


Analysing Paradigms for Managing Product Development: Conventional, Agile and Hybrid Approaches

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Abstract

As the complexity of products and their development processes increases, a trend emerged where companies try to manage the complexity through implementing agile practices on all or on some levels of the development process. It is not yet clear if an agile approach is the solution or under which circumstances it can be most effective in the development of physical products. This paper aims to compile the information from existing empirical and meta-studies to give an overview of the strengths and weaknesses of conventional, agile and hybrid paradigms.

Keywords: project management, conventional product development, agile development, agile management, hybrid product development

1. Introduction

In the past years, the demand for cyber-physical systems and product service systems increased. This affects the product development process. As these processes involve various disciplines, new challenges for managing individual design activities and collaboration across disciplines arise (Ayhan and Petra, 2011; Browning, 2009).

Several concepts, methods and tools exist that intend to increase the efficiency of development processes, rationalise creativity and improve the communication between disciplines (Blessing, 1995; Eisenbart *et al.*, 2011). Unfortunately, in the literature, there is not always a clear distinction between design methodologies, design methods and project management methods. One explanation for the fuzzy boundaries of the definitions of those terms lies in the problem that design methodologies are often used to manage development projects and in the difficulty of combining a design methodology with a project management method (Jetter *et al.*, 2016). To avoid the problem of clearly defining and separating the different terms in this paper tools, methods and methodologies were assigned to different paradigms, which will further be discussed as conventional, agile and hybrid approaches. This perspective allows a brief overview of the advantages and disadvantages of the paradigms and enable a good starting point to further discuss the concepts in different contexts in the future.

The first paradigm, represented by conventional approaches, is characterised by a plan-driven proceeding where the scope of possibilities is limited progressively and where decisions with presumably great consequences are taken as early as possible to avoid modifications later in the development process (Wynn and Clarkson, 2018). Examples for conventional management approaches include the 'Integrated Product Development' (Andreasen and Hein, 2000), the 'Stage-Gate-Model' (Cooper, 1990), the 'V-model' (VDI2206, 2006) as well as the VDI 2221 (VDI2221, 2019). These approaches are said to be most useful when market conditions, as well as requirements, are stable and predictable (Gericke and Blessing, 2011; Rigby *et al.*, 2016) and when the benefits of allowing changes do not compensate the benefits of financial predictability and safety (Collyer *et al.*, 2010).

Agile paradigms, on the other hand, are characterised by proceeding iteratively and incrementally. The main emphasis is put on change because it is considered as a core part of the agile principle that adds value (Conboy, 2009; Serrador and Pinto, 2015). Other key points are customer collaboration, frequent delivery as well as maintaining a light and fast development cycle (Albers, Heimicke, Müller, *et al.*, 2019a; Standish Group, 1994). In order to enable flexibility and responsiveness to change, light documentation is important, and design features are locked as late as possible (Serrador and Pinto, 2015). The conditions in which agile approaches are most applicable are situations when the problem that needs to be solved is complex, when the solution is unknown at the outset, when it is highly probable that product requirements are going to change throughout the development process or when a close collaboration with end users can be realised (Rigby *et al.*, 2016). Prominent approaches that correspond with the agile management paradigm are Scrum (Schwaber and Beedle, 2001), XP (Beck, 2000) and SAFe (Scaled Agile Framework) (Leffingwell, 2011).

Hybrid approaches promise to entail the advantages of both of the previously mentioned paradigms (Cooper and Sommer, 2018). This is eligible because most agile methods and methodologies are seen as customised for software solutions rather than physical products (Conforto and Amaral, 2016). Some approaches that represent the hybrid management paradigm are the Agile-Stage-Gate model by Cooper and Sommer (2016a), the Agile Systems Design (ASD) by Albers *et al.* (2019b) and the IVP2 model (Iterative and Visual Project Management Method) by Conforto (2010). They all seek to combine agile practices and techniques with the concept of processing stages and gates (Conforto and Amaral, 2016).

Looking at the mentioned paradigms above that are currently prevalent in most of the companies developing physical products, the question arises which of the predominant paradigms bear the potential of inspiring future methods and methodologies in product development and in which contexts or industries a certain paradigm will dominate the field. This paper aims to characterize the different paradigms as preliminary work to further be able to compare them in specific contexts and industrial branches. As a first step to approach this question, this paper aims to answer the following research questions:

RQ 1: What are the strengths and weaknesses of the different approaches?

RQ 2: In what aspects do the paradigms differ?

2. Study Design

In order to answer the research questions as well as to identify literature trends, frequently discussed topics and potential gaps, an explorative literature review was carried out. The mainly used research platform was Scopus. Mendeley and ResearchGate were used for additional information, e.g. for a list of the latest findings of established researchers in agile management in mechatronics.

The search for literature on conventional process models results in numerous matches (50,580 findings when searching for 'process models product development'). Because of the high number of findings, not all of the results were analysed. The conventional paradigm is well studied, which is why it was not the intention of this paper to cover all of the currently available methods and methodologies, but rather to use well established literature like Pahl and Beitz (2021), Wynn and Clarkson (2018) or Gericke and Blessing (2011) to gain an overview of conventional approaches. From this point, the referred literature was scanned for additional research that was likely to contain information concerning a critical analysis of conventional process models and management approaches.

The challenge in searching for research that addresses agile management approaches lies in identifying the literature that focuses on the development of physical products rather than software solutions. However, the enthusiasm for agile approaches originates in numerous achievements in the software industry. In order to get an impression on the experiences with agile approaches in software as well as mechatronics development, current research was scanned for advantages and disadvantages that emerged. Subsequently, publications of authors with a high number of publications were reviewed in detail.

The number of publications focussing on hybrid approaches is smaller (48 results when searching for 'agile stage gate hybrid' and 8,558 findings when searching for 'hybrid product development'). The

focus while analysing the search results was on finding combinations of conventional and agile practices.

After an initial search for suitable publications, the found literature was analysed for empirical studies and meta-studies that reported experiences and different views of practitioners. Subsequently, the literature was analysed for patterns, and headings and further information were assigned.

3. Findings

In this section, the information is displayed that was gathered from current experiences presented in the literature. The individual aspects were clustered in different categories, which have resulted from the explorative study. The first category addresses the fundamental approach of the respective paradigms. The second category, 'execution', shows information regarding positive effects and problems that occurred when implementing process models of the respective paradigms. The following categories express how models of the paradigms cope with management aspects, risk and change. In the category 'interference', the strengths and weaknesses are displayed on how the different models influence the development process, whereas the category 'interactions' concerns all interactions between team members and external stakeholders. A comparison of conventional and agile approaches is listed in tables 1 to 6.

Table 1. Strengths and weaknesses of conventional and agile paradigms concerning the fundamental approach

Approach		
Conventional		Agile
<ul style="list-style-type: none"> • Straightforward, methodical and structured (Fruhling and De Vreede, 2006) • Predictability, stability, high assurance (Boehm and Turner, 2003) • Stages contain known success-drivers and tasks (Cooper and Sommer, 2016a) • Built-in best practices (Cooper and Sommer, 2016a) • Cross-functional (Cooper and Sommer, 2016a) 	+	<ul style="list-style-type: none"> • Iterative and incremental development (Albers, Heimicke, Müller, et al., 2019a) • Increased transparency of the process and tasks (Gustavsson, 2016; Schmidt et al., 2019) • Continuous design is emphasised (Serrador and Pinto, 2015)
<ul style="list-style-type: none"> • Iterations are only intended within but not between stages (Macmillan et al., 2002) • Further development of existing solutions is neglected in most models (Macmillan et al., 2002) • Too linear, too rigid, too planned to handle innovative or dynamic projects (Becker, 2006; Cooper, 2014) • Not adaptive enough (Becker, 2006; Cooper, 2014) • Too much attention on control and bureaucracy (Becker, 2006; Cooper, 2014) 	–	<ul style="list-style-type: none"> • Significant document reduction causes dependence on tacit knowledge (Cho, 2009) • Lack of process visibility (Gustavsson, 2016)

As it can be seen in table 1, both, conventional or agile approaches, offer many advantages. However, most advantages are linked to certain disadvantages, resulting in trade-offs when selecting a suitable approach. For example, in order to ensure a structured and stable development process, there has to be a lot of bureaucracy and realising a continuous and incremental development has an effect on the visibility of the process.

Table 2. Strengths and weaknesses of conventional and agile paradigms concerning the execution of the corresponding processes

Execution		
Conventional		Agile
<ul style="list-style-type: none"> • Enables large-scale organisation and management (Browning, 2009) 	+	<ul style="list-style-type: none"> • Shorter development cycles → faster time to market (Boehm and Turner, 2003; Miller and Larson, 2005; Parrish et al., 2004) • Increased productivity and speed (Gustavsson, 2016) • Good understanding of goals, tasks and requirements (Gustavsson, 2016) • High quality (Gustavsson, 2016)
<ul style="list-style-type: none"> • Challenges in creating a complete set of requirements up front (Cho, 2009; Standish Group, 1994) • → resulting in unsuccessful projects, if assumptions fail or information are missing (Serrador and Pinto, 2015) • Different models are often used simultaneously, which results in overlapping information (Browning, 2009) • Too general to support daily decisions (Wynn and Clarkson, 2018) • Abstract character requires interpretation and adaption → can lead to communication problems (Gausemeier and Möhringer, 2003; Roozenburg and Cross, 1991) • Missing information on what has to be done separately or collaboratively (Macmillan et al., 2002) • Does not encourage experimentation (Becker, 2006; Cooper, 2014) • Early commitment to features entail compromises late in the development process (Cooper and Sommer, 2016a) • Rigidity leads to "pathologies" as a consequence, which leads to excessive rework, lack of flexibility and customer dissatisfaction (Serrador and Pinto, 2015) • Models are being used to make decisions even though sufficient information is missing (Browning, 2009) 	–	<ul style="list-style-type: none"> • Successful implementation requires training (Rigby et al., 2016) • Not sufficiently tested for safety-critical or large-scale projects (Cho, 2009; Ovesen and Sommer, 2015) • Not adequate for highly stable or routine projects (Cho, 2009; Rigby et al., 2016) • Can only be successful with talented individuals who favour many degrees of freedom (Cho, 2009) • Members of development teams often have overlapping tasks and diverse responsibilities (Ovesen and Sommer, 2015; Sommer, 2019) • Challenges concerning prototyping and external dependencies on a more technical level (Schmidt et al., 2019) • Challenges with breaking down the product into meaningful increments and realising deliverables within one iteration (Schmidt et al., 2019; Zasa et al., 2020) • Challenges due to certification to certain guidelines and assessments, e.g. ISO 9000, ASPICE (ISO 15504) (Heimicke et al., 2019; Ovesen and Sommer, 2015) • Requires the ability of a team to self-manage (Zasa et al., 2020)

Many problems associated with the different paradigms occur while executing conventional or agile process models. This demonstrates the necessity of clarifying the context in which the approach is to be applied and that a good understanding of the paradigm, as well as a respective process model, is essential for a successful implementation.

Table 3. Strengths and weaknesses of conventional and agile paradigms concerning management aspects

Management		
Conventional		Agile
	+	<ul style="list-style-type: none"> • Deals with resourcing issues (Cooper and Sommer, 2016a) • Increased project-related commitment (Schmidt et al., 2019)
<ul style="list-style-type: none"> • Tendency to be over budget and behind schedule (Boehm and Turner, 2003; Wynn and Clarkson, 2018) • Management aspects are excluded because the focus lies on the product (Wynn and Clarkson, 2018) • Relies on command and control (Dybå and Dingsøyr, 2008) 	-	<ul style="list-style-type: none"> • Unsuitable corporate culture and structure • → leading positions fear the loss of power and responsibility (Schmidt et al., 2019)

Agile approaches deal with the resourcing issue of team members because the paradigm is based on the view that team members should be 100 % involved in a project, which in turn affects the project related commitment. Conventional approaches do not address this problem and rather rely on command and control.

Table 4. Strengths and weaknesses of conventional and agile paradigms in dealing with change and risk

Change and risk		
Conventional		Agile
<ul style="list-style-type: none"> • Avoiding rework through gradually narrowing the design space (Wynn and Clarkson, 2018) • Decisions with expected consequences are taken early in the process (Wynn and Clarkson, 2018) • Gates allow defined moments for Go/Kill decisions (Cooper and Sommer, 2018) 	+	<ul style="list-style-type: none"> • Quick adaption to rapidly changing business requirements due to iterative approach and increased flexibility (Gustavsson, 2016; Schmidt et al., 2019; Schwaber and Beedle, 2001) • Copes with uncertainty and ambiguity (Cooper and Sommer, 2016a) • Design features are "frozen" as late as possible (Serrador and Pinto, 2015) • Change is seen as a part of the process and as valuable (Serrador and Pinto, 2015)
<ul style="list-style-type: none"> • Slow adaption to rapidly changing business requirements (Boehm, 2002; Cho, 2009) 	-	<ul style="list-style-type: none"> • Does not deal with the issue of whether a company should proceed with a project (Cooper and Sommer, 2018)

Conventional approaches tend to avoid changes in order to avoid risk. This has the disadvantage that most of the process models do not offer enough possibilities to respond to change later in the development process. Agile approaches embrace change and see it as a part of the development process.

Table 5 displays the ways in which process models of conventional and agile paradigms interfere with the development process. While an agile approach requires a change in mindset for it to work, it has not many instructions on how the work has to be executed. Conventional approaches are often criticised for leaving out various important aspects (e.g. the consequences that certain activities can have (Browning, 2009)).

Table 5. Strengths and weaknesses of conventional and agile paradigms concerning the intervention with the process execution

Interference		
Conventional		Agile
<ul style="list-style-type: none"> • Various methods for the early stages in design (Wynn and Clarkson, 2018) 	+	
<ul style="list-style-type: none"> • Insufficient methods for the embodiment and detail design phase (Wynn and Clarkson, 2018) • Each model contains specific aspects of project information while others are neglected (Browning, 2009) • Models contain actions that should be performed, but information on reasons or execution are missing (Macmillan et al., 2002) • No specifications for creative leap (Wynn and Clarkson, 2018) • Problems with loss of learning and integration of new information after project approval (Sethi and Iqbal, 2008) 	–	<ul style="list-style-type: none"> • Requires changes in mindset, fundamental principles and ways of working to allow flexibility (Gustavsson, 2016; Sommer, 2019) • Lack of integration of technical or process-related knowledge (Heimicke et al., 2019)

Table 6. Strengths and weaknesses of conventional and agile paradigms concerning internal and external interactions

Interactions		
Conventional		Agile
<ul style="list-style-type: none"> • Provides suppliers with specific and fixed requirements as well as predetermined budgets (Zasa et al., 2020) 	+	<ul style="list-style-type: none"> • High value on customer collaboration and communication (Standish Group, 1994) • → increased customer feedback through built-in voice of the customer (Cooper and Sommer, 2016a) • → high customer satisfaction (Boehm and Turner, 2003; Miller and Larson, 2005; Parrish et al., 2004) • Better collaboration and communication in the team (Gustavsson, 2016; Schmidt et al., 2019) • Higher team morale (Edwards et al., 2019)
<ul style="list-style-type: none"> • Teamwork or promotions on effective collaboration are not included (Macmillan et al., 2002) • No explicit support of transdisciplinary collaboration (Gausemeier and Möhringer, 2003) 	–	<ul style="list-style-type: none"> • Problems in communication result in reduced motivation (Ovesen and Sommer, 2015)

Agile approaches emphasize the collaboration with internal and external stakeholders, whereas this is less prominent in most conventional approaches (table 6).

Seeing the results, it would be an obvious assumption that the strengths of both approaches combined in a hybrid approach could eliminate their weaknesses. The external pressure and internal complexity on B2B firms are increasing. Due to the pace of change, traditional approaches are no longer feasible. This is why companies try to implement agile practices in their existing organisational structures that are aligned to conventional approaches. Initial studies show that the productivity could be improved

by 30 %, and the time to market could be reduced by 30 % (Cooper and Sommer, 2018). Also, the work effort per project and rework was reduced by 20-25 % (Cooper and Sommer, 2016b). Nonetheless, many challenges emerge when combining agile and conventional practices. Table 7 displays the advantages but also the challenges that come from applying hybrid process models.

Table 7. Strengths and weaknesses of hybrid approaches

Strengths	Weaknesses
<ul style="list-style-type: none"> • Fast customer feedback through rapid, iterative and incremental release of concepts, design and prototypes (Cooper and Sommer, 2018) • Gates provide vital go/kill decision points (Cooper and Sommer, 2018) • Increased design flexibility (Cooper and Sommer, 2018) • Copes with uncertainty and ambiguity (Cooper and Sommer, 2016a) • Improved productivity, communication and coordination among team members (Cooper and Sommer, 2016a) • Facilitates teams working autonomously (Zasa et al., 2020) • Increased transparency (Zasa et al., 2020) • Focused projects result in better prioritisation of time & effort (Cooper and Sommer, 2018) • Raised team morale (Cooper, 2016; Cooper and Sommer, 2016b) • Increased creativity (Zasa et al., 2020) • Responsive to changing customer needs and product requirements (Cooper, 2016) • Customer insight (Cooper, 2016; Edwards et al., 2019) • Deals with resourcing issue (Cooper, 2016) • Reduces cycle time and increases delivery speed (Cooper, 2016; Zasa et al., 2020) • Better and more visually intuitive progress metrics (Cooper and Sommer, 2016b) • Rapid sprint-iterations encourage experimentation and testing (Cooper and Sommer, 2016b) • Dedication of teams increase development speed (Cooper and Sommer, 2016b) • Enhances knowledge transfer and strengthens tacit knowledge (Edwards et al., 2019) • New procedures in already burdened innovation systems (Edwards et al., 2019) • Higher probability of success (Edwards et al., 2019) • Reduced interdependencies (Zasa et al., 2020) 	<ul style="list-style-type: none"> • Difficulties in acquiring team members and keeping project teams connected to the rest of the organisation (Cooper and Sommer, 2018) • Mismatches between requirements of agile and the company's reward system (Cooper and Sommer, 2016b) • Still too much bureaucracy (Cooper and Sommer, 2016b, 2018) • Management scepticism, conflict and resistance (Cooper and Sommer, 2016b; Zasa et al., 2020) • Lack of resources to support dedicated teams (Cooper and Sommer, 2016b; Zasa et al., 2020) • Difficulty of producing concrete product demonstrations in a two-week sprint (Cooper and Sommer, 2016b; Zasa et al., 2020) • Challenge in properly diagnosing and understanding the critical conditions to properly adapt the practices (Conforto and Amaral, 2016) • Trend in ignoring long-range planning in order to focus on a current sprint (Cooper and Sommer, 2016b) • Lack of scalability (Cooper and Sommer, 2016b) • Proliferation of meetings (Cooper and Sommer, 2016b) • Lack of management buy-in due to differences from familiar gating systems (Cooper and Sommer, 2016b) • Adding new methods and tools in pre-existing management systems can saturate flexibility and be counterproductive • → flexibility can only be obtained if relevant technical and managerial skills are available (Edwards et al., 2019)

Looking at hybrid approaches, the experiences show a successful consolidation of various advantages when integrating agile practices into conventional process models. However, this induces other challenges due to the dichotomy of conventional and agile paradigms that deal with different topics contradictory, like change or risk, as is shown in table 4. In addition, there are inconsistencies between the approaches, e.g. fixed versus fluid product definitions or long-term versus short-term planning cycles, which have to be conquered.

4. Discussion

The approaches that are presented in this paper make many promises. Analyses of experiences in industry show that many of these promises are not fulfilled yet. The main reason is often a false understanding and, therefore, incorrect applications of the process models (Albers, Heimicke, Müller, *et al.*, 2019a; Becker, 2006). The findings in table 1 show that neither a conventional nor an agile approach is an "all-rounder" but rather have to be evaluated in a specific context. Strengths and weaknesses protrude different in different industrial branches. This can be confirmed by the findings of Boehm and Turner which show, that the success of pursuing a certain paradigm depends on the respective project constellation (Boehm and Turner, 2003). Therefore, the strengths of one of the approaches is not necessarily a weakness of the other. Additionally, it has to be taken into account that not all of the aspects mentioned above have the same value and that a weighting was not carried out. Thus, solely weighting the number of strengths against the number of weaknesses is neither a sufficient nor a significant result. One of the main differences between conventional and agile approaches that can be extracted from table 5 is, that conventional process models interfere with the development process while most of the agile process models (except XP) are based on the principle, that teams work autonomously and define their activities independently. The majority of the conventional process models on the other hand is offering predefined tasks and activities in different phases of the development process. Another difference that can be pointed out is the value that agile approaches attach to team as well as customer collaboration and communication, which results in higher team morale and increased customer satisfaction. Both aspects tend to be neglected in conventional approaches.

Evaluating the trends in the literature, it can be seen that some manufacturers have already successfully implemented agile process models despite the fact that the transformation takes several years (Schmidt *et al.*, 2019). Even though dividing the product into meaningful increments and realising deliverables was criticised by some authors (Cooper and Sommer, 2016b; Zasa *et al.*, 2020), others found out that working on two-week iterations is no hurdle (Schmidt *et al.*, 2019). Hybrid approaches can be successfully executed when managers want to increase their flexibility without losing their structure and control (Cooper and Sommer, 2018). However, in hybrid approaches, agile practices are often integrated into existing conventional structures and processes on a certain project level without adapting them to the respective conditions (Heimicke *et al.*, 2019; Schuh *et al.*, 2018). When trying to combine such contradictory approaches, like conventional and agile, new problems occur and significant decisions have to be made. For example, looking at the response mechanisms concerning change, it can be seen that conventional approaches intend to prevent change, whereas agile approaches embrace change as a part of the development process. Companies have to decide in which situation which paradigm should prevail in order to avoid chaos and counterproductive work.

5. Conclusion

Conventional, agile and hybrid approaches each promise several advantages, but also have a long list of weaknesses. The positive and negative aspects can only be opposed with reservations because they are all eligible under specific conditions. It has yet to be investigated which approach can be recommended in certain industries or environments in the future and what actions are going to be required to support the process. Therefore, in the future, the strengths and weaknesses of the different paradigms will always have to be considered in a certain industrial sector individually. This paper represents a good starting point for a comparison in an individual area of application. Another aspect that has to be examined is how companies that follow different paradigms can work together effectively and how companies can overcome the contradictions when implementing some kind of hybrid approach.

Existing hybrid models propose a certain course of action that already show achievements but still entail many problems due to the dichotomy of conventional and agile approaches. Therefore, it has to be examined how and under what conditions hybrid models can be most effective.

References

- Albers, A., Heimicke, J., Müller, J. and Spadinger, M. (2019a), “Agility and its Features in Mechatronic System Development: A Systematic Literature Review”, *ISPIM Conference Proceedings*.
- Albers, A., Heimicke, J., Spadinger, M., Reiss, N., Breitschuh, J., Richter, T., Bursac, N., et al. (2019b), “A systematic approach to situation-adequate mechatronic system development by ASD - Agile Systems Design”, *Procedia CIRP*, Vol. 84, available at:<https://doi.org/10.1016/j.procir.2019.03.312>.
- Andreasen, M.M. and Hein, L. (2000), “Integrated Product Development”, Lyngby: Institute for Product Development, Technical University of Denmark.
- Ayhan, E. and Petra, B.S. (2011), “Information behavior in multidisciplinary design teams”, *ICED 11 - 18th International Conference on Engineering Design - Impacting Society Through Engineering Design*, Vol. 7.
- Beck, K. (2000), *Extreme Programming Explained: Embrace Change*. Addison-Wesley Professional, 1999., XP Series.
- Becker, B. (2006), “Re-Thinking the Stage-Gate Process - A Reply to the Critics”, *Management Roundtable*.
- Blessing, L. (1995), *Comparison of Design Models Proposed in Prescriptive Literature, The Role of Design in the Shaping of Technology*.
- Boehm, B. (2002), “Notes for Systems Development Paradigms Get Ready for Agile Methods , with Care”, *Ieee*, No. Jan.
- Boehm, B.W. and Turner, R. (2003), “Using Risk to Balance Driven Methods”, *PoLAR*, Vol. 36 No. June.
- Browning, T.R. (2009), “The many views of a process: Toward a process architecture framework for product development processes”, *Systems Engineering*, Vol. 12 No. 1, pp. 69–90.
- Cho, J. (2009), “a Hybrid Software Development Method for Large-Scale Projects: Rational Unified Process With Scrum”, *Issues In Information Systems*, pp. 340–348.
- Collyer, S., Warren, C., Hemsley, B. and Stevens, C. (2010), “Aim, fire, aim - Project planning styles in dynamic environments”, *Project Management Journal*, Vol. 41, available at:<https://doi.org/10.1002/pmj.20199>.
- Conboy, K. (2009), “Agility from first principles: Reconstructing the concept of agility in information systems development”, *Information Systems Research*, Vol. 20 No. 3, available at:<https://doi.org/10.1287/isre.1090.0236>.
- Conforto, E.C. and Amaral, D.C. (2016), “Agile project management and stage-gate model—A hybrid framework for technology-based companies”, *Journal of Engineering and Technology Management - JET-M*, Vol. 40, available at:<https://doi.org/10.1016/j.jengtecman.2016.02.003>.
- Cooper, R.G. (1990), “Stage-gate systems: A new tool for managing new products”, *Business Horizons*, Elsevier, Vol. 33 No. 3, pp. 44–54.
- Cooper, R.G. (2014), “What’s next? After stage-gate”, *Research Technology Management*, Vol. 57 No. 1, available at:<https://doi.org/10.5437/08956308X5606963>.
- Cooper, R.G. (2016), “Agile-stage-gate hybrids”, *Research Technology Management*, Vol. 59 No. 1, available at:<https://doi.org/10.1080/08956308.2016.1117317>.
- Cooper, R.G. and Sommer, A.F. (2016a), “Agile-Stage-Gate: New idea-to-launch method for manufactured new products is faster, more responsive”, *Industrial Marketing Management*, Vol. 59, available at:<https://doi.org/10.1016/j.indmarman.2016.10.006>.
- Cooper, R.G. and Sommer, A.F. (2016b), “The Agile–Stage-Gate Hybrid Model: A Promising New Approach and a New Research Opportunity”, *Journal of Product Innovation Management*, Vol. 33 No. 5, available at:<https://doi.org/10.1111/jpim.12314>.
- Cooper, R.G. and Sommer, A.F. (2018), “Agile–Stage-Gate for Manufacturers: Changing the Way New Products Are Developed Integrating Agile project management methods into a Stage-Gate system offers both opportunities and challenges”, *Research Technology Management*, Vol. 61 No. 2, available at:<https://doi.org/10.1080/08956308.2018.1421380>.
- Dybå, T. and Dingsøyr, T. (2008), “Empirical studies of agile software development: A systematic review”, *Information and Software Technology*, available at:<https://doi.org/10.1016/j.infsof.2008.01.006>.
- Edwards, K., Cooper, R.G., Vedsmann, T. and Nardelli, G. (2019), “Evaluating the agile-stage-gate hybrid model: Experiences from three SME manufacturing firms”, *International Journal of Innovation and Technology Management*, Vol. 16 No. 8, available at:<https://doi.org/10.1142/S0219877019500482>.

- Eisenbart, B., Gericke, K. and Blessing, L. (2011), "A framework for comparing design modelling approaches across disciplines", *ICED 11 - 18th International Conference on Engineering Design - Impacting Society Through Engineering Design*, Vol. 2.
- Fruhling, A. and De Vreede, G.J. (2006), "Field experiences with eXtreme Programming: Developing an emergency response system", *Journal of Management Information Systems*, available at:<https://doi.org/10.2753/MIS0742-122220403>.
- Gausemeier, J. and Möhringer, S. (2003), "Die neue Richtlinie VDI2206: Entwicklungsmethodik für mechatronische Systeme", *VDI Berichte*, No. 1753.
- Gericke, K. and Bender, B. (2021), *Pahl/Beitz Konstruktionslehre*, Pahl/Beitz Konstruktionslehre, available at:<https://doi.org/10.1007/978-3-662-57303-7>.
- Gericke, K. and Blessing, L. (2011), "Comparisons of design methodologies and process models across disciplines: A literature review", *ICED 11 - 18th International Conference on Engineering Design - Impacting Society Through Engineering Design*, Vol. 1.
- Gustavsson, T. (2016), "Benefits of agile project management in a non-software development context - A literature review", *Project Management Development – Practice and Perspectives: Fifth International Scientific Conference on Project Management in the Baltic Countries April 14-15, Riga, University of Latvia*, No. April.
- Heimicke, J., Niever, M., Zimmermann, V., Klippert, M., Marthaler, F. and Albers, A. (2019), "Comparison of existing agile approaches in the context of mechatronic system development: Potentials and limits in implementation", *Proceedings of the International Conference on Engineering Design, ICED*, Vol. 2019-August, available at:<https://doi.org/10.1017/dsi.2019.226>.
- Jetter, A., Albar, F. and Sperry, R. (2016), "The practice of project management in product development: Insights from the literature and cases in high-tech", *The Wiley Guide to Managing Projects*.
- Leffingwell, D. (2011), *Agile Software Requirements: Lean Requirements Practices for Teams, Programs, and the Enterprise, Networks*.
- Macmillan, S., Steele, J., Kirby, P., Spence, R. and Austin, S. (2002), "Mapping the design process during the conceptual phase of building projects", *Engineering, Construction and Architectural Management*, available at:<https://doi.org/10.1108/eb021213>.
- Miller, K.W. and Larson, D.K. (2005), "Agile software development: Human values and culture", *IEEE Technology and Society Magazine*, Vol. 24 No. 4, available at:<https://doi.org/10.1109/MTAS.2005.1563500>.
- Ovesen, N. and Sommer, A.F. (2015), "Scrum in the Traditional Development Organization: Adapting to the Legacy", *Modelling and Management of Engineering Processes*, pp. 87–99.
- Parrish, A., Smith, R., Hale, D. and Hale, J. (2004), "A field study of developer pairs: Productivity impacts and implications", *IEEE Software*, Vol. 21 No. 5, available at:<https://doi.org/10.1109/MS.2004.1331306>.
- Rigby, D.K., Sutherland, J. and Takeuchi, H. (2016), "Embracing agile", *Harvard Business Review*.
- Roozenburg, N.F.M. and Cross, N.G. (1991), "Models of the design process: integrating across the disciplines", *Design Studies*, Vol. 12 No. 4, available at:[https://doi.org/10.1016/0142-694X\(91\)90034-T](https://doi.org/10.1016/0142-694X(91)90034-T).
- Schmidt, T., Atzberger, A., Gerling, C., Schrof, J., Weiss, S. and Paetzold, K. (2019), *Agile Development of Physical Products - An Empirical Study about Potentials, Transition and Applicability*.
- Schuh, G., Dölle, C., Kantelberg, J. and Menges, A. (2018), "Identification of Agile Mechanisms of Action As Basis for Agile Product Development", *Procedia CIRP*, Vol. 70, available at:<https://doi.org/10.1016/j.procir.2018.02.007>.
- Schwaber, K. and Beedle, M. (2001), *Agile Software Development with Scrum*, Cdswebcernch.
- Serrador, P. and Pinto, J.K. (2015), "Does Agile work? - A quantitative analysis of agile project success", *International Journal of Project Management*, Vol. 33 No. 5, available at:<https://doi.org/10.1016/j.ijproman.2015.01.006>.
- Sethi, R. and Iqbal, Z. (2008), "Stage-gate controls, learning failure, and adverse effect on novel new products", *Journal of Marketing*, Vol. 72 No. 1, available at:<https://doi.org/10.1509/jmkg.72.1.118>.
- Sommer, A.F. (2019), "Agile Transformation at LEGO Group", *Research-Technology Management*, Vol. 62 No. 5, available at:<https://doi.org/10.1080/08956308.2019.1638486>.
- Standish Group. (1994), *The Chaos Report*, available at: https://www.standishgroup.com/sample_research_files/chaos_report_1994.pdf.
- VDI2206. (2006), *Design Methodology for Mechatronic Systems (VDI2206)*.
- VDI2221. (2019), *Systematic Approach to the Design of Technical Systems and Products (VDI2221)*.
- Wynn, D.C. and Clarkson, P.J. (2018), "Process models in design and development", *Research in Engineering Design*, Vol. 29 No. 2, available at:<https://doi.org/10.1007/s00163-017-0262-7>.
- Zasa, F.P., Patrucco, A. and Pellizzoni, E. (2020), "Managing the Hybrid Organization: How Can Agile and Traditional Project Management Coexist?", *Research Technology Management*, Vol. 64 No. 1, available at:<https://doi.org/10.1080/08956308.2021.1843331>.