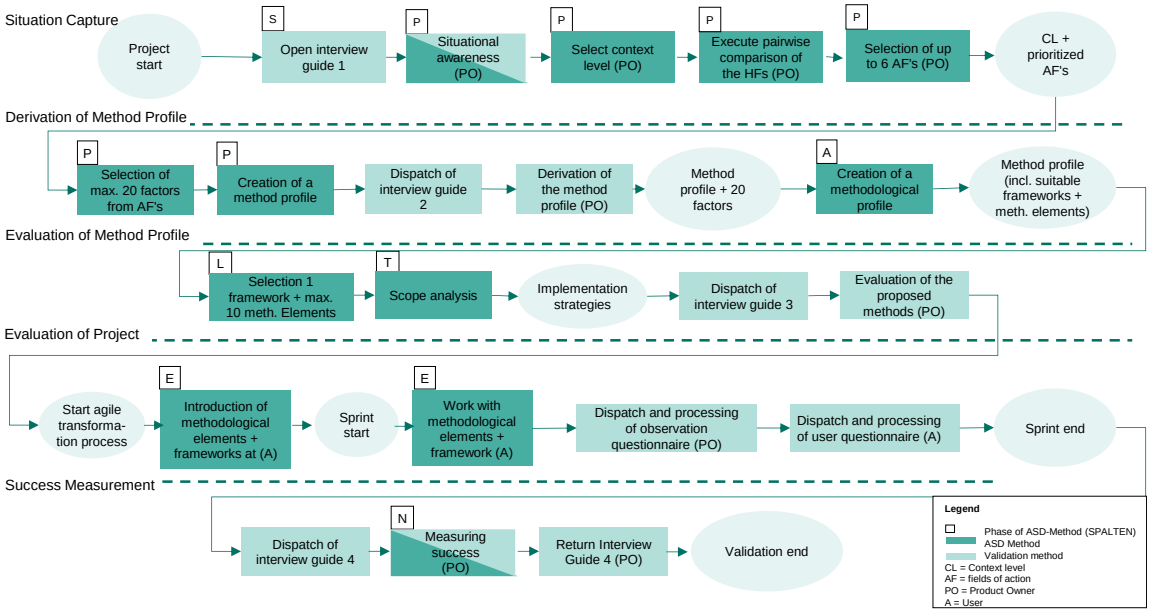

Figure 3. Overall content-related flowchart of the method for the situation- and demand-oriented introduction of ASD - Agile System Design with measurement and evaluation points of the validation method presented in the paper (no time scale).

Success measurement: After completion of the project or reaching a milestone, depending on the scope of the project, concrete results can be assessed from the perspective of the client and conclusions can thus be drawn about the effectiveness of the method for the situation- and needs-based introduction of ASD - Agile System Design. For this purpose, in the last validation step, the measurement of success, the product owner should evaluate, on the basis of the project outcome, which successes have been achieved with the application of the introduced or used framework and the methodological elements and how high the user acceptance is. During the implementation method, the last process solution step, *Recapitulate and Learn* (N), begins here at the same time, in which the implemented process solution is analysed and further developed for use in a next iteration in the same use case.

4.2. Application of the Evaluation Method

The method for the situation- and demand-oriented introduction of ASD - Agile System Design was carried out completely or partially in three use cases, whereby the method for evaluating the procedure presented in 4.1 was carried out in parallel in each case. Here, users of three different cases (each in engineering) were supported in the implementation of process improvements and this application was evaluated. One participant was part of a company developing and producing highly automated machine

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tools (laser cutting development department with 15 product engineers). The second participant coordinated a student development project as part of a university institute (the team consisted of 6 engineers). The third user was part of the engineering department of an entertainment electronics manufacturer (engineering department with 4 engineers). In all three use cases, initial agile ways of working already existed. The findings were based in particular on the observations of the three interview participants. The evaluation of the results provides initial insights into the quality of the method in use and enables an iterative improvement process (see Figure 4).

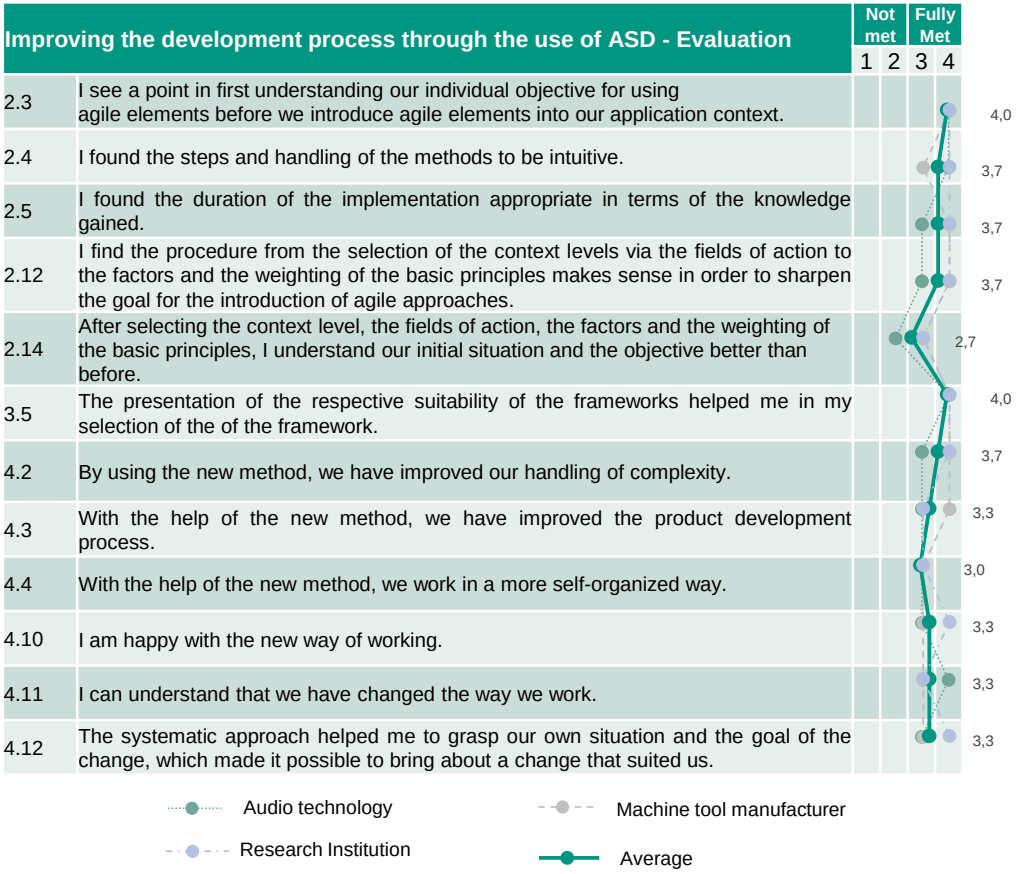

Figure 4. Evaluation results of the survey conducted as part of the implementation process

In the area of success measurement, the method for the situation- and demand-oriented introduction of ASD - Agile System Design was convincing in that it could help the user with its assigned methodological elements and frameworks to an improved product development process and to a better handling of complexity. However, the user cannot agree to an improvement in the success criterion of self-organized work through the application of the ASD method. In the area of acceptance, the method fulfils its intended purpose with its ability to provide a basic selection of fields of action and factors for selection and to assign methodological elements and frameworks in an application-specific manner (2.3 - 2.5, 2.12 - 2.14). In addition, the users feel that the approach suggested by the method makes sense; they are satisfied with the new way of working recommended by the method (4.2 - 4.4). Here, the main success is that respondents feel they have improved their product development process (4.3). Thus, it can be concluded that the method fulfills its basic functionality. The decisive factor for this is that the method is also rated very well under the acceptance criterion Understanding (4.10 - 4.12). The evaluation category acceptance is very important from the company's point of view in order to establish new ways of working in the long term, as otherwise there is a risk of reverting to old process flows in critical phases. In addition, it should be communicated to the users what exactly being agile means, because many sequences of actions are already agile in practice, but they are not explicitly described as such. It is not a matter of executing a completely new development process, but of supplementing the existing with suitable new elements. In the applicability category, the users note that the method accompanies them comprehensively through the problem-solving

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process, with the various tools supporting them in particular. Part of the tools were collaboration tools such as JIRA or Trello and suitable engineering tools such as CAD or FEM solvers. On the basis of the feedback, it was possible to identify and implement potential for improvement despite the good evaluation results. These changes led to improved assessment results in the subsequent application. The method of introducing ASD - Agile System Design according to the situation and needs leads the user to look at his current situation, to define future goals and challenges in the area of agile collaboration and to make change needs explicit. The feedback discussions were also able to reinforce the need for the method for the situation and needs-based introduction of ASD - Agile System Design in this respect.

5. Discussion

The aim of the contribution was to develop and apply a method for evaluating the process of introducing agile elements into the processes of mechatronic system development in line with the situation and requirements. For this purpose, the basic evaluation types according to Blessing and Chakrabarti were expanded to include specific criteria for measuring the acceptance and perceived added value of agile elements, and interview guidelines were developed for assessing the criteria at different levels of maturity in the implementation process. Advantages for practice result from the visualisation of potentials and challenges in the agile transformation as well as in the increase of the measurability of successful agile development. The scientific contribution consists in the generation of a reusable methodology to compare different agile transformation projects with each other and to identify patterns in transformation processes on this basis. Critically, however, it should be noted that the transfer of the validation method presented in the article to further use cases was not evaluated. Additionally, the contribution as well as the interpretation of the findings is based exclusively on the presented state of research and is explicitly not assumed to be comprehensive. Furthermore, the validation method was initially developed iteratively in a student development project and then evaluated in three specific use cases. The validity of the method is thus initially limited to these framework conditions. Finally, although the criteria used for the specific use case represent a broad coverage of possible requirements, they were not examined in the project with regard to suitability or completeness.

6. Conclusion and Outlook

There are various approaches to the agile transformation of organizational units of manufacturing companies, such as the introduction of existing agile methods, which usually originate from other industries. For this reason, it is necessary to adapt methods that support the targeted and use case-specific introduction of agile elements into the development processes of producing companies to the circumstances and framework conditions present here. After the implementation of process improvements through agile elements, the question often arises as to how the success of the process improvement can be made measurable and how the implementation process itself can be evaluated. In order to evaluate the effectiveness of process improvements, a systematic was presented in this paper that evaluates the method-supported generation and introduction of agile elements into the processes of producing companies with regard to success, applicability and support performance. For this purpose, five interview guides were developed, which can be used to evaluate the process of introducing agile elements at four different levels of maturity. In this way, the individual problem-solving process for the situation- and demand-oriented introduction of agile and plan-driven elements is to be improved. Different criteria were determined, which were evaluated by users at different points in the introduction process using a Likert scale, in order to derive implications for the further development of the introduction method. This was carried out in three use cases in companies. The evaluation of the interviews leads to improvement impulses of the method for the situation- and demand-oriented introduction of agile elements. In particular, the method is to be made more intuitive and the elements underlying the method (generic influencing factors, fields of action for process improvement but also the catalogue of agile methods and process models) are to be described in a more comprehensible way. The relationship between the elements should also be made explicit. On the other hand, the clear structuring of process improvement into the seven steps and the templates provided (e.g. a specific method profile or a generic method profile) were perceived as helpful in the targeted enhancement of development processes. After testing its suitability, the method can be used in future research projects to evaluate methodically

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induced process improvements, in particular, using the Advanced Systems Engineering paradigm. For this purpose, the criteria underlying the interviews can be expanded to include additional use case-specific criteria. In addition, apart from collecting qualitative and subjectively perceived metrics, the concept of performance measurement should also identify quantitative metrics which will be expanded in further research to this end. Finally, further use cases will be carried out in other manufacturing companies to improve the transferability of the methodology.

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Appendix

Situation detection - Interview guide 1	
1.1	In which function do you work in the company? Please describe your role. (Participant, organizer, professor, etc.)
1.2	How many years of experience do you have?
1.3	What competencies in the area of agility do the later users of the method possess?
1.4	What criteria would you like to use to measure the success of an agile approach?
1.5	What challenges do you see in your project?

Deriving the Method profile - Interview guide 2	
2.1	It was easy for me to identify suitable manipulated variables for my application from the proposed factors.
2.2	In my eyes, the factors reflect those that should be optimized first in order to achieve an improvement in my use case.
2.3	I see a point in first understanding our individual objective for using agile elements before introducing agile elements into our application context
2.4	I found the steps and handling of the methods to be intuitive.

Evaluation of proposed methods - Interview guide 3	
3.1	For me, the methodological elements fit the use case.
3.2	I can well imagine that with the help of the suggested methodical elements, the above-mentioned challenges and problems can be actively addressed.
3.3	The proposed frameworks fit very well to my application context.
3.4	Assign yourself to the management or the developer view.
3.5	It was easy for me to choose suitable methodological elements.

Project evaluation - Observation form	
O.1	What methodological elements are made available to the user?
O.2	The participants can easily present their visions and tasks with the help of the agile project management method?
0.3	The participants can quickly implement their planning using the agile project management method?
0.4	The subjects perceive the application of the agile project management method as support.
O.6	The agile project management method supports the participants in not losing sight of goals defined at the beginning.

Project evaluation - User questionnaire	
U.1	I recognize the purpose of using the agile project management method.
U.2	I can easily present my visions and tasks with the help of the agile method
U.3	Were there any activities where the agile method was less applicable?

Performance measurement - Interview guide 4	
4.1	We have increased our room for maneuver with the new method and accelerated the handling of change requirements.
4.2	Using the new method, we have improved our handling of complexity.
4.3	The team works in a self-organized manner.
4.4	Using the new method, we have integrated customers more intensively into the development process.
4.5	I am interested in how we can continuously improve.
4.6	The systematic supported us in the agile transformation of our application context.
4.7	The new process flows were adapted to the company.

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