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A Comprehensive Approach for the Strategic Determination of Individual Target Levels of Agility in Product Development

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Abstract: Agility in product development addresses innovation capability and market dynamics, but its application is challenging. The method developed in this research effort defines the optimal agility level, integrating agile and plan-driven elements in mechatronic systems development. It consolidates findings into an Agility Impact Model with three components: Goals, Strategies, and Success Factors. Five steps systematically guide strategic agility target level determination, enhancing productivity and project success empowering practitioners to navigate modern engineering challenges with confidence.

Keywords: Agility, Product Development, Innovation Management, Target Level of Agility, Development Methodology

1 Introduction

Today's markets are changing rapidly, the ability to adapt and innovate is crucial for the success of organizations. This is especially true for the field of mechatronic systems product development, where the interaction of mechanical, electronic, and software components presents unique challenges and opportunities. As markets shift, customer demands evolve, and unforeseen disruptions occur, organizations must navigate this landscape of uncertainty with shorter innovation times. (Bauer et al. 2018)

Agility has proven to serve as a key strategy for organizations seeking to thrive in this volatile environment. Originally rooted in software development, agile methodologies have gained increasing popularity across a broad range of industries to foster flexibility, collaboration, and responsiveness to change. However, the application of agile principles in the context of mechatronic systems product development poses distinct challenges. Unlike purely software-based projects, mechatronic systems involve a complex interplay of physical and digital components, with differing requirements for reliability, safety, and performance. (Schoeck et al. 2022b; Albers et al. 2020; Schoeck et al. 2022a)

1.1 Motivation

Agile methodologies are characterized by benefits like rapid iteration, integration of customer feedback, and adaptive planning, but their applicability must be carefully evaluated within the context of mechatronic engineering. Hence, a systematic approach is required, to integrate agile principles into the product development of mechatronic systems. The goal is not to simply adopt agile practices, but rather to tailor them to the specific requirements and constraints of mechatronic system development. (Michalides et al. 2022; Förster and Wendler 2012)

At the core of this endeavor, the challenge of determining the appropriate level of agility for a given project or organization is found. A balance between the structured predictability of traditional, plan-driven approaches and the flexibility and responsiveness of agile methodologies will have to be determined. The diverse range of available agile methods and practices, each with its strengths, weaknesses, and suitability for different contexts further increases the complexity in the decision-making process (Albers et al. 2019; Heimicke et al. 2022).

Furthermore, the strategic determination of the target level of agility requires a deep understanding of the goals, constraints, and dynamics of mechatronic system development. It involves not only identifying the specific areas where agile practices can add value but also assessing the readiness of the organization to adopt agile principles and the potential challenges associated with their implementation. The appropriate target level of agility in organizations thus contributes to the innovation capability of organizations. (Schöck et al. 2023; Schoeck et al. 2023)

1.2 Agility in the Product Development of Mechatronic Products

Since the initial publication and further development of the Agile Manifesto (Beck et al. 2001) in 2001, agile methodologies have gained widespread acceptance, even becoming a standard in software development. Driven by dynamic market conditions, advancing customer needs, and continuous technological advancements, the ability to respond to changing requirements has become crucial for organizations. Agile practices are characterized by short planning cycles, close collaboration with stakeholders, early and continuous validation, and iterative improvement of product increments (Albers et al. 2019). These practices emphasize iterative, incremental, and evolutionary development, making the creation of tangible prototypes within defined intervals for customer feedback and iterative refinement in the context of validation necessary (Weiss et al. 2023). For product development teams, agile methodologies promote self-organization and autonomy.

While the agile manifesto outlines guiding principles, various frameworks such as SCRUM have been developed to support operationalization of these principles, facilitating short-cycle incremental development (Schwaber and Sutherland 2020). In recent years, the adoption of agile practices has extended beyond software development and gained traction in physical product development and mechatronic systems (Schmidt 2019; Heimicke et al. 2021a). Studies across industry sectors have highlighted the applicability of agile methodologies in mechatronics, despite certain challenges (Albers et al. 2022). Complex interdependencies among subsystems as well as the high degree of cross-domain integration complicates synchronization and collaboration among product developers pose barriers to continuous validation and iteration. (Berger and Eklund 2015).

In response to these challenges, there's an increasing recognition that agile frameworks cannot be directly transferred from software to physical product development without adaptations. One approach that addresses this need for a tailored, situation- and demand-oriented implementation is ASD - Agile Systems Design (Albers et al. 2020; Albers et al. 2018). This methodology, based on nine core principles, proposes a strategic combination of structuring and agile elements to support development projects effectively (Albers et al. 2020):

1. The developer is the center of product development.
2. Each product development process is unique and individual.
3. Agile, situation- and demand-oriented combination of structuring and flexible elements.
4. Each process element can be located in the system triple, and each activity is based on the fundamental operators' analysis and synthesis.
5. All activities in product development are to be understood as a problem-solving process.
6. Each product is developed based on references.
7. Product profiles, inventions, and business models are necessary parts of the innovation process.
8. Early and continuous validation serves the purpose of continuous comparison between the problem and its solution.
9. For a situation- and demand-oriented support in every development project, methods, and processes must be scalable, fractal, and adaptable.

These principles serve as a foundation for this research effort, which aims to provide methodological support for determining the appropriate target level of agility in mechatronic system development. The authors seek to bridge the gap between theoretical principles and frameworks, and practical implementation to meet the specific needs of organizations and problem-solving teams.

2 Research Gap & Target

In mechatronic systems development, the interplay of mechanical, electronic, and software engineering poses unique challenges that require innovative approaches to project management and methodology selection.

A critical gap in existing research lies in the strategic determination of the appropriate level of agility for mechatronic system development. While agile methodologies offer benefits such as rapid iteration and adaptive planning, their suitability for mechatronic systems – which often involve long development cycles, regulatory requirements, and interdisciplinary collaboration – is not well understood. Furthermore, the diverse range of available agile methods and practices adds complexity to the decision-making process, making it challenging for organizations to identify the most suitable approach for their specific context.

The objective of this research is to address this gap by developing a comprehensive methodology for strategically determining the target level of agility in mechatronic systems development. Our approach seeks to bridge traditional, plan-driven approaches and agile methodologies.

2.1 Research Questions

Based on the context and motivation outlined in section 1 as well as previous research efforts of the authors, the research hypothesis for this research effort is, that **‘methodological support is needed for determining the appropriate and individual target level of agility.’**

Research questions have been designed to form the basis for the objectives of this research effort:

RQ1. What are the aspects for the determination of the right level of agility in mechatronic system development?

a. What is an appropriate way to define overarching targets as well as associated metrics for an organization?
b. How can those targets be linked to strategies (agile / plan-driven) and how can a decision be made on which strategies to follow?

RQ2. Which ASD-principles / success factors can help to successfully implement the activities and support operationalization in the team of product developers?

RQ3. How can the decision for the right level of agility be methodically supported and specifically determined for an organization / problem-solving team in mechatronic system development?

By addressing these research questions, the authors aim to contribute to mechatronic systems development methodologies by empowering organizations to navigate the complexities of modern engineering projects with confidence and agility.

3 Findings

In this chapter, the authors present the findings of the research on the strategic determination of the appropriate level of agility in mechatronic systems development. Building upon the theoretical foundations described briefly in the previous chapters, the authors aim to focus on the practical application of agile methodologies within the context of mechatronic system development. The authors' approach is based on a review of existing literature, case studies, and expert interviews, providing valuable insights into the challenges, opportunities, and best practices of the combination of agile and plan-driven methodologies.

In the context of ASD - Agile Systems Design, effective decision-making in mechatronic systems development is based on a systematic understanding of three interconnected elements: targets, strategies, and success factors / ASD principles as also shown in *Figure 1*. These elements collectively form the basis to guide and shape the development process, ensuring alignment with organizational goals and stakeholder needs.

- *Targets*: Identification and definition of specific targets that characterize the desired outcomes and objectives of the development endeavor are the basis for the methodical support proposed by the authors. These targets serve as a 'guiding North Star', providing clarity and direction for the development team throughout the project lifecycle. By defining clear and measurable targets, organizations can effectively prioritize their efforts and focus on delivering value.
- *Strategies*: Complementary to targets, strategies comprise approaches and methodologies to achieve the defined targets. Strategies outline the actionable steps and processes required to realize the desired outcomes. Hence, strategies serve as 'the blueprint' for translating targets into tangible results.
- *ASD Principles / Success Factors*: ASD principles and success factors summarize the essential elements for supporting a successful operationalization of strategies, providing the guiding principles and best practices for navigating the complexities of product development.

Collectively, targets, strategies, and ASD principles / success factors form a holistic framework for driving innovation, efficiency, and excellence in mechatronic systems development. By embracing these elements, organizations can navigate the dynamic landscape of product development with confidence, agility, and foresight.

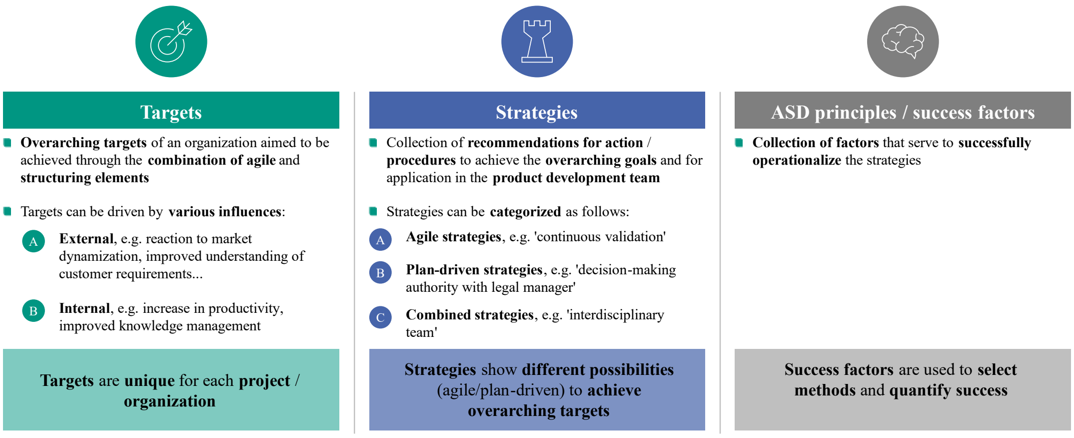

Figure 1: Targets, strategies and ASD-principles / success factors

3.1 A Methodology to Define the Appropriate Target Level of Agility in Organizations

Based on the context and motivation, the research target and design, as well as the three elements – targets, strategies and ASD principles / success factors outlined at the beginning of this chapter, the authors developed a methodology based on a five-step approach to support the determination of the appropriate target level of agility for organizations. The overarching approach will be described in detail before detailed explanations and scientific insights will be given in the following.

The strategic determination of the target level of agility developed by the authors follows five dedicated steps:

1. *Definition of the Target System:* In this initial step, organizations utilize a structured approach, supported by a Target System Workshop, to identify overarching goals for the utilization of agile elements in mechatronic systems development. The objective is to systematically generate a comprehensive list of overarching goals, corresponding metrics, and a prioritization/weighting of the goals.
   Additionally, current activities in the product development process are systematically captured, along with an assessment of the current state of agile element implementation. This includes capturing the G_{n-1} reference process model and planned activities, providing insights into the existing landscape and the extent to which agile elements are currently integrated.
   Hence, organizations can establish a clear understanding of their objectives, evaluate the current situation, and form the basis for strategic decision-making and planning in mechatronic systems development.
2. *Connection of targets and (agile or plan-driven) strategies:* Building upon the defined goals, this step involves linking targets with corresponding strategies and success factors, leading to a so called ‘Agility Impact Model’. This model serves as a comprehensive framework for understanding the interdependencies between goals, strategies, and success factors, enabling organizations to determine specific activities (either agile or plan-driven) that have the most significant impact on achieving the defined goals. By establishing these connections, organizations can gain valuable insights into the most effective approaches for realizing their objectives and driving meaningful progress in mechatronic systems development.
3. *Prioritize and select strategies:* With a clear understanding of the connections between targets and strategies, the next step is to prioritize and select the most suitable strategies for implementation. This involves optimizing the selected strategies to align with the defined goals and objectives, considering factors such as resource availability, project timelines, and organizational priorities. By determining the scope of transformation for a defined sprint length (e.g., the upcoming development generation G_{n+1}), organizations can streamline their efforts and focus on initiatives that will have the greatest impact in the short term while laying the foundation for long-term success.
4. *Implementation:* Once the strategies have been prioritized and selected, the focus shifts to operationalization. Organizations must carefully consider factors such as team composition, skill sets, and organizational culture when operationalizing strategies within the product development teams (PLT). By effectively implementing strategies, organizations can drive tangible progress towards achieving their goals and objectives.
5. *Retrospective:* The final step in the methodology involves conducting a retrospective analysis to reflect on the outcomes of the implementation efforts and identify opportunities for improvement. This retrospective process serves as a valuable learning opportunity, allowing organizations to evaluate the effectiveness of their chosen strategies, identify areas of success, and define areas for refinement or adjustment. By updating the connections between goals, strategies, and success factors in the ‘Agility Impact Model’ based on lessons learned, organizations can iteratively improve their approach to mechatronic systems development and learn how to effectively make use of agile elements in this context.

An overview of the methodology can be found in *Figure 2*. The methodology follows the SPALTEN approach as described by ALBERS (Albers et al. 2005). While the definition of the target system, as well as analyzing the status quo of the use of agile elements can be considered as part of the situation analysis (S), the connection of targets and strategies is part of the problem containment (P) and the search of alternative solutions (A). It is important to note, that when establishing the connections, there is no kind of prioritization or choice of strategies. This is done as part of the prioritization and selection of targets and linked strategies and thus can be considered as the selection of solution (L). In the same step, a careful weighing up of the alternatives of different strategies (whether agile or plan-driven), considering consequences and effects (T), as well as the specific boundary conditions of the team of product developers is conducted, before condensing all information, prioritizing strategies, and making an informed decision (E). This directly leads to the operationalization of the respective solutions. In the retrospective, the connections of target/strategy/success factor will be adjusted according to the learnings from the application of the methodology (and is thus part of recapitulate and learn (N) of the SPALTEN problem-solving methodology). Given the fractal character of the SPALTEN approach, for each step a separate SPALTEN cycle can be used.

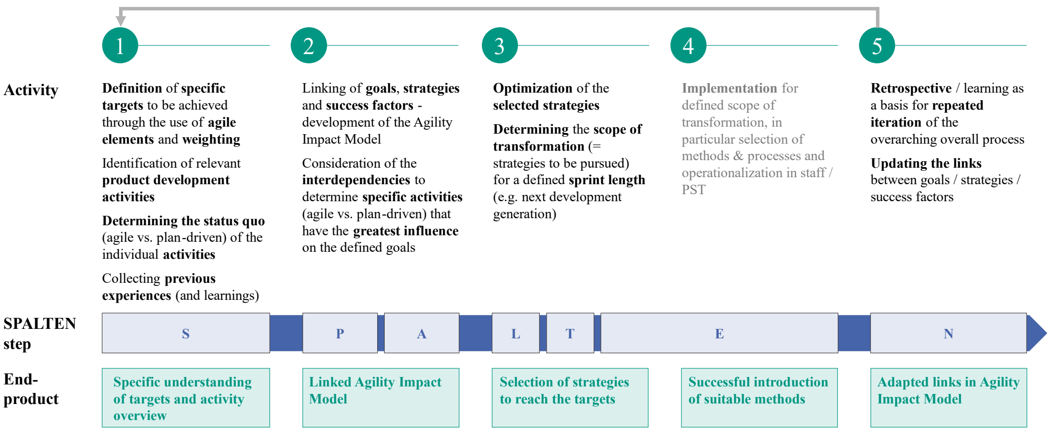

Figure 2: Methodology to define the appropriate target level of agility in organizations

In the following, each step will be described in detail.

3.1.1 Definition of the Target System

Agility in product development, especially concerning physical products and mechatronic systems, demands a systematic approach to define target systems effectively. This research effort presents a structured methodology derived from the Goal-Question-Metric (GQM) approach tailored to this area (Basili et al. 2014; Basili and Rombach 1988).

The 'Target Definition Workshop', a pivotal component of the developed methodology, guides stakeholders through the following steps:

1. *Introduction:* Stakeholders are introduced to the workshop's objectives and rules, fostering collaboration and ensuring alignment with organizational goals.
2. *Consideration of Context Factors:* Contextual constraints and opportunities are identified and used as the basis for goal definition, ensuring relevance and feasibility. These factors are separated into constraints (limitations) and support factors (opportunities) to provide a comprehensive understanding of the product development project's environment.
3. *Formulation of Goals:* Overarching goals are formulated, addressing the primary attributes of the problem manifestation and specifying the purpose of each goal. This step involves answering four guiding questions: What is the object for which the goal is defined? What is the primary attribute of the problem manifestation? What purpose should the goal serve? From whose perspective (stakeholder) should the goal be achieved?
4. *Derivation of Questions:* Each goal aspect is characterized by distinct questions, focusing on how objects (product, process, or resource) contribute to achieving the overall goal of the GQM model. Three guiding questions assist in this process: How can we characterize the object in terms of the overall goal? How can we characterize the attributes of the object relevant to the specific GQM model? How do we evaluate the characteristics of the object relevant to the specific GQM model?
5. *Definition of Metrics & Acceptance Criteria:* Objective and subjective metrics are established to quantitatively measure each question, distinguishing between objective metrics (dependent solely on the object) and subjective metrics (dependent on both the object and the standpoint). Objective metrics include quantifiable data, while subjective metrics include qualitative assessments like team members' satisfaction or user-friendliness.
6. *Goal Review:* The defined goals, questions, and metrics are reviewed to ensure consistency, exhaustiveness, and alignment with organizational objectives.
7. *Goal Prioritization:* Using pairwise comparison, goals are weighted and prioritized based on their relative importance, guiding resource allocation and decision-making.

Utilizing the GQM framework, this approach ensures a comprehensive understanding of the target system's requirements and constraints, ensuring informed decision-making.

Secondly, current activities in the product development process are systematically captured, along with an assessment of the present state of agile element implementation. This includes capturing the G_{n-1} reference process model and planned activities, providing insights into the existing landscape and the extent to which agile elements are currently integrated into product development.

3.1.2 Connection of Targets and (Agile or Plan-Driven) Strategies:

In previous research efforts, the authors conducted an extensive empirical interview study aimed at identifying a set of strategies for effectively operationalizing targets in mechatronic systems development. These strategies – a collection of recommendations and approaches – serve as guidance for teams of product developers in achieving overarching goals and objectives.

Strategies can be categorized into three main types:

- *Agile Strategies*: These strategies emphasize flexibility, adaptability, and iterative development processes. Examples include "continuous validation," which involves ongoing testing and feedback loops to ensure alignment with customer needs and project objectives.
- *Plan-Driven Strategies*: In contrast to agile approaches, plan-driven strategies prioritize structured planning, clear decision-making hierarchies, and adherence to predetermined schedules. An example is "decision-making authority with the legal manager," which ensures that key decisions are made in accordance with legal requirements and organizational policies along the organizations hierarchy.
- *Combined Strategies*: These strategies leverage elements from both agile and plan-driven approaches to optimize outcomes. An example is "interdisciplinary team collaboration," which fosters cross-functional collaboration and knowledge sharing to drive innovation and problem-solving.

Each strategy identified in our study is initially linked with typical targets and objectives of organizations. This link enables organizations to select and implement strategies that best support the achievement of specific targets.

For each strategy, a specific set of actions has been defined based on empirical data gathered during interview studies. These actionable recommendations serve as practical guidelines for product development teams, providing a roadmap for implementing strategies in their unique context. However, it is important for teams to adapt these actions to their specific needs, boundary conditions, and organizational characteristics to ensure effectiveness and relevance.

In summary, the identification and classification of strategies for operationalizing targets provide valuable insights and actionable recommendations for organizations.

As part of this research effort, the authors recognized the critical role of ASD principles as success factors in supporting the implementation and operationalization of chosen strategies for mechatronic systems development. These principles provide a framework for decision-making and action. Furthermore, they offer valuable insights for the selection of specific methods to be employed within teams of product developers.

For each strategy and corresponding action identified in previous research efforts, the respective corresponding ASD principles have been determined. These principles serve to ensure alignment with the core values of the ASD – Agile System Design methodology and play a crucial role in supporting the implementation and operationalization of chosen strategies.

In essence, the integration of ASD principles as success factors enriches the implementation and operationalization of specific actions and methods.

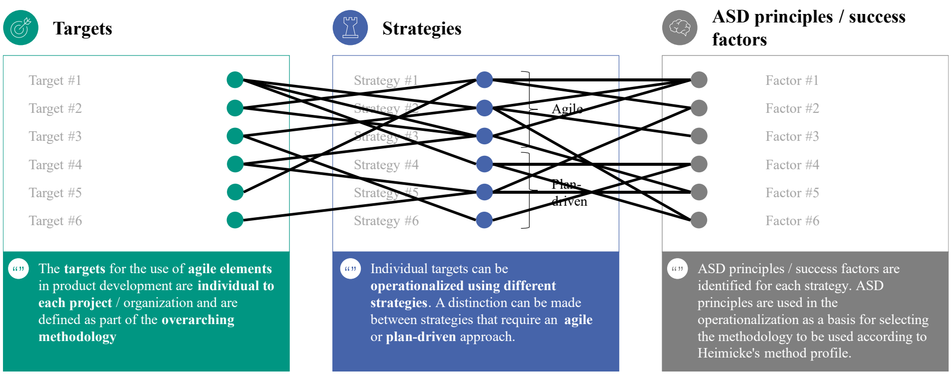

Figure 3: The developed Agility Impact Model (exemplary)

The second step involves linking identified targets with corresponding strategies and success factors, ultimately culminating in the creation of the ‘Agility Impact Model’. This model serves as a comprehensive framework for understanding the interdependencies between targets, strategies, and success factors, enabling organizations to determine specific strategies and underlying activities (whether agile or plan-driven) that have the most significant impact on achieving the defined goals (see *Figure 3*).

3.1.3 Prioritize and Select Strategies

In this critical phase of the developed methodology, focus shifts on prioritizing and selecting the most suitable strategies for implementation, focused on the overarching goals and objectives identified in the previous steps.

The first step in this phase (see step A in *Figure 4*) involves analyzing target coverage, to select the optimal combination of strategies that maximally cover the linked targets. This process is framed as an optimization problem, where the goal is to identify strategies that effectively address the identified targets while minimizing redundancy and maximizing impact. Central to this phase is also the definition of the transformation scope, which means defining the strategies and actions, that are applied to the next iteration (e.g. the next development cycle).

In addition to defining target coverage and transformation scope, this phase also involves determining the associated ASD principles and success factors (see step B in *Figure 4*). The combination of strategies, success factors, and ASD principles serves as input for the creation of a method profile (Heimicke et al. 2021b). This profile outlines the recommended methods and processes to be utilized in the implementation of selected strategies, providing a structured framework for decision-making and action.

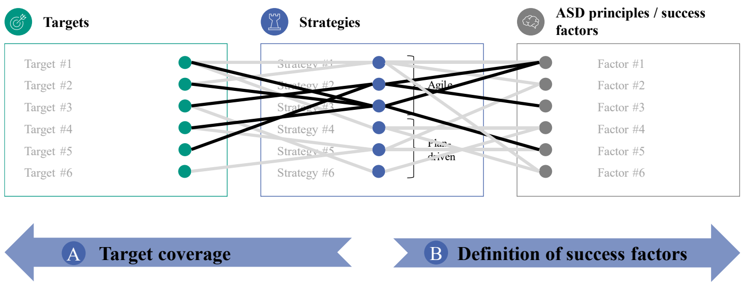

Figure 4: Prioritization and selection of strategies in the Agility Impact Model

In essence, in this phase of the methodology the focus shifts from identification to implementation. By prioritizing strategies, defining transformation scope, and aligning with ASD principles, organizations can define a clear path forward for realizing their goals and objectives in mechatronic systems development.

3.1.4 Implementation

The fourth step involves the selection and operationalization of suitable methods within the product development team. While this aspect falls outside the scope of this research effort, it represents a critical component of translating strategic objectives into actionable plans. Based on e.g. the ASD method profile developed by HEIMICKE (Heimicke et al. 2021b), teams can leverage a selection of methods and processes tailored to their specific context and objectives. This ensures the effective execution of selected strategies.

3.1.5 Retrospective / Learning

In the final stage of the developed methodology, emphasis is put on retrospective and continuous learning, serving as foundation for iterative refinement and improvement of the overarching process.

This fifth step involves conducting a retrospective analysis to reflect on the outcomes, challenges, and lessons learned throughout the implementation process and determination of strategies. By providing a structured forum for team members to share their insights, experiences, and observations, this step supports the collective learning in the team of product developers and promotes a culture of continuous improvement. During the retrospective, the teams are to revisit the initial goals and objectives defined in earlier stages of the process, assessing the extent to which these targets were achieved and identifying any gaps or areas for enhancement. This retrospective analysis serves as a basis for refining strategies, adjusting implementation approaches, and realigning organizational priorities as needed.

As part of the retrospective process, the connections between goals, strategies, and success factors in the ‘Agility Impact Model’ are updated and refined based on the insights gained from the implementation experience. This iterative refinement ensures that the overarching process remains responsive to evolving needs, changing conditions, and emerging opportunities.

4 Conclusion

In this research effort, the authors presented a comprehensive methodology for supporting decision-makers and product developers in defining the most appropriate level of agility in mechatronic systems development. Based on previous empirical research and leveraging established frameworks such as ASD - Agile Systems Design, the methodology offers a structured approach to navigating the complexities of modern product development landscapes in mechatronics.

This research efforts makes several key contributions to the field. Firstly, we address the need for a systematic and methodical approach to defining the right level of agility, recognizing the dynamization of markets, changing customer requirements, and unforeseen events that characterize nowadays product development environments. By integrating agile and plan-driven elements in a strategic manner, the methodology enables organizations to enhance their innovation capabilities and adaptability while mitigating risks and uncertainties.

Secondly, we bridge the gap between theoretical frameworks and practical implementation, providing actionable recommendations and guidelines for product development teams. Through a series of structured steps, our methodology supports the alignment of strategic objectives with operational realities, empowering meaningful progress towards organizational goals.

5 Outlook

Looking ahead, future research efforts explore the application of our methodology in diverse industry contexts. First studies are already being conducted by the authors and show promising results. Furthermore, the authors aim to delve deeper into specific aspects of the methodology, such as enhancing decision quality for the selection and operationalization of methods, to provide more detailed guidance.

In conclusion, our methodology offers a valuable framework for supporting decision-makers and product developers in navigating the complexities of mechatronic systems development. By embracing agility and leveraging the principles of ASD, organizations can enhance their innovation ability in an increasingly dynamic and competitive landscape.

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