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Development of a Methodology Profile Based on the Current Maturity Level of Agile Development in Mechatronic Product Engineering

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Abstract: The agile approaches established in software development are also increasingly being used in the development of physical products. Currently, their use and the applied process models often do not lead to the desired and sustainable success. This paper uses a survey and expert interviews to identify the general level of penetration of agile methods in the development of mechatronic systems as well as the challenges in the application and implementation of the process models used. The findings are used to develop a methodology profile, which represents the basis for a methodology toolbox.

Keywords: Agile Development, Agile Management, Change Management, Product Development, Research Methodologies and Methods

1 Introduction

1.1 Motivation

Product development is facing a constantly growing dynamic due to digitalization and increasingly complex technologies and systems (Kagermann, 2015). In addition to market developments, this has a significant influence on competition and the need to respond quickly and flexibly to individual requirements, e.g. due to the environment, new technologies, customers, etc. In order to cope with this and to be able to react to unpredictable and predictable changes according to the situation and requirements, a high level of adaptability is required (Lévárdy and Browning, 2009). The approach of agile product development follows exactly this philosophy - to enable high responsiveness and adaptability through short iterative development steps, regular delivery of performing products, high customer integration and interdisciplinary teams (Schmidt, 2019). Agile methods have established themselves as a standard procedure in software development (Komus, 2017). Flexibility, adaptability and transparency in the development process as well as customer-centric development are the key success criteria here (Beck et al., 2001). Due to the existing success in software development, there have been increasing attempts to use these approaches for the development of physical products as well (Schmidt et al., 2019). In this context, various methods have been implemented in different industries, such as medical technology (Schrof et al., 2018), aerospace (Furuhjelm et al., 2017; Carlson and Turner, 2013) and automotive (Hohl et al., 2016; Weber, 2015), etc.

1.2 Problem Definition

The use of agile methods is being evaluated more and more positively. A look at practice shows that agility is fundamentally applicable in the development of physical products. Furthermore, companies are aware of the necessity in the increasingly dynamic development environment. Nevertheless, it has not yet been possible to transfer a similar added value as already seen in the development of software (VersionOne, 2019) to the development of physical products. On the one hand, this is due to physicality and, on the other, to the discipline-specific requirements of agile development. In practice, companies often integrate agile approaches into the processes of developing mechatronic systems that were designed in and for the context of software development. However, these agile approaches do not take into account the fact that a physical product cannot be delivered incrementally and short-cycle as a performing product in the manner of software, nor the organization-specific product and process knowledge. Although the integration of agile approaches into the processes of mechatronic system development often results in the desired effects such as transparent team organization or the earlier inclusion of customers in the short term, a sustainable implementation and the associated long-term use of agile working methods is made more difficult by a large number of aspects.

The fundamental problem in implementing agile approaches is thus that a large number of changed framework conditions compared to software development are not taken into account, be it the physicality of the product, the feasibility of individual agile tools or the corporate structures. Sometimes agile approaches are projected template-like onto existing structures without specifically selecting, adapting or even questioning the tools according to the given situation. This leads increasingly to misguided goal setting and consequently to interpreted failure. However, the reason for this is not related to the philosophy of agile development or the methods themselves. The challenge is to adapt agile methods and their tools

to the structural, company- and product-specific boundary conditions. This is accompanied by a concrete goal orientation that corresponds to the agile approach. Currently, however, there are no guidelines or a kind of orientation basis for which agile methods and tools can be useful for what kind of boundary conditions and how these are to be adapted context-specifically.

1.3 Research Goal

The aim of this work is to develop a methodology profile which represents the basis of a methodology toolbox and a guideline which can be derived from it. In this context, the current degree of penetration of agile procedures in mechatronic system development will be evaluated in a survey. Furthermore, expert interviews (Heistinger, 2013) will be conducted to gain insights into the status quo with regard to the use of process models that various companies apply to develop their products. In addition, the corresponding requirements for the previously determined challenges will be identified in this context. This methodology profile contains an initial description of the methodology, underlying basic principles and guiding motifs from a normative and strategic perspective, as well as potential targeted benefits (objectives) from a strategic and operational perspective that can be used to achieve the implementation of agile elements.

2 State of the art - Agility in the product development process

Since the publication of the Agile Manifesto (Beck et al., 2001) in 2001, agile ways of thinking and acting have become widespread in software development. Driven by a dynamic environment, rapidly changing customer requirements and a continuous development of the underlying technologies, it is often necessary to react to changing requirements. Therefore, the agile ways of thinking and acting used are characterized by short planning cycles, close collaboration with customers and users, continuous and early validation, and continuous improvement of the product (Albers et al., 2019). It uses a high-frequency iterative, incremental, and evolutionary approach, and requires that the team build tangible prototypes within defined time intervals, the customer can try them out, and the team can provide resilient feedback for the next iteration (Atzberger et al., 2020). At the team level, the approaches are characterized by a high degree of self-organization and autonomy of the development team. While the agile manifesto describes principles, numerous frameworks have been developed over time to operationalize these principles. The best-known representative of the agile frameworks is SCRUM, which describes various roles and events based on the core values of commitment, focus, openness, respect and courage, which enable a short-cycle incremental approach (Schwaber and Sutherland, 2020).

For several years, the use of agile development methodologies from the software industry has increasingly been applied to the development of physical products. Cross-industry studies have shown that agile development of physical products is becoming interesting for an increasingly growing range of companies in mechatronics, and initial implementation approaches have been made (Komus and Kuberg, 2017; Michalides et al., 2023). However, there are some obstacles in the application due to constraints imposed by the technical system. Significantly longer generation cycles and the need for a production system ensure that testable increments of a product can only be manufactured at significantly longer intervals, thus making continuous validation more difficult. An immense additional effort is additionally reflected in the continuous setup and further development of the validation system (Albers et al., 2016). In addition, mechatronic products have a high level of cross-domain networking between the individual subsystems, which makes for a high level of complexity within the product. Here, challenges arise in the synchronization of domains, interactions of developers, and discrepancies in development times, cycles, and procedures (Berger and Eklund, 2015). Therefore, it has become widely understood that Agile frameworks cannot be transferred 1 to 1 from software development, but that adaptations are required.

An existing approach for situation- and demand-oriented implementation from a combination of structuring and agile elements is Agile Systems Design. The method is based on 9 basic principles on a strategic level (Heimicke et al., 2022):

- 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

These principles will be taken up again in the following research and form the basis for the developed methodology profile.

3 Methodology

The aim of this research project is to shed light on the current application of agile procedures in mechatronic system development with regard to their prevalence and the existing challenges in order to subsequently define a methodology profile that can support companies in meeting the current challenges in the introduction and implementation of agile methods and in establishing the methods successfully and in the long term. Based on the methodology profile, a guideline will then be developed that also supports the implementation operationally. In summary, the following research questions can be formulated to achieve this goal:

1. What is the current penetration of agility in mechatronic system development companies?

For this purpose, the maturity model according to Schmidt et al. (2017) is used, which assesses the maturity level of a team with regard to the application of agile approaches on the basis of defined criteria on five dimensions. In this way, the status regarding the use of agile approaches as well as the understanding of agility on a personal and organizational level is recorded. The evaluation of the level of experience of the participating companies requires classic forms of data collection. For this purpose, quantitative research based on a survey is conducted. The survey was distributed through various channels. These included the VDI (Association of German Engineers) Agile Expert Committee, the distribution list of the study "Agile Development of Physical Products" and chair-related distribution lists consisting of current and former project and network partners and graduates. Well-known networking platforms such as LinkedIn were also used to acquire participants. The survey was started by 101 people coming mainly from the DACH region. A total of 31 people completed the survey, with these 31 being distributed across the following sectors: automotive and transportation technology (10), mechanical and plant engineering (7), medical technology (4), electrical engineering/electronics (2), research institutes (2), measurement and automation technology (1), IT and telecommunications (1), construction and building technology (1), software design (1), services (1) and other (1). Of the 70 people who did not complete the survey, 54 dropped out after the first question at the latest. This is partly due to the fact that the survey explicitly addressed people who work in an agile manner, as well as no pure software companies or no companies without interfaces to hardware products. In the first part of the survey, industry, company greetings and proportion of personnel in R&D were requested, then information about the respondent personally. (Department, position, experience, knowledge of agile approaches and methods). Subsequently, the degree of fulfillment of criteria was queried in 5 different categories: product-related (9), process-related (16), employee-related (10), management-related (10) and environmental criteria (2). A total of 47 criteria were rated across the categories using a 5-point Likert scale. Respondents were asked to rate the degree of fulfillment of the criterion from very low to low, medium, high to very high. In addition, there was the option of not giving an answer if, for example, the factor was unknown.

2. What challenges do the companies have with their existing agile approach or in implementing further agile methods?

To identify the challenge, 14 industry experts from 14 different companies in different sectors of mechatronic product development were interviewed. It cannot be ruled out that participants in the interview study also answered the questionnaire, as it was evaluated anonymously. This involved conducting and recording a guide-based, semi-structured interview, which was then transcribed and coded. In this process, similar to the survey in the first question block, facts about the interviewee's company and his or her position, role and experience were requested. In the context of the company, the industry, size, number of employees in R&D, and share of hardware and software in the product mix were queried in order to better contextualize the statements. The subsequent block dealt with the status quo of agility in the company, focusing on which methods and frameworks are in use. In addition, the circumstances of the introduction were highlighted, i.e., the specific need, the trigger of the introduction, time frame and expected benefits. Subsequently, the focus was placed on the challenges encountered during the current implementation, but also retrospectively on the process of introduction was queried. Finally, the respondents were asked about their subjective opinion on the use of agile methods/approaches in order to gain an assessment of their success.

3. What requirements can be derived from the collected findings from FF1 and FF2 for a methodology profile that should support companies in implementing agile elements successfully and sustainably?

Finally, the insights gained about penetration and challenges are used to derive requirements for a methodology profile. This methodology profile should contain an initial description of the methodology, underlying basic principles and guiding principles from a normative and strategic perspective, the intended benefit (objective) from a strategic and operational perspective, a description of the requirements situation, and requirements and constraints for the methodology from an operational perspective.

4 Results

4.1 Current level of penetration of agility in mechatronic system development companies - analysis of a survey

A survey was used to collect data for the determination of the level of maturity and penetration. The methodology behind this was described in Chapter 3. The survey was completed entirely by 31 people. The results were then collected and statistically analyzed. The primary aim is to identify trends as to which criteria are more or less strongly fulfilled in the opinion of the participants in order to be able to derive a rough classification of the maturity level. Due to the focus on trends, a significance value is not calculated at this point. Based on the survey results, the 47 criteria were filtered and summarized according to the response tendencies (level of fulfillment from very low to very high). The evaluation focuses in depth on the criteria with a particularly high or particularly low level of fulfillment, as these criteria indicate the areas in which there is a high or low level of maturity regardless of the company. At the same time, widespread problems can be identified as a result. Criteria with the largest proportion of medium fulfillment levels are not considered in more detail in the further evaluation, as there is no noticeable trend here and therefore no concrete conclusion can be drawn about the cross-company maturity of the respective items. The following two diagrams (Figures 1 and 2) show the results according to the trends in terms of the degree of fulfillment and the absolute number of participants who rated the respective criterion accordingly. The relative value can be read from the bars.

4.1.1 High level of fulfillment

Figure 1 shows, in descending order from top to bottom, the most important criteria for which the sum of the high and very high level of fulfillment is over 50%. The highest level of fulfillment is the high level of *interdisciplinarity* at 81.3%. This relates to interdisciplinary work in general and therefore includes working in interdisciplinary teams and beyond. Over 63% of respondents rate the *frequency, team members and other teams are consulted in the search for solutions with* (*very rarely = quarterly, very frequently = daily) and the *fulfillment of customer requirements* as fulfilled, which is also significantly high. 57.1% consider *management's trust in development teams* to be fulfilled. Almost 54% of respondents consider the *quality and scope of the infrastructure provided* and the *extent of customer involvement* to have a high level of fulfillment. Just over half rate the *modularity of the product*, the *level to which there is an open error culture* and the *quality of customer involvement* as having a high to very high level of fulfillment. The criteria *scope and strictness of adherence to company guidelines and traditions* (**) with 57.1% and *number of parallel projects in which an employee is involved* (***) with 55.2% also show a high level of fulfillment. The latter means that more than half of the respondents confirm that employees in their companies practice multi-project management and work on several projects at the same time. In contrast to the other criteria with a high level of fulfillment, this is contrary to the maturity of agility.

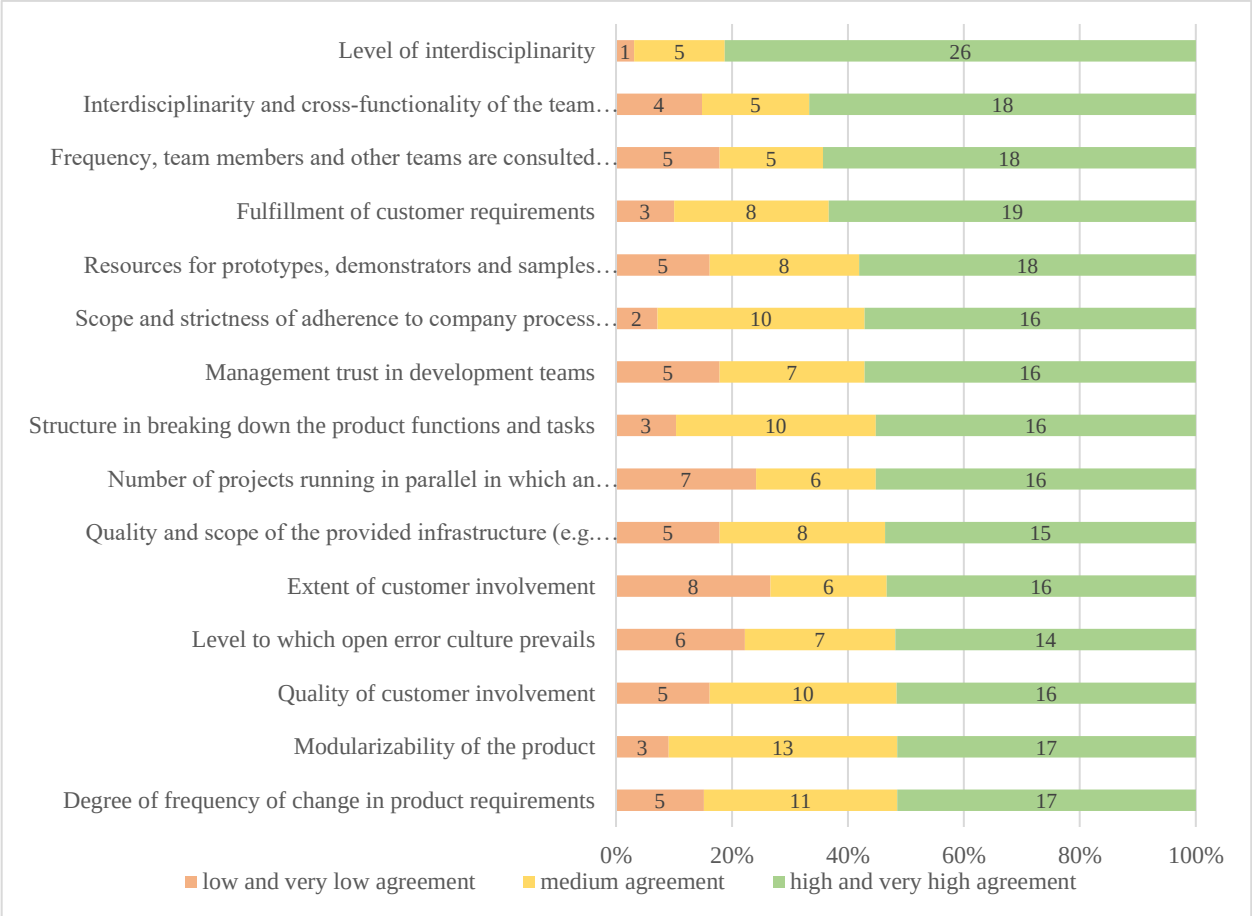

Figure 1. Criteria with an overall high and very high degree of fulfillment of 50% and more

4.1.2 Low fulfillment level

Figure 2 lists the criteria in descending order from top to bottom for which the sum of the low and very low level of fulfillment is around 40% or higher. The lowest level of fulfillment, at 58.1%, is the *potential deliverability of the increments*. In line with this, the *ability to keep development options open* was rated as low to very low fulfillment at 46.7%. Another challenge is the *internalization of the agile culture*, which 50% of respondents consider to be not fulfilled. Furthermore, the *changeability or uncertainty of the technologies* (53.6% low to very low) and *protective spaces provided by management* (50% low to very low) have a low level of fulfillment. 39.3% of respondents stated that there tended not to be any *flat hierarchies in the company*. Although the *perception of a loss of control or power by management* (****) is also considered to be rather poorly fulfilled (approx. 46% low to very low), in contrast to the other items, this can be assessed positively and indicates an increased level of maturity and penetration.

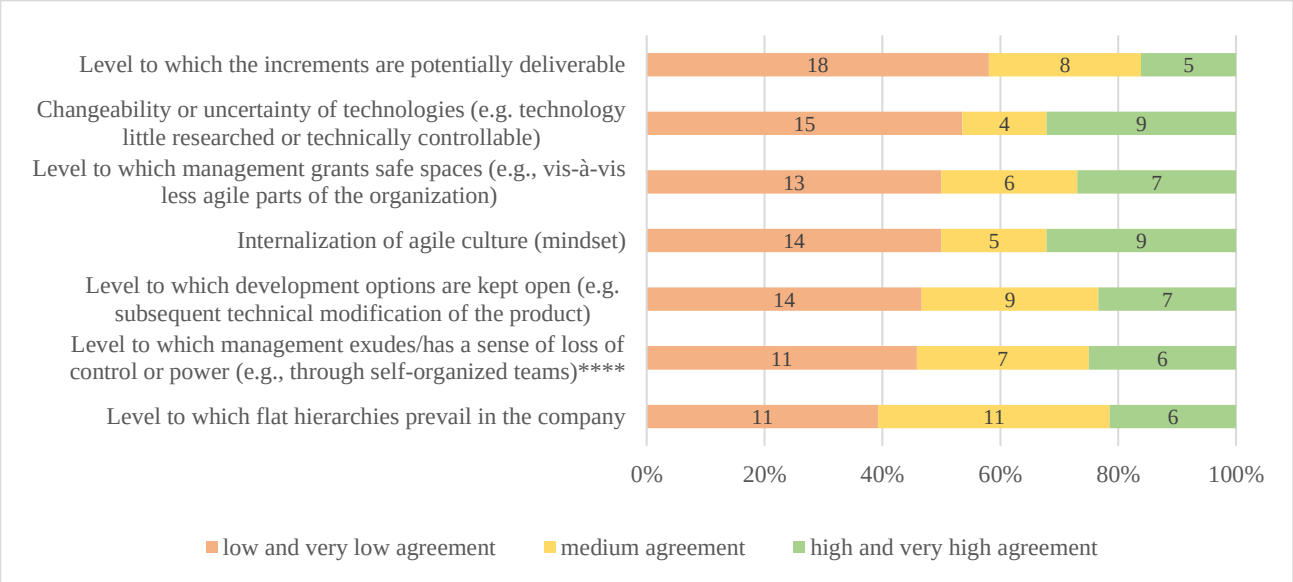

Figure 2. Criteria with an overall low and very low degree of fulfillment of 40% and more

4.2 Current Challenges of the Agile Approach at Companies - Evaluation of an Interview Study

As already described in Chapter 3, semi-structured qualitative interviews were conducted using a questionnaire. Subsequently, the challenges and hurdles mentioned were collected and clustered as seen in Figure 3. In the process, four main categories were defined in the first step: Process-related, Product-related, Employee-related and Management-related challenges.

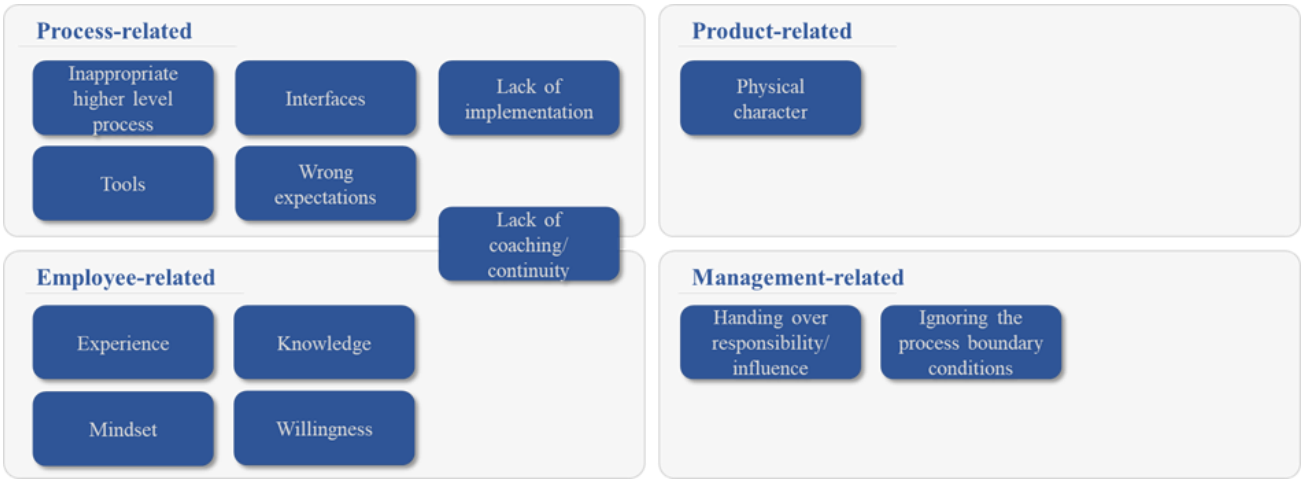

Figure 3. Clustered Challenges

4.2.1 Process-related challenges

Most of the identified challenges are in this area, this is strongly related to the fact that agile transformation fundamentally changes the product development process, or the organizational mission.

- False expectations: Employees have a sense of failure because the expected benefits do not match the experienced ones. For example, faster and more cost-effective development is often expected, but the improvements fall short of the expectation.
- Lack of introduction: The initial introduction of the agile approach was not detailed enough, and too little knowledge was passed on to employees to enable them to implement the approach.
- Lack of coaching/advocacy: Due to the lack of coaching capacity (internal and external), the agile approach cannot be perpetuated. In addition, there is a lack of an external view in retrospectives for the continuous further development of the process and the consolidation of successful approaches.
- Unsuitable superordinate process: There is a cross-company superordinate development process that must be applied and which specifies fixed milestones that stand in the way of iterative development.
- Inappropriate/undefined interfaces: There are interfaces between agile and non-agile parts of the company or teams that do not exchange information to a sufficient extent. In particular, the interface between the agile team and non-agile management ensures that information is not exchanged with the right frequency and at the right time.
- Tools: There are two manifestations of this challenge: 1. The necessary tools are not available to support the agile approach. 2. there are too many tools available, some of which have the same functionalities.

4.2.2 Employee-related challenges

After the process-related challenges, the most challenges are in this area. The employee is an important factor in the implementation of an agile approach, because he has to understand and execute the new process. In addition, change always means uncertainty, which the employee must overcome.

- Mindset: Employees do not have the right mindset and do not have the thinking. And ways of acting are not internalized at the deepest level. As a result, they automatically fall back into old patterns when they receive too little support. It is often observed that rituals have been introduced, but the meaning behind them is not understood.
- Knowledge: As a result of the lack of introduction described above, employees have too little knowledge about their new responsibilities, the new dates and events that have been introduced and the new planning procedure. Thus, he cannot concentrate on the implementation, but is busy trying to understand the process.
- Experience: Without the necessary experience, many employees automatically fall back into old patterns in day-to-day business and do not manage to follow the agile approach again on their own.
- Willingness: Employees are not willing to change their way of working for a variety of reasons. Repeatedly cited reasons for this are the unwillingness to take on more responsibility and the unwillingness to allow transparency about their own work.

4.2.3 Management-related challenges

Management faces its own set of challenges vis-à-vis employees. A lack of commitment can be observed in two dimensions.

- Surrender of responsibility/influence: some managers are unwilling to surrender their responsibility for fear of losing influence and power themselves.
- Non-commitment to process boundary conditions: By adding tasks to the team past the normal planning and sprint rhythm, management creates an overload in the team.

4.2.4 Product-related challenges

Contrary to expectations, the area of product-related challenges contains the fewest formulated obstacles.

- Physical character: The physical character of products ensures that the deliverability of increments cannot take place in the same short cycles as the delivery of software increments, for example.

It can therefore be summarized that even years after the introduction of agile procedures, companies still face problems and challenges for a wide variety of reasons. Awareness of these challenges helps to define the requirements for a methodology profile.

4.3 Requirements for the methodology profile

Based on the results gathered, the following requirements therefore emerge for the methodology profile. The methodology must be highly accessible and understandable so that it can be used by users with any level of prior experience. This requires an initial description of the methodology in which the background, mode of operation and expected benefits of the application can be presented. In order to counteract an unsustainable and superficial introduction of agile elements, it is then necessary to explain the basic principles and motives of the agile approach. Understanding these principles and motives is the first step towards a sustainable adaptation of the mindset and thus sustainable success in the implementation. Another requirement of the methodology profile is the management of expectations. It must be made clear through the

methodology profile which benefits are to be expected, but also which are unrealistic based on existing research and experience. In this way, it is possible to start the change process with a realistic target picture. This target picture is additionally supplemented by a description of the demand situation. Only when it is clear which challenge is to be met in the existing process can the appropriate agile elements be identified that have the greatest chance of meeting this need. In addition, the methodology profile must ensure that the corresponding boundary conditions for the implementation of agile elements are presented in order to enable the users to compare them with the actual situation.

4.4 Methodology profile

The individual components of the methodology profile, which are based on the requirements described above, are explained below. The initial description of the methodology forms the first part of the methodology profile. At the beginning, reference is made to the procedure in the development of the methodology profile. Thus the user knows on which basis the following information and statements originate. Subsequently, the functionality of the methodology is described in the form of a user story. In this way, the user can estimate the scope and effort involved and gain an initial overview. The second part describes the basic principles and motifs that are fundamental to the implementation of agile ways of thinking and acting as seen in Table 1.

Table 1. Basic principles and guiding motifs for the implementation of agile ways of thinking and acting

Basic principles	**Guiding motifs for (development) teams**	**Guiding motifs for leadership/management level**
By making mistakes, you learn faster and better.	Making mistakes is good (and desired). The learning effect through experience (making mistakes) is greater than through teaching (preaching).	Having confidence is essential. Let mistakes happen (even if you anticipate them). The learning effect through experience (making mistakes) is greater than through teaching (preaching).
Taking responsibility does not imply higher risk or punishment. (before: does not mean higher risk or "punishment")	Making mistakes is good (and desired). Responsibility (or rather: making decisions) is not a standard of evaluation.	Everyone needs (the same) responsibility.
Giving responsibility does not mean to be less important. (before: to mean)		The degree of responsibility does not stand for the performance rendered.
Transparency is for information, not for judgment or evaluation.	(Neither are you being judged nor are you judging yourself.)	Clear communication of what information is being disclosed (what) and what it is being used for (why) takes away fear and apprehension.
Early communication and a sense of inclusion strengthens the team.	Every voice is heard and carries weight.	Everyone wants and needs to be included.
Regular communication is essential.	Communication is purely informational and constructive.	
Permanent access to knowledge and experience (external) facilitates acceptance and strengthens the effect.	The external consultant may be asked always and everything.	An external consultant role is mandatory.
Success of agile working is neither measurable in the short term nor in monetary terms.		Success delivers (or: success indicators are...) the good product, the satisfied customer and the functioning and harmonious team.
You do not develop faster, only better (for all stakeholders).		Formulate soft goals instead of hard goals. Correctly formulated goals are essential.

The methodology profile then defines possible targeted benefits that can be achieved with the implementation of agile elements. In this way, the user is supported in defining his own benefits, which then serve as a starting point for creating the target image. The following benefits are defined by the methodology profile:

4.4.1 Process

Responsiveness/ speed

Due to the flexible process design, the development team can react to changes in stakeholder requirements that occur, for example, due to the market or changes in technologies. By continuously updating the planning, it is possible to react quickly to changing requirements and incorporate them into the product development process.

Internal learning processes and knowledge generation

The team uses an open error culture and continuous feedback loops to learn from past mistakes. Short iteration cycles allow for continuous validation where product specifications are aligned with stakeholder requirements. Continuous testing can uncover errors in function and form, which are then fixed. Each defect is recorded as a learning to prevent reoccurrence.

Exploiting the qualities (competencies and skills of the employees)

The process allows each employee to be used for tasks that fit his or her competence profile. Interdisciplinary teams ensure cross-domain understanding.

4.4.2 Employees & Management

Transparency

Defined formats for exchange between team members can promote transparency within the team.

Self-organization

Development teams organize themselves independently and solve problems within the team itself. Tasks are planned jointly and assigned to individual team members.

Capacity planning

Through transparency and joint planning, the capacity of each individual employee can be considered. In this way, overload situations can be identified early on and, if necessary, tasks can be reallocated.

Employee satisfaction

The factors described above are intended to increase employee satisfaction. If problems nevertheless arise, they can be dealt with and solved in predefined formats.

Team chemistry

Through the previously described elements, the exchange within the team and the satisfaction of the employees is strengthened. This should ensure that the team chemistry increases and the team appears stronger as a unit.

4.4.3 Product

Product quality / functionality

Continuous validation allows deviations between requirements and characteristics of the developed product to be identified earlier. This allows a response at the earliest possible stage to minimize the resources required to implement changes.

Customer satisfaction

Higher product quality/functionality means that customers are significantly more satisfied with their product. As a result, there is an increased probability of successful placement on the market and thus economic success for the company.

Some benefits have mutual dependencies, so it does not make sense to limit oneself to individual goals, but to use a far-reaching implementation of the methodology.

In the last step, requirements and boundary conditions that must be considered for the implementation are described. Here, too, the collection is intended to provide the user with a reference point for his own assessment of the existing boundary conditions. In addition, the methodology profile describes the optimal characteristics of the individual boundary conditions in relation to the implementation of the methodology for the sustainable introduction of agile elements. The boundary conditions are divided into the cluster environment and surroundings, company, project structure and people. Each of the 4 clusters should be emphasized, but the focus should be particularly on people as the implementers of the methodology.

5 Discussion

The results from chapters 4.1 and 4.2 confirm the current trend that agile approaches promote or bring about effects such as interdisciplinarity, open and regular communication, and the earlier involvement of customers. The open error culture, frequency of and openness in retrospectives, the infrastructure provided and the extent and quality of customer involvement are certainly reinforcing drivers here. At the same time, however, the results also show that the degree of maturity can certainly be rated as low and sustainable implementation can only be observed in a few companies. The reasons for this can be found in various areas. Physicality makes it difficult to continuously deliver a (physical) product. Furthermore, this physicality hinders the possibility of keeping development options open (for a long time) in the development process and making technical changes later or carrying out regular and short-cycle tests and evaluations of system components. Here, the results of the survey and the interviews coincide, but the findings from the interviews show that acceptance of this problem is increasing and the focus is therefore shifting more towards dealing with it and potential counter-effects as well as other challenges.

In addition to physicality, the adherence to old structures in general and a lack of commitment and conviction at management level represent further challenges. In many companies, hierarchical structures are often maintained and responsibilities are only partially delegated by management. At the same time, management does not provide sufficient protection for teams working in an agile manner, and process constraints are not taken into account. In the process, tasks are transferred without taking into account normal planning, which leads to overload. The situation is similar with the apparent practice of multi-project management, which is contrary to the philosophy of agile development. Here, too, the results of the survey and interviews coincide. In general, some of the points mentioned illustrate a disbalance between those things that are prescribed by the management and those that are practiced. This is also registered as such by the employees and consequently weakens their commitment.

While all of these aspects represent relevant challenges to be addressed, the central challenge is the human being with his or her individual abilities and character as well as social attributes, competencies and attitudes. The results from the survey suggest a non-negligible correlation between successful agile working and the frequently used term mindset. This impression is reinforced by the interviews. In the discussions with the interview partners, it became clear that acceptance and willingness are directly related to the successful and sustainable implementation of agile ways of thinking and acting. This includes the acceptance of changing structures and new tasks as well as the willingness to work transparently, to take responsibility and to engage with and embrace the agile culture. Another aspect here is the knowledge of the acting persons. A distinction must be made between knowledge of the agile methods and tools on the one hand and experience in their application on the other. At this point, suitable support in the form of available knowledge - whether through detailed introduction or continuous support by experienced personnel (e.g., coaching) - as well as the right infrastructure is crucial. It is not uncommon that tools are misappropriated or used in the wrong way.

All of these challenges highlight the need for an urgently required methodology toolbox which, on the one hand, recommends a suitable selection of tools and procedures according to the process-, product-, and person-related boundary conditions and, on the other hand, identifies suitable and achievable goals. This also includes the implementation of basic principles and guiding motifs in order to create and perpetuate an agile culture at both an operational and strategic level.

6 Summary and Outlook

In the scope of this work, a survey and interviews were used to evaluate the current degree of penetration of agile approaches in mechatronic system development and to identify the challenges in the use and implementation of agile process models. People from different industries and in different roles were considered in order to obtain a comprehensive overview. In general, the results allow the conclusion that the agile maturity and thus the level of penetration of agile methods in the development of physical products must currently still be classified as low. This is due in particular to the broad distribution of the mentioned reasons. In addition to physicality, these include the lack of target-oriented adaptation to the existing structures, the correct use of tools, the use of the right tools and the mindset at developer and management level. The detailed and intensive analysis of the deficits and challenges in the context of agile development has shown that the typical problems, such as physicality, are increasingly being accepted and openly addressed. Nevertheless, these product-specific challenges, in addition to the process-related and personal conflicts, represent uncertainties in the sustainable implementation of agile development methods for mechatronic systems. Based on the challenges identified and the needs derived from them, a methodology profile was developed that contains basic principles and guiding motifs

as a foundation for the successful implementation of agile ways of thinking and acting. Furthermore, this methodology profile defines potential benefits as an orientation aid to serve as a starting point for the creation of a suitable target vision.

Following on from this, the link between the strategic and operational levels can be developed into a holistic methodology in the next steps. Specifically, methodological elements for supporting the operational level should be collected and clustered into so-called fields of action (e.g. team composition or prototype construction). These clusters, which represent a collection of methodological elements classified according to recurring use cases, serve to structure the methodological toolbox. At the same time, a generic process model is going to be developed that can be adapted to specific contexts and thus supports development teams or agile working companies in general in the development process according to their situation and requirements. All elements of the methodology profile are to be compiled in a website-based guide that suggests the most suitable strategic objectives, guiding principles and methodological elements to users based on their objectives, constraints and strategic focus using a database-based access logic.

References

Albers, A., Heimicke, J., Müller, J. and Spadinger, M. (2019), "Agility and its Features in Mechatronic System Development: A Systematic Literature Review", Conference: ISPIM Innovation Conference, Vol. 2019.

Albers, A., Reiß, N., Bursac, N. and Richter, T. (Eds.) (2016), iPeM – integrated Product engineering Model in context of Product Generation Engineering: CIRP Design 2016.

Atzberger, A., Nicklas, S.J., Schrof, J., Weiss, S. and Paetzold, K. (2020), Agile Entwicklung physischer Produkte.

Beck, K., Beedle, M., van Bennekum, A., Cockburn, A., Cunningham, W., Fowler, M., Grenning, J., Highsmith, J., Hunt, A., Jeffries, R., Kern, J., Marick, B., Mrtin, R., Mellor, S., Schwaber, K., Sutherland, J. and Thomas, D. (2001), "Manifest für Agile Softwareentwicklung", available at: https://agilemanifesto.org/iso/de/manifesto.html (accessed 10 January 2022).

Berger, C. and Eklund, U. (2015), "Expectations and Challenges from Scaling Agile in Mechatronics-Driven Companies – A Comparative Case Study", in Agile Processes, in Software Engineering, and Extreme Programming: 16th International Conference, XP 2015, Helsinki, Finland, May 25-29, 2015, Proceedings, Springer International Publishing, Cham, pp. 15–26.

Carlson, R. and Turner, R. (2013), "Review of Agile Case Studies for Applicability to Aircraft Systems Integration", Procedia Computer Science, Vol. 16, pp. 469–474.

Furuhjelm, J., Segertoft, J. and Justice, J. u. Sutherland, J. J. (2017), "Owning the Sky with agile: Building a Jet Fighter Faster, Cheaper, Better with Scrum".

Heimicke, J., Czech, C., Schoeck, M., Mueller, J., Rapp, S. and Albers, A. (2022), "Introducing Agility into the Processes of Manufacturing Companies: A Method for Evaluating Success, Support and Applicability", Proceedings of the Design Society, Vol. 2, pp. 2463–2472.

Heistinger, A. (2013), Qualitative Interviews – ein Leitfaden zu Vorbereitung und Durchführung inklusive einiger theoretischer Anmerkungen.

Hohl, P., Münch, J., Schneider, K. and Stupperich, M. (2016), "Forces that Prevent Agile Adoption in the Automotive Domain", in Abrahamsson, P. (Ed.), Product-focused software process improvement. Lecture Notes in Computer Science, Springer International Publishing, pp. 468–476.

Kagermann, H. (2015), "Change Through Digitization - Value Creation in the Age of Industry 4.0", in Albach, H., Mef-fert, H. and Pinkwart, A. u. Reichwald, R. (Eds.), Management of permanent change, Springer Fachmedien, Wiesbaden, pp. 23–45.

Komus, A. (2017), "Abschlussbericht: Status Quo Agile 2016/2017. 3. Stud. über Erfolg und Anwendungensformen von Agil".

Komus, A. and Kuberg, M. (2017), Abschlussbericht: Status quo agile 2016/2017, Studie über Erfolg und Anwendungsformen von agilen Methoden.

Lévárdy, V. and Browning, T. (2009), "An Adaptive Process Model to Support Product Development Project Management", IEEE Transactions on Engineering Management, Vol. 56, pp. 600–620.

Michalides, M., Bursac, N., Nicklas, S.J., Weiss, S. and Paetzold, K. (2023), "Why Companies Scale Agile Development of Physical Products: An Empirical Study", Vol. 3, pp. 1163–1174.

Schmidt, T. (2019), "Towards a Method for Agile Development in Mechatronics - A Lead User-based Analysis on How to Cope with the Constraints of Physicality", Dissertation, Institut für Technische Produktentwicklung, Universität der Bundeswehr München, München, 2019.

Schmidt, T.S., Atzberger, A., Gerling, C., Schrof, J. and Weiss, S. u. Paetzold, K. (2019), Agile Development of Physical Products: An Empirical Study about Potentials, Transition and Applicability.

Schmidt, T. S., Wallisch, A., Böhmer, A. I., Paetzold, K. & Lindemann, U. (2017) "Media richness theory in agile development: Choosing appropriate kinds of prototypes to obtain reliable feedback", 2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC), S. 521–530

Schrof, J., Schmidt, T. and Paetzold, K. (2018), "Eignungsanalyse agiler Prinzipien für die Entwicklung physischer Produkte".

Schwaber, K. and Sutherland, J. (2020), "The 2020 Scrum Guide", available at: https://scrumguides.org/scrum-guide.html#product-owner (accessed 5 January 2022).

VersionOne (2019), 13th Annual State of Agile Report, available at: https://www.duxdiligens.com/wp-content/uploads/2019/09/13th-annual-state-of-agile-report_7_May_2019.pdf (accessed 2 November 2023).

Weber, S. (2015), "Agile in Automotive – State of Practice 2015", in Kugler Maag Cie.

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