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Validation of an Approach to Determine Individual Target Levels of Agility in Product Development

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Abstract

The increasing dynamization of markets, changing customer requirements and unpredictable occurrences pose new challenges for product development and design. Agile methods and processes can serve as a solution to secure the innovation capability of organizations in this environment, but its application is challenging. An approach for the Strategic Determination of Individual Target Levels of Agility in Product Development shall overcome these challenges. The approach investigated 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. The aim of this paper is the application, validation and evaluation of this approach for determining the individual target level of agility as a combination of structuring and agile elements. A quasi-experimental design is used to measure effects in a two-group experiment and to draw conclusions about the contribution of the methodology. A Live-Lab in the form of a student product development project with an industrial partner at the Karlsruhe Institute of Technology (KIT) serves as the research environment. The Validation is based on the overarching success criteria applicability, usefulness and acceptability. The applicability was rated as sufficient in a qualitative study. For the success criterion of usefulness, positive effects are identified in terms of the impact on the product developers' behavior.

Keywords
Method Validation, Development Methodology, Agile Product Development, Innovation Management, Mechatronic Systems.

1. Introduction

The increasing dynamization of markets, rapidly changing customer requirements, and unpredictable disruptions – such as technological breakthroughs or global crises – pose significant challenges for product development (Cooper, 2019). Traditional plan-driven (waterfall) approaches, while structured and predictable, often struggle to adapt to these dynamic conditions, leading to inefficiencies and delayed market responsiveness (Highsmith, 2009). Conversely, agile methodologies, with their iterative and flexible nature, have emerged as a promising solution to enhance innovation capability and adaptability (Rigby et al., 2016). However, the indiscriminate adoption of agile practices without considering contextual factors can lead to inefficiencies, misalignment with organizational goals, and even project failures (Boehm & Turner, 2004).

Research indicates that a hybrid approach, combining agile and plan-driven elements, may offer the optimal balance between flexibility and stability (Kuhrmann et al., 2017). Yet, determining the appropriate degree of agility for a given product development context remains a critical challenge. Too much agility may introduce chaos in structured environments, while excessive rigidity can stifle innovation in dynamic settings (Conforto et al., 2014). Existing

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frameworks, such as the '*Agility Measurement Index*' (Sherehiy et al., 2007) and the '*Hybrid Software and System Development Model*' (Kuhrmann et al., 2019), provide foundational insights but lack a comprehensive, empirically validated approach for agility allocation.
To address this challenge, a structured method for the '*Strategic Determination of Individual Target Levels of Agility in Product Development*' is proposed by Schoeck et al (2024). This method aims to systematically assess contextual factors – such as market volatility, project complexity, and organizational maturity – to define an optimal agility share tailored to specific product development scenarios based on the iPeM – Integrated Product Engineering Model (Albers et al., 2016)

This study seeks to validate the methodology developed by Schoeck et al. (2024) in industrial practice, that supports decision-makers in strategically balancing agile and plan-driven elements. By leveraging a case-based validation conducted in a Live-Lab, this approach aims to enhance both efficiency and adaptability in product development, ultimately contributing to sustained innovation in volatile markets.

2. Background & Related Work

This chapter examines the theoretical foundation and validation challenges of agility determination in product development. It introduces Schoeck et al.'s (2024) framework for strategic agility target-setting and Eisenmann's (2023) Validation Navigator as key methodological anchors for this study.

2.1 Core of this study – A Comprehensive Approach for the Strategic Determination of Individual Target Levels of Agility by Schoeck et al. (2024)

This study seeks to validate the "*Comprehensive Approach for the Strategic Determination of Individual Target Levels of Agility*" in mechatronic product development developed by Schoeck et al., (2024) addressing the critical challenge of balancing agile flexibility with plan-driven structure in complex engineering environments. Building upon the iPeM – Integrated Product Engineering Model (Albers et al., 2016) and the Agile Systems Design (ASD) framework (Albers et al., 2019), the approach systematically integrates three core elements: targets that define desired outcomes, strategies that operationalize these goals through either agile or plan-driven approaches, and ASD success factors that guide effective implementation. (Schoeck et al., 2024).

The methodology emerged from extensive empirical research including case studies and expert interviews, revealing that successful agility adoption requires more than mere process adaptation – it demands a holistic alignment of organizational objectives, development constraints, and team capabilities. (Schoeck et al., 2023a) By providing structured decision-support, the framework enables organizations to navigate the inherent tensions between rapid iteration (characteristic of agile methods) and rigorous verification (essential in mechatronic systems), particularly in mechatronic systems design, to enhance innovation capability. (Schoeck et al., 2023b) Findings are consolidated into an *Agility Impact Model*, which connects Goals, Strategies, and Success Factors to ensure adaptability without compromising stability (Schoeck et al., 2024). By systematically guiding decision-making, it empowers organizations to navigate uncertainty while enhancing innovation capability in product development of mechatronic systems.

2.2 Validation in product development

While methodological approaches – like the approach described in chapter 2.1 – offer structured solutions for balancing agile and plan-driven elements, the transition from theoretical frameworks to practical implementation remains challenging. Research shows that even well-developed methods often face limited adoption in industry practice due to issues of acceptance and adaptability (Gericke et al., 2016). Common barriers include excessive rigidity (Pahl, 1994), high abstraction levels (Braun & Lindemann, 2004), and insufficient tool integration (Birkhofer et al., 2005) – challenges particularly relevant for agility determination methods that must balance structure and flexibility.

The validation of such methods presents unique difficulties. Product development environments exhibit high variability in team dynamics, problem complexity, and organizational constraints (Eisenmann et al., 2021), making controlled validation studies particularly challenging. Furthermore, the human factor in agility adoption introduces variables that resist quantitative measurement (Reich, 2010), while the context-dependent nature of agility makes standardized evaluation problematic (Vermaas, 2014). Many existing validation approaches focus narrowly on technical applicability while neglecting organizational fit and long-term sustainability (Eisenmann et al., 2021).

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The '*Validation Navigator*' developed by Eisenmann (2023) represents a structured reference process for conducting validation studies of engineering design methods. This framework provides a standardized approach for operationalizing success criteria in validation research, with particular emphasis on two key dimensions: applicability and effectiveness.

The process follows an experimental research approach and embeds its activities between two impact models – an initial model representing hypothesized effects and a verified model confirming empirical results. This structure enables systematic verification of a method's claimed benefits.

The validation process consists of two main phases (Eisenmann, 2023):

1. A *qualitative study* investigating applicability examines how the method influences users' thinking and actions, ensuring proper understanding and implementation. This phase establishes the necessary foundation for subsequent effectiveness evaluation.
2. The *quantitative effectiveness study* measures the method's actual impact through empirical investigation, focusing specifically on its utility as part of the effectiveness criterion.

Both phases follow three core activity categories: study design, operationalization and interpretation of results. This comprehensive approach addresses the challenges of validating design methods while maintaining scientific rigor and practical relevance (Eisenmann, 2023) and is well suited to support validation of the methodical support in focus of this work.

3. Research Objective and Approach

This chapter defines the study's objectives and research questions, focusing on validating an agility determination methodology through empirical assessment of its applicability, effectiveness, and organizational alignment in mechatronic development contexts.

3.1 Objectives

The primary objective of this study is to conduct a comprehensive empirical validation of the methodology for determining individualized agility target levels developed by Schoeck et al. (2024, see chapter 2.1 & 4.1 respectively). The validation focuses on three key dimensions: applicability in real-world product development contexts, effectiveness in achieving defined agility goals, and continuous alignment with organizational objectives throughout the validation process. The study adopts a dual perspective, examining both the technical robustness of the methodology and its practical utility in mechatronic systems development environments.

3.2 Research Questions

The investigation is guided by the following core research questions:

1. To what extent does the methodology support organizations in determining optimal agility levels as a hybrid of structured and flexible elements, and in achieving their defined agility targets?
   a. How can the methodology be validated regarding applicability, usefulness, and acceptance through empirical study?
   b. What degree of support does the methodology provide for goal attainment, measured against the success criteria of applicability, usefulness, and acceptance?

4. Research Design

Structured around Schoeck et al.'s (2024) five-step methodology, this chapter outlines its empirical validation through a Live-Lab case study and quasi-experimental design, assessing applicability, usefulness, and acceptance in mechatronic development contexts.

4.1 Subject of Investigation of this study

The methodical support to be validated in this research effort is described in chapter 2.1. It operationalizes through five rigorously defined steps (Schoeck et al., 2024):

1. *Definition of the System of Objectives*: Organizations conduct structured workshops using an adapted Goal-Question-Metric (GQM) approach to establish weighted, measurable objectives while simultaneously

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capturing current process maturity through reference modeling of existing development activities (see also Schoeck et al (2025) for details).
2. *Connection of Targets and (agile or plan-driven) Strategies*: The so-called Agility Impact Model is created, that maps causal relationships between 30+ identified strategies (categorized as agile, plan-driven, or hybrid) and organizational targets, incorporating empirical data from longitudinal industry studies to validate these connections.
3. *Prioritization and Selection of Strategies*: Using multi-criteria optimization techniques, organizations evaluate strategy combinations against constraints (resources, timelines) and ASD principles, focusing particularly on fractal implementation across organizational hierarchies to ensure scalability.
4. *Implementation*: Selected strategies translate into concrete methods via ASD method profiles, with adaptation mechanisms for team-specific factors including regulatory requirements (e.g., ISO 26262 compliance in automotive) and subsystem interdependencies in mechatronic architectures.
5. *Retrospective and Learning*: Each development cycle concludes with model refinement of the Agility Impact Model based on quantitative metrics (e.g., requirement volatility indices) and qualitative assessments (team capability evaluations), creating organizational learning loops that progressively enhance agility calibration accuracy.

The process embeds the SPALTEN problem-solving methodology (Albers et al., 2005) throughout, ensuring systematic handling of mechatronic development's inherent complexity while maintaining traceability from strategic decisions to operational outcomes.

4.2 Study Environment

The research presented in this work is conducted within the Live-Lab "Integrated Product Development (IP)" at the Karlsruhe Institute of Technology (KIT), in close cooperation with KARL MAYER Group, a leading industry partner in textile machinery. A Live-Lab is defined as an experimental research environment that allows for the study and refinement of product development methods, tools, and processes under near-real conditions while maintaining a high degree of control over boundary conditions (Walter et al., 2016). In this setting, 42 engineering student product developer, organized into seven development teams, undertake a full product development cycle – from initial market research and concept generation to prototyping – guided by a real-world industry challenge.

For the 2023/24 iteration, KARL MAYER set the theme, focusing on the development of user-centered solutions for textile machinery. The company not only provided the task but also actively participated in milestone reviews, ensuring practical relevance and industry alignment. This collaborative Live-Lab approach serves a dual purpose: it advances academic research in engineering methodologies while delivering actionable, industry-ready innovations. By bridging theory and practice, the IP Live-Lab exemplifies how university-industry partnerships can drive both educational excellence and technological progress.

4.3 Study Design

The study design follows a quasi-experimental two-group approach (Blessing and Chakrabarti 2009, pp. 264 ff.), consisting of an experimental group (EG) and a control group (CG) utilizing the validation framework of Eisenmann (2023, see chapter 2.2). The aim is the structured execution of the empirical analysis for validating the methodology.

Experimental Study Design: The experimental design is illustrated in Figure 1 and is divided into three phases: pre-tests ($O_{V.i}$), method exposure (X_i), and post-tests ($O_{N.i}$). The pre-tests serve to analyze potential initial differences between the groups. Post-tests are used to measure the effects achieved (Blessing and Chakrabarti 2009, p. 265). The exposure of the experimental group to the subject of investigation (chapter 2.1 and 4.1) is referred to as method exposure (X_i) and takes place between the pre- and post-tests.

Experimental and Control Groups: The participants of the Live-Lab were divided into seven development teams across two rooms. Three teams in Room A formed the experimental group (EG), while three teams in Room B constituted the control group (CG). One team did not participate in this study. The group sizes were identical. The EG received additional training on the application of the methodology, whereas the CG only received general training on agility. All teams were initially introduced to agile principles and the SCRUM framework and were encouraged to structure their development process accordingly. The EG thus operated with methodological support, deliberately deviating from the "normal situation" defined by the general training level of all participants.

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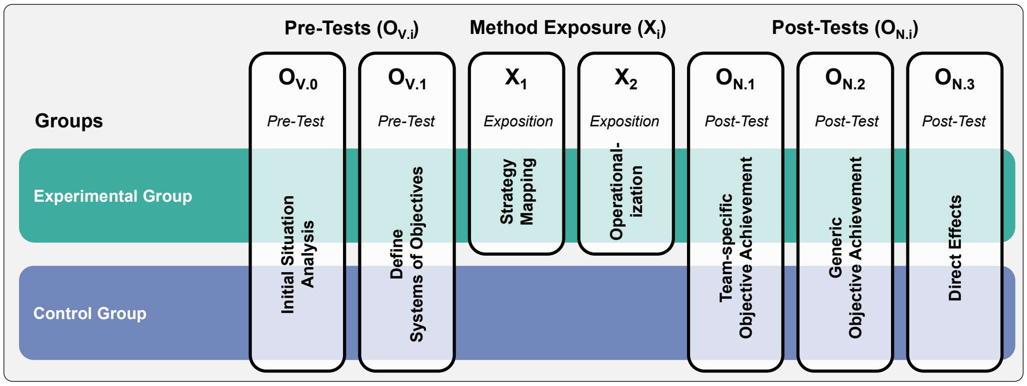

Figure 1. Study Design for the Experimental Validation of the Methodology

Pre-Test ($O_{V.i}$): The pre-test is divided into two steps: the initial situation analysis ($O_{V.0}$) and the definition of the System of Objectives ($O_{V.1}$). The situation analysis ensures that the groups are comparable in terms of team composition, training in development methodology and the mandatory application of agile principles. This step is applied to all groups as a prerequisite. The main component, $O_{V.1}$, involves defining the individual agility system of objectives at the team level. This is done using the systematic goal definition process developed in the prescriptive study. The defined target systems serve both to operationalize agile measures and as the basis for later measuring goal achievement ($O_{N.1}$). This step is conducted in both EG and CG.

Method Exposure (X_i): The method exposure (X_i) is divided into two steps: strategy and measure mapping (X_1) as well as operationalization (X_2). These steps are applied exclusively to the experimental group (EG). In the strategy and measure mapping phase (X_1), strategies and related recommendations for action are derived based on the previously defined goals ($O_{V.1}$). These recommendations may be agile or plan-driven elements. In the operationalization phase (X_2), the identified strategies and measures are selected and adapted. The teams review which activities are already in use and tailor newly selected agile or plan-driven measures to their specific team environment.

Post-Test ($O_{N.i}$): The purpose of the post-tests ($O_{N.i}$) is to evaluate the effects of the method application (X_i). The follow-up investigation is divided into three elements: team-specific achievement of systems of objectives ($O_{N.1}$), overarching achievement of objectives ($O_{N.2}$), and measurement of direct effects ($O_{N.3}$).
$O_{N.1}$ assesses the achievement of the team-specific systems of objectives defined in $O_{V.1}$ and is conducted with both the experimental and control groups. Deviations in objective achievement are expected to provide insights into the effects of the method. $O_{N.2}$ measures overarching objective achievement and aims to increase the generalizability of the results within the scope of this study. $O_{N.3}$ captures the direct effects on the thinking and behavior of the developers. As in $O_{N.2}$, these effects are assessed across all groups. The goal is to identify differences between teams that received only general agility training (e.g., SCRUM) and those that applied the method (X_i).

4.4 Empirical Validation Process

This section translates the previously described elements of the study design into a structured validation process. The objective is to evaluate the development methodology along the success criteria of applicability, usefulness, and acceptance. Furthermore, activities of the experimental investigation plan are mapped to the corresponding success criteria. The overall process follows the validation navigator by Eisenmann (2023) and is illustrated in Figure 2 and is structured into four steps:

I. Describing Expected Effects: Initial Impact Model

The initial Impact Model ($IM_{initial}$) represents the expected direct and indirect effects of the methodology. The model focuses on the criterion of efficacy, referring to the direct impact on users' thinking and behavior. Additionally, causal chains are used to represent indirect effects in terms of effectiveness.

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II. Analyzing Applicability: Qualitative Study on Applicability

Applicability is considered a prerequisite for usefulness and is operationalized through the variables *understandability* ("Ease of understanding"), *usability* ("Ease of use"), and *correctness of application* ("Extent of being followed correctly"). (Kroll and Weisbrod 2020)

The qualitative study focusing on applicability ($S_{A.i}$) consists of four elements:

- $S_{A.0}$: Systematic definition of systems of objectives
- $S_{A.1}$: Connection of targets and (agile or plan-driven) strategies
- $S_{A.2}$: Operationalization
- $S_{A.3}$: Status quo interviews

These elements correspond to the previously described pre-test $O_{V.0}$ and the method application X_i of the experimental study design (see Chapter 4.3). The objective is to develop a qualitative understanding of the method's application and implementation in order to assess its applicability.

III. Assessing Usefulness: Quantitative Study on Usefulness

The quantitative study measures the success criterion usefulness, subdivided into effectiveness (indirect effects) and efficacy (direct effects). The following elements of the post-test ($O_{N.i}$), previously explained in Chapter 4.3, serve as the foundation:

- $S_{N.1}$: Team-specific achievement of objectives: Comparison of EG and CG based on the systems of objectives defined in $S_{A.0}$
- $S_{N.2}$: Overarching objective achievement – Measurement of generic project goals and agility-related goals
- $S_{N.3}$: Measurement of direct effects (efficacy) along five aspects – operationalization, goal orientation, operational understanding/tangibility, determination of the appropriate agility level and acceptance

IV. Describing Actual Effects: Updated Impact Model

In the final step, the actual effects of the methodology are consolidated and visualized in the Updated Impact Model ($IM_{reviewed}$). The expected effects from the initial model are verified, falsified, or expanded based on the empirical findings.

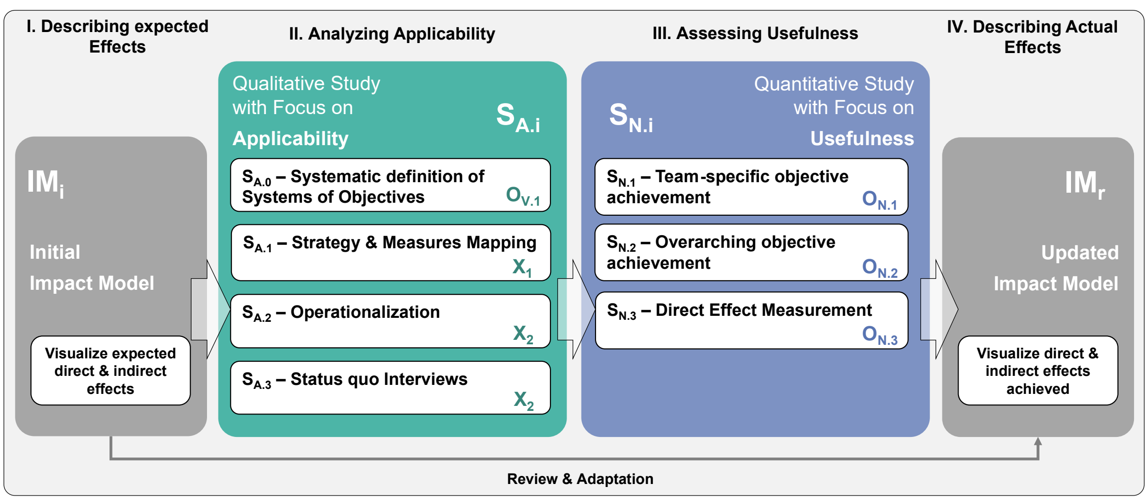

Figure 2. Process for the Empirical Validation of the Methodology

5. Results and Discussion

The analysis synthesizes qualitative applicability findings (correctness, understandability, usability) with quantitative results on usefulness, demonstrating robust direct effects (efficacy) but inconclusive indirect impacts, highlighting the methodology's strengths in tactical agility implementation over strategic outcomes.

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5.1 Qualitative Study on Applicability

The applicability is assessed from two perspectives. First, the evaluation of the strategy and measure linkage ($S_{A.1}$) is conducted, which represents a central step in determining the individual agile target level. This step was carried out by the researchers; the evaluation was conducted through an interview. The correctness of application serves as the evaluation criterion. Second, the applicability of team-specific measures is examined based on data from the operationalization ($S_{A.2}$) and the status quo interview ($S_{A.3}$). The variables used for evaluation are understandability and usability.

Correctness of Application: The application of the methodology in step $S_{A.1}$ is assessed as sufficiently fulfilled. The use of the GQM approach to structure the definition of objectives supported the selection of suitable strategies and measures by systematically formulating objectives based on defined parameters and further characterizing them through guiding questions. Although the potential of the methodology could only be partially leveraged in the given research environment, the level of agility within the participating teams was purposefully increased.

Understandability: The understandability of the measures was assessed through individual training sessions and status quo interviews. The team-specific training as well as the documentation linking objectives and measures contributed to participants' comprehension. Continuous clarification during the sessions helped resolve misunderstandings directly. In terms of documentation, more specific instructions and templates for implementation would have been helpful in some cases. Overall, the understandability of the methodology in the context of operationalization is rated as sufficient.

Usability: The majority of measures were implemented by the teams. Limiting factors such as capacity constraints and time pressure occasionally hindered application. Nevertheless, the measures were adapted to the specific team environments. The documentation of the objective-measure linkage as part of the Agility Impact Model was perceived by some development team members as partly redundant and unclear; clustering the measures could improve clarity. Overall, there is potential to improve usability, particularly in terms of implementation support. However, the application of the measures was largely feasible, and no additional need for measures or instructions was indicated.

The assessment of applicability was influenced by several external factors: differences in prior knowledge regarding agility, which could not be fully controlled; the correct implementation of measures within the teams; and project-specific conditions. However, the chosen Live-Lab environment offered the advantage of limited professional experience among participants, thereby increasing comparability. Although the application of the measures could not be fully tracked, a solid understanding was established through training sessions, documentation, and interviews. Moreover, the status quo interviews enabled a complementary evaluation during the application phase.

5.2 Quantitative Study on Usefulness

The quantitative investigation of the methodology's usefulness is divided into three elements: team-specific achievement of objectives ($S_{N.1}$), overarching achievement of objectives ($S_{N.2}$), and measurement of direct effects ($S_{N.3}$). Data on the achievement of objectives were collected using standardized templates as well as an online survey conducted after the project was completed.

Table 1. Team-specific Goal Achievement of the experimental and control group ($S_{N.1}$)

Experimental Groups	**Target Achievement (TA) / Weighted TA** [Mean value]	**Control Groups**	**Target Achievement (TA) / Weighted TA** [Mean value]
ET1	4,00 / 4,25	CT1	3,00 / 2,85
ET2	3,80 / 3,70	CT2	3,80 / 3,65
ET3	4,20 / 4,25	CT3	4,20 / 4,30
	4,00 / 4,07		**3,67 / 3,60**

Team-Specific Objective Achievement ($S_{N.1}$): The purpose of element $S_{N.1}$ is to identify the effects of the methodology at the individual level by comparing the experimental group (EG) and the control group (CG). The basis for this is the systems of objectives defined in $S_{A.0}$.

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Table 1 presents the teams' achievement levels on a scale from 0 to 5. The EG rated its objective fulfillment at an average of 4,00 (weighted: 4,07), while the CG rated it at 3,67 (weighted: 3,60). Thus, the EG achieved slightly higher values than the CG. Although no statistically significant effect can be demonstrated, the results indicate a positive influence of the methodology. However, the diversity of defined objectives and their influence on the evaluations represent a methodological limitation and require nuanced interpretation. Overall, the methodology is assessed as supportive for achieving objectives at the team level (Table 2).

Table 2. Overarching Goal Achievement of the experimental and control group ($S_{N.2}$)

Cluster	**Category**	**Experimental Group** [Mean value]	**Control Group** [Mean value]
Generic	Generic Goal Achievement	3,64	4,21
Agile	Communication & Behavior	4,06	4,17
	Competencies	4,08	4,50
	Satisfaction	3,17	4,42
	Feature Prioritization	3,83	4,42
	Use of Resources	3,83	4,25
	Risk Minimization	3,78	3,89

Overarching Objective Achievement ($S_{N.2}$): Element $S_{N.2}$ aims to capture indirect effects at a generic level. A distinction is made between general project objectives (e.g., satisfaction with results, resource assessment) and agile-specific objectives (e.g., communication, feature prioritization, resource use). The results do not show a consistent pattern. While some positive effects were observed within the experimental group, the control group generally performed better. Despite the use of a standardized measurement system, no clear conclusions regarding the effectiveness of the methodology can be drawn. Based on these observations, the effectiveness in terms of overarching objective achievement is assessed as insufficient.

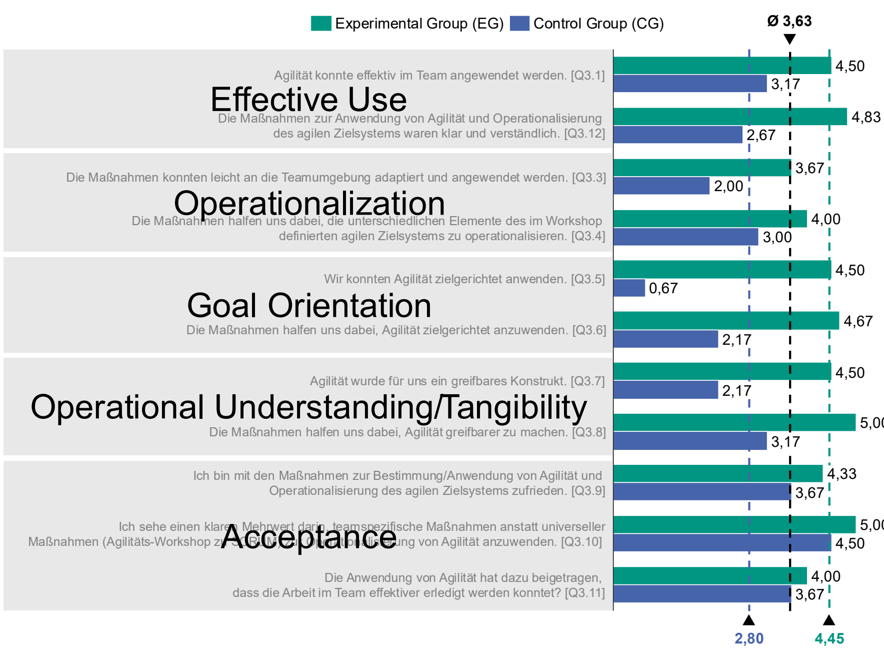

Figure 3. Results of the quantitative survey on efficacy (direct effects, $S_{N.3}$)

Measurement of direct effects ($S_{N.3}$): The direct effects assessment ($S_{N.3}$) addresses the success criterion of efficacy. The aspects evaluated include operationalization, goal orientation, understanding, and the determination of an appropriate target level of agility.

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Figure 3 presents the results of the quantitative survey. The EG rated the mentioned aspects with an average of 4,45, while the CG averaged 2,38. Based on statistical analysis using the Mann-Whitney U test and the calculation of effect size *r*, the efficacy of the methodology is rated as sufficient. Strong effects were particularly observed in terms of tangibility and operational understanding as well as goal orientation and operationalization; moderate effects were found regarding the effective use and acceptance of agility.

Figure 4 visualizes the effect sizes: the further a corner point of the pentagon extends outward, the stronger the effect of the methodology as the difference between the experimental group and the control group.
The success criterion of usefulness is fulfilled only partially. While no significant or consistent effects were identified regarding effectiveness ($S_{N.1}$ and $S_{N.2}$), the results for $S_{N.3}$ demonstrate a clear efficacy of the methodology in terms of positively influencing the thinking and behavior of the developers. Overall, the methodology's direct effects on operational aspects of agility are assessed positively.

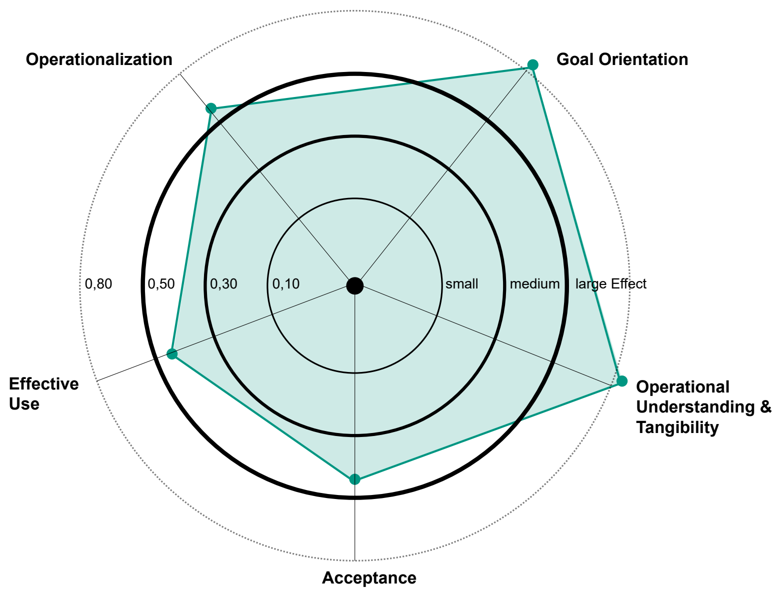

Figure 4. Effects of the validated methodology by Schoeck et al. (2024) measured by the effect size |r| classified according to Cohen (1988)

6. Conclusion

This paper presents the application and empirical validation of a methodology for determining individual target levels of agility in product development developed by Schoeck et al. (2024). The methodology aims to support organizations in tailoring agile and plan-driven elements to their specific development context. Based on a quasi-experimental study design and a Live-Lab environment, the method was evaluated against the success criteria applicability, usefulness, and acceptability.

The results of the qualitative study demonstrate that the methodology is applicable in terms of correct implementation, user understanding, and contextual adaptability. In particular, the structured goal definition ($S_{A.0}$), the derivation of strategies and measures ($S_{A.1}$), and their team-specific operationalization ($S_{A.2}$) supported participants in aligning their development process with agility-related goals.

The quantitative study revealed a differentiated picture: While the effectiveness of the methodology regarding goal achievement remains inconclusive ($S_{N.1}$, $S_{N.2}$), its direct impact on developers' thinking and behavior could be demonstrated ($S_{N.3}$). From a methodological perspective, the dual approach of team-specific and overarching objectives is justified: While overarching objectives enhance comparability across teams, team-specific goals support the individualized nature of the investigated methodology. However, both approaches come with limitations. The standardized objectives in $S_{N.2}$ were assessed over a short time period and are limited in their quantifiability. In $S_{N.1}$, the quality of results depends heavily on the quality of the defined systems of objectives and associated metrics. The better performance of the control group in certain $S_{N.2}$ items suggests the need to further explore potential confounding variables such as team dynamics or environmental constraints in future studies. Nevertheless, the strong direct effects observed in $S_{N.3}$ indicate a positive influence on indirect outcomes over longer timeframes, supporting the relevance of the methodology.

In terms of direct effects ($S_{N.3}$), significant differences between the experimental and control groups were observed in the areas of goal-orientation, operationalization as well as understanding and tangibility of agility. These findings confirm the method's effects in shaping agile transformation processes on an individual and team level.

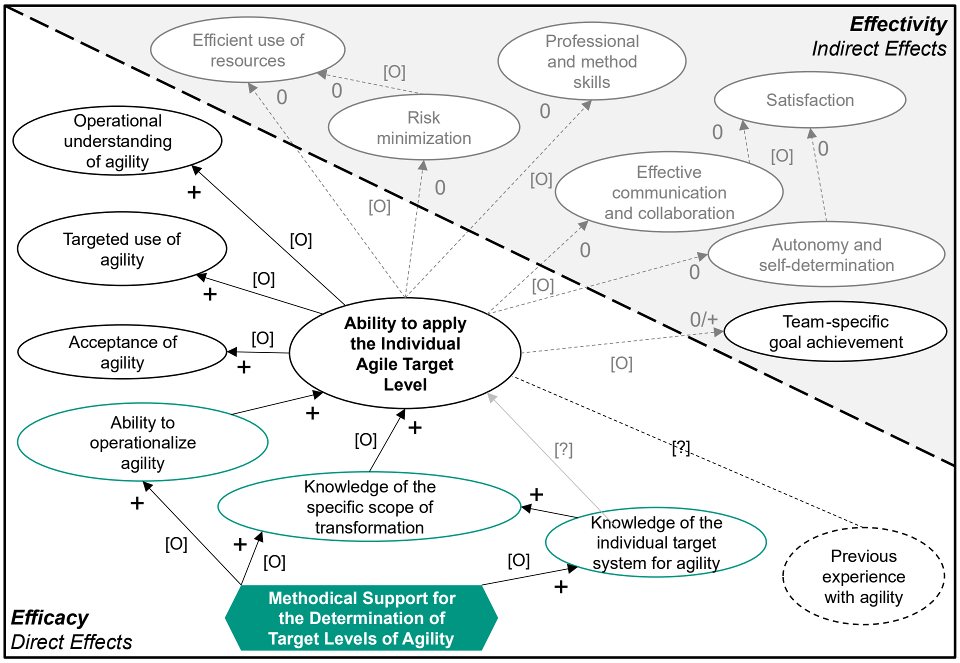

Figure 5. Impact Model of the validated methodology by Schoeck et al. (2024)

The updated Impact Model (IM_r) in Figure 5 illustrates how the developed methodology strengthens key capabilities such as defining agile goals, determining transformation scope, and operationalizing agility. These enable the application of an individual agile target level and contribute to behavioral change and perceived value. Although the study setting was limited to an academic environment, the developed study design offers a transferable structure for future validations in industrial settings. Further research should focus on long-term field studies, increased measurement objectivity, and the transferability of generic and specific goals.

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Biographies

Moritz Schöck holds a Master's degree in Mechanical Engineering from the Karlsruhe Institute of Technology (KIT) and an MBA in General Management from Collège des Ingénieurs (CDI) in Paris. With a background spanning automotive and semiconductor industries, as well as management consulting, he brings a unique blend of industrial and strategic expertise to his current role as a doctoral researcher and graduate student at IPEK – Institute of Product Engineering at KIT. His scientific work focuses on enhancing organizational innovation capability and strategically integrating agile methods into mechatronic product development, addressing critical challenges in balancing flexibility and structure in complex engineering environments.

Gabriel Moser graduated with a Master's degree in Industrial Engineering with a focus on Innovation Management. Since 2024, he has been a doctoral research associate and graduate student at the IPEK – Institute of Product Engineering at the Karlsruhe Institute of Technology (KIT), working in the research group Design Methods and Innovation Management. His research focuses on sustainability and circularity in product development, particularly

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the circularity of mechatronic systems in the context of system generation engineering (SGE). He is also involved in designing and facilitating innovation formats and Live-Labs to foster collaboration between research, teaching, and industry.

Johannes Müller graduated with a Master's degree from the Karlsruhe Institute of Technology (KIT) in 2022. He is a doctoral researcher, graduate student and team leader in the research group Design Methods and Innovation Management at the IPEK - Institute of Product Engineering of the KIT. His research focuses on the application of agile thinking and practices in the development of cyber-physical systems and the measurement of process improvements through such methods. Additionally, he is an expert in innovation workshops and Live-Labs for collaboration between research, teaching, and industry.

Tobias Düser has been a full professor for product engineering and head of IPEK – Institute of Product Engineering at the Karlsruhe Institute of Technology (KIT) since October 2022. After his studies at the Karlsruhe Institute of Technology and subsequent doctorate at IPEK - Institute of Product Engineering, Tobias Düser held various positions within the AVL Group in the field of innovative development and validation methods. In particular, he worked on novel automation and simulation solutions for test benches. Among other things, he was involved in the development of a new business area, the product portfolio and partner network in the area of Advanced Driver Assistant Systems as well as for Automated Driving. He was a member of the global ADAS/AD leadership circle and also intensively involved in global strategy development. From 2015, he was responsible for the Advanced Solution Lab at AVL and head of the Karlsruhe branch office. In 2020, he additionally assumed global responsibility for ADAS/AD Virtual Testing Solutions. Tobias Düser and his team worked on virtual and XiL-based validation methods for the validation and testing of Advanced Driver Assistant systems as well as for Automated Driving. Furthermore, he participates in various working groups such as IAMTS or UNECE.

Albert Albers has been a full professor for product development and head of IPEK – Institute of Product Engineering at the Karlsruhe Institute of Technology (KIT) since 1996. He received his doctorate in 1987 under Prof. Palandan of the University of Hannover. Before his appointment to Karlsruhe, Prof. Albers worked for LuK GmbH & Co. OHG, most recently as head of development and deputy member of the management board. He is a founding and former board member of the scientific society for product development WiGeP, a member of the German Academy of Science and Engineering (acatech), and a member of the Advisory Board of the Design Society. Since 2008, he has been President of the Allgemeiner Fakultätentag (AFT e. V.). In addition, Prof. Albers engages in the VDI and serves on the advisory boards of several companies. In 2016, he and the IPEK team were awarded the Honorary Award of the Schaeffler FAG Foundation for excellent achievements and competencies in science, research and teaching in the technical-scientific field.

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