Centre for Technology Management working paper series
ISSN 2058-8887

No. 1

March 2021

Agile New Product Development in Not-PurelySoftware Projects

doi:10.17863/CAM.66232

Linus Gerdes
Dr. Rob Phaal*
Dr. Valerie Lynch

* Please contact the corresponding author for feedback:
rp208@cam.ac.uk

UNIVERSITY OF CAMBRIDGE

IfM Centre for Technology Management

Agile New Product Development in Not-Purely-Software Projects

Linus Gerdes[1], Dr. Rob Phaal[2], Dr. Valerie Lynch[3]

[1]lhg34@cam.ac.uk, [2]rp108@cam.ac.uk, [3]valerie.lynch@andtr.com

---

Abstract

Purpose – In Agile new product development, the product is incrementally and iteratively developed involving the customer and cross-functional teams. As manufacturing companies increasingly face challenges with sequential processes in uncertain and fast changing conditions, Agile practices taken from software development have experienced traction. Although multiple isolated case studies exist, there is a gap between academic literature and industry practice regarding cross-industry implementations and the required adaption of Agile practices to the hardware context. This research aims to bridge that gap by focusing on when and how manufacturing companies use Agile practices in their new product development.

Design – A cross-industry multiple case study with 17 manufacturing companies was conducted and findings were validated using a focus group at a workshop at the University of Cambridge. The data collection was undertaken using semi-structured interviews and the transcripts were cross-analysed using conceptually ordered displays to identify recurring patterns.

Findings – The results show that there are multiple interpretations of Agile:

- Agile as a method for team collaboration
- Agile as a method to integrate the customer into the NPD process
- Agile as a method to manage tasks
- Agile as a method to learn through early prototyping

Most companies use Agile only in specific conditions, such as high uncertainty of requirements or no confidence in technology, whereas other companies suggest to always use Agile. Cross-functional teams were found to be common, but adaptions in the role of the customer were found to be required. The definition-of-done for an increment must also be adjusted due to constraints of physicality. Implementing Agile must be accompanied by a change in project governance. For this a novel governance model is proposed that balances team autonomy and alignment with the rest of the company, using the project manager as the interface between the Agile team and the management and customers. Finally, it was found that soft benefits such as increased communication are quick-wins when implementing Agile, whereas hard benefits such as shorter time-to-market are rare and difficult to measure.

Contribution – The study expands the body of knowledge on the current state of Agile in new product development for not-purely-software projects and conceptualizes the differences in interpretation. This helps companies navigate the hype around Agile and provides them with an understanding of cross-industry similarities.

1 Introduction

New product development (NPD) projects are in an increasingly challenging environment with shorter product lifecycles (Eversheim & Schuh, 2005), rising product complexity and requirements, as well as higher customer quality expectations (Steffen & Jilg, 2009). These unstable market and technology conditions are referred to as a VUCA environment, which stands for Volatile, Uncertain, Complex and Ambiguous. Traditional development methods such as the Stage-gate process by Cooper (1990) struggle in these conditions being too rigid and linear (Cooper & Sommer, 2018). To overcome these challenges, novel development approaches such as Agile have seen traction since the 1990's (CollabNet VersionOne, 2019) with the promise of a reduced time-to-market, high degree of flexibility and a closer customer integration.

Originally developed to address these issues in software development, Agile development approaches were formalized in the Agile manifesto (Beck, et al., 2013) and have become the standard in the software domain in companies, for example at Google, Amazon or Spotify (Eklund & Berger, 2011). These approaches are characterized by an incremental delivery of the final product through an iterative and flexible development process with a cross-functional team. Simultaneously, the process is constantly including customer feedback to ensure market fit throughout the process (Hruschka, Rupp, & Starke, 2009). For simplification, in this paper Agile practices, tools and elements are simply referred to as Agile.

However, product development projects involving non-software elements still tend to prefer traditional approaches over Agile in the development process (Böhmer, Hugger, & Lindemann, 2017). Applying Agile outside of the purely software domain has seen first pilots in various manufacturing industries, with varying adaptions and mixed outcomes (see for example Cooper & Sommer, 2018; Ahmed-Kristensen & Daalhuizen, 2015; Garzaniti, Briatore, Fortin, & Golkar, 2019; Goevert, Gökdemir, Peitz, & Lindemann, 2017). Particularly in not-purely-software (NPS) NPD projects involving software, electronics and/or mechanics modified adoptions of Agile approaches including hybrid models can yield significant benefits in VUCA environments (Cooper & Sommer, 2016). At the same time, the transfer of Agile from software to NPS NPD projects face notable challenges through 'constraints of physicality', lead times of components and challenges of scale, resulting from dependencies, and complex project structures. Adoption is still low as the applicability of Agile practices in the context of NPS NPD remain unclear (Schrof, Atzberger, Papoutsis, & Paetzold, 2019).

Therefore, the topic has seen an increase in attention from academics and industry to understand the implications of implementing Agile in NPS NPD. Yet, while first pilot studies have evaluated the potential of Agile, there is a gap between academic literature and industry practice. Many manufacturing companies have been pushing ahead with introducing Agile and these evolving industry practices require a further examination. The aim of this research[1] is to bridge that gap by extending the knowledge on the applicability of Agile practices in NPS NPD based on industry experiences.

Therefore, the research question is:

When and how do manufacturing companies use Agile development practices in not-purely-software new product development?

The research question is answered by conducting multiple case studies with manufacturing companies from a range of industries. From these, commonalities or patterns are identified and then validated in a workshop. To ensure constant feedback and validation of interpretations, the interim findings are continuously discussed with leading researchers in the field.

This paper starts by reviewing the literature and identifying a research gap in Section 2. Section 3 then outlines the research methodology. This is followed by a data collection summary in Section 4. The analysis and discussion in Section 5 then present cross-industry findings and reviews common themes. Finally, Section 6 summarises the results and the contribution of the study, sets out limitations, and proposes future research.

2 Literature review

2.1 Research scope

Methods for NPD have become a subject of attention as the complexity of processes increases (Browning & Ramasesh, 2007). Particularly the area Agile in NPS NPD projects has seen increased attention from academic literature with publications per year more than tripling from 2011 to 2019 as seen in Figure 1. MIT professor Eppinger (2019) states in an interview that: "*Every company is trying to be more Agile — it's become part of the regular engineering management lexicon*".

[1] Gerdes, L. (2020), *Applicability of agile principles to not-purely-software projects,* MPhil thesis, Institute for Manufacturing, University of Cambridge.

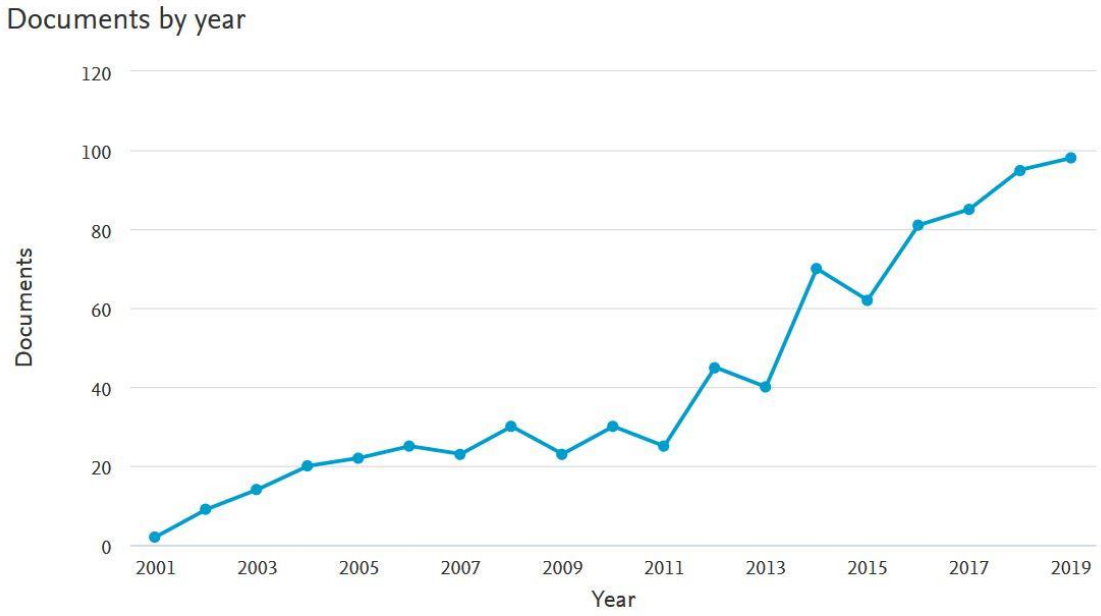

Figure 1: *Documents published per year on Web of Science using the search logic: Agile AND development AND (hardware OR "systems engineering" OR mechatronic*)*

However, the word 'Agile' is a multi-faceted concept and shares aspects with other research areas. Adjacent research areas in NPD often overlap with Agile, are concepts included in Agile or can be combined with Agile. Therefore, it is imperative to clearly state and prioritize the research areas covered in this study regarding its importance for the outcome of the research project. Ultimately, the research areas are split up into three distinctive categories:

- **Primary research domain**: Agile development, Agile hybrid models, SCRUM
- **Secondary research domain**: Lean product development, Agile frameworks, Stage-gate, Leagile
- **Tertiary research domain:** Customer centricity, Systems engineering, Waterfall model, V-model, Six Sigma

The research focuses on the primary research domains, with additional papers reviewed from the secondary domain. The tertiary domain covers peripheral areas that are considered when necessary to support the primary and secondary domain.

2.2 Traditional New Product Development

Traditionally, NPD projects were carried out using a linear progression in which planning, development and testing occur sequentially. This model was introduced by Royce in 1970 and was popularized as the waterfall development model, as seen in Figure 2. Interestingly, Royce

(1970) himself already acknowledged the challenge that the rigidness of the model would lead to expensive re-designs if constraints are not fully understood initially.

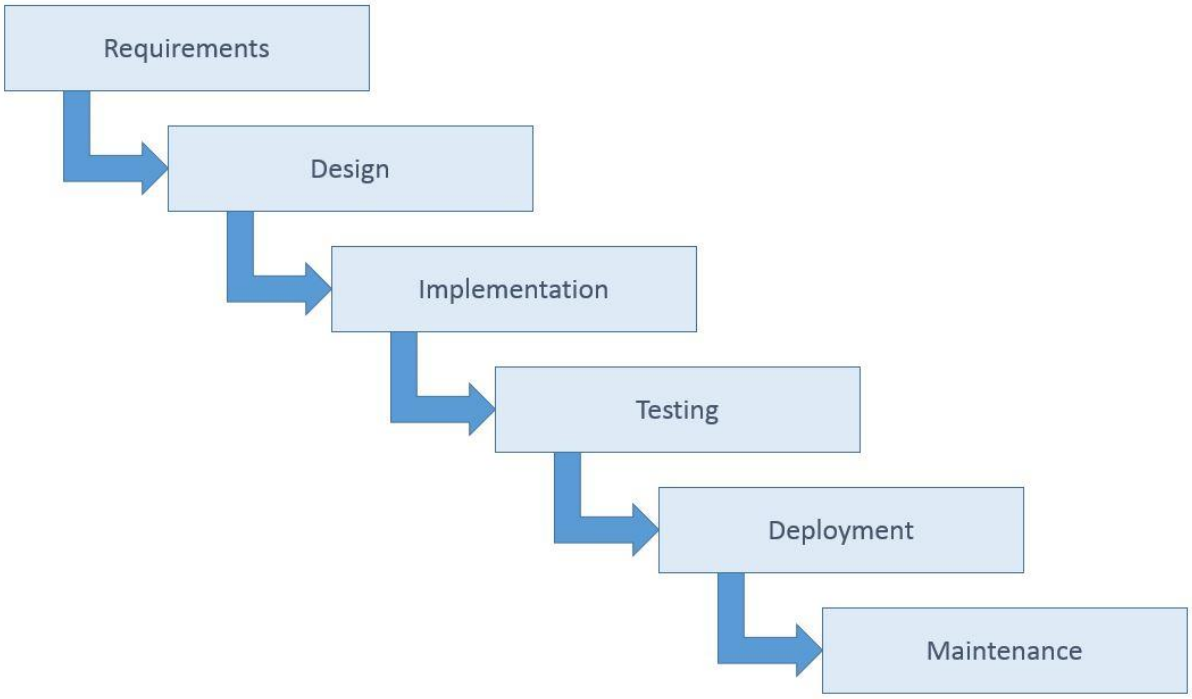

Figure 2: *Waterfall model based on Royce (1970)*

Following the process proposed by Royce, the stage-gate model was developed by Cooper in the 1980s as an evolution of the waterfall process. Similar to the waterfall model it follows a linear development process, in which the project is divided into multiple stages, each divided by a gate at which the decision to Go/Kill the project is made (Cooper, 2011). The gates function as quality checkpoints moving from one stage to the next. As of today, most manufacturing companies still rely solely on this development method (Ibid). The first version of the stage-gate NPD method as described by Cooper (1990) can be seen in Figure 3. Here, the project is split up into Ideation, Concept, Business Case, Development, Testing and finally Launch.

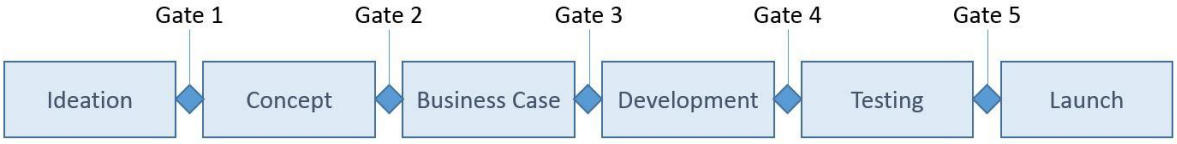

Figure 3: *Stage-gate model based on Cooper (1990)*

The stage-gate process has multiple characteristics (Cooper & Sommer, 2016; Ahmed-Kristensen & Daalhuizen, 2015; Cooper, 1990; Zhang, 2013):

- Extensive documentation ensures a smooth transition between different stakeholders and stages.
- Features of the product, the timeline and allocated budgets are decided early in the process (plan-driven).
- The final success is defined by the degree to which the final product meets the defined deadline with initially specified requirements with minimal cost. This implies well-known conditions and a stable technology base.
- In the transition between stages the responsibility over the projects activities changes.

However, these sequential development methods face challenges in volatile, uncertain, complex and ambiguous (VUCA) conditions. First, customer needs and market requirements evolve rapidly, and disruptive technologies emerge more frequently (Cooper & Sommer, 2018). This makes choosing appropriate customer requirements in the planning stage difficult, as they might change during the development process. Furthermore, the complexity of requirements increases as product customization becomes more popular (Hruschka, Rupp, & Starke, 2009). Additionally, product life-cycles are shorter requiring a faster time-to-market of new products (Cooper, 2017). Putting the VUCA context aside, the rule of increasing cost of change states that design changes later in the process are disproportionally costly (Boehm, 1976). Gaubinger et al. (2015) found that many innovation projects fail as technical feasibility is clarified too late. Team members think too narrowly and not independently through the standardized process (Cooper, 2011). Hence, traditional methods are considered too rigid and unresponsive to these emerging challenges (Schmidt, Weiss, & Paetzold, 2018).

2.3 Agile New Product Development

Compared to its sequential counterparts, the Agile approach embraces change rather than aim to diminish it (Poppendiek & Poppendiek, 2003). According to the Merriam-Webster dictionary, the word ‘Agile’ means that something is “*able to move quickly and easily*”. In the context of NPD, Conboy (2009) defines Agile as the ability to “*rapidly or inherently create change, proactively or reactively embrace change, and learn from change while contributing to perceived customer value (economy, quality, simplicity), through its collective components and relationships with its environment*” (p. 340).

Early adaptions to the waterfall model through the introduction of iterations, overlapping phases and cross-functional teams are considered the emergence of Agile in NPD (Boehm, 1986; Sutherland, 2011). However, only with the formulation of the "Manifesto for Agile Software Development" in 2001 by Beck et. al a first common ground for Agile in software development was derived. The Manifesto consists of four values and twelve principles to drive Agile transformation in organizations, as seen in Figure 4.

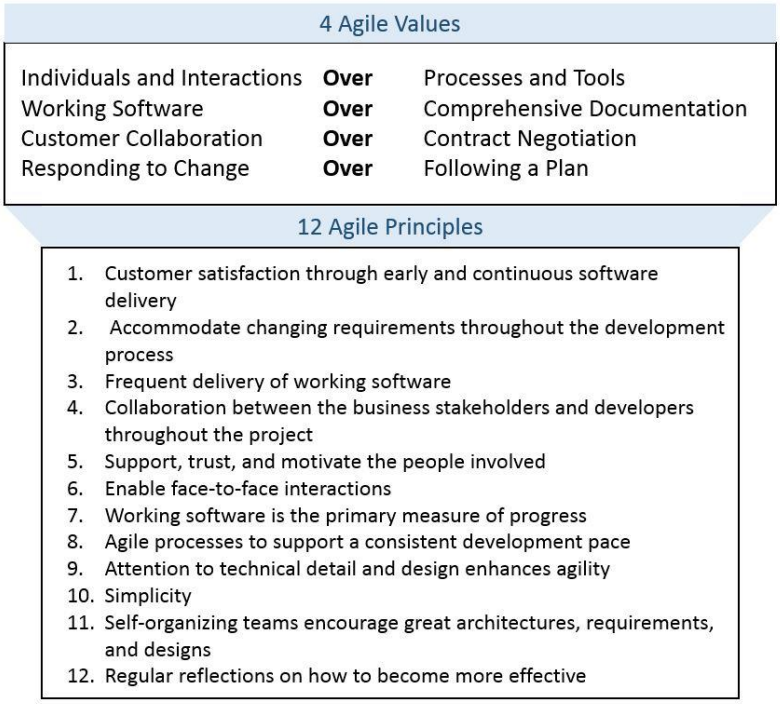

Figure 4: *Agile values and principles based on Beck et al (2001)*

Particularly the four values describe what is referred to as an Agile **mindset**. Other elements of Agile product development are **method**, **principle** and **practice** based on the level model derived from a large-scale Agile study in the DACH region by Schmidt, Paetzold and Weiss (2018).

Principles of Agile development are defined by its iterative nature in which the product is developed incrementally in short iterations. Contrary to traditional models, every iteration results in an increment (e.g. prototype, new feature) with testing being part of the process from the start (Highsmith, 2002). Additionally, the planning is also done in increments to allow for a 'fail fast, learn fast' environment (Ries, 2011). Simultaneously, the process is accompanied by continuous customer involvement and feedback, which ensures that the product features meet changing customer requirements. Other characteristics are self-organizing and cross-functional teams as well as active communication between stakeholders and the development

team (Eklund & Berger, 2011). The teams are usually co-located and use visualization tools to share information and progress. These characteristics result in a change of how the project success is measured: rather than delivering the final product with pre-defined specifications on-time, the progress of product increments (PI) and their fit to customer needs is emphasized (Cooper & Sommer, 2016).

Practices vary depending on the chosen **method** with SCRUM, eXtreme Programming and Feature-driven Development being amongst the most popular methods. As Abrahamsson et al (2003) explain, only the SCRUM framework is explicitly aimed at managing projects across the NPD process. Furthermore, the majority of implementations of Agile in NPS NPD are based on the SCRUM method (Ahmed-Kristensen & Daalhuizen, 2015; Cooper, 2016; Rigby, Sutherland, & Takeuchi, 2016; Böhmer, Hugger, & Lindemann, 2017). Therefore, this study will focus specifically on SCRUM as an Agile method.

2.4 Lean and Agile NPD

Parallel to the emergence of Agile other concepts such as Lean product development (LPD) have influenced how NPS NPD projects are executed. An overview of the evolution of Agile and Lean concepts is shown in Figure 5. Whereas Agile was brought to maturity in software development, Lean originates from manufacturing companies and their need for waste reduction in terms of time, resources and effort. Both Lean and Agile have their roots in Deming's PDCA process for continuous improvement (Rother, 2009). However, Lean was characterized by the Toyota Production System in the 1980s (Liker, 2004), and since then has spread to other areas of business, including program management and product development (Liker & Morgan, 2006). As Agile emerged after the Lean concept, the two concepts are closely interlinked and the 'Agile Manifesto' is strongly influenced by Lean ideas (Sutherland, 2011). First, a focus on customer value and a customer-centered approach is common in both concepts. Additionally, the aim of a shortening development cycles and reduction of wasteful activities are shared by both concepts (Petersen, 2011). Many techniques from Lean are also included in Agile NPD methods. Even in its simplest form, SCRUM uses a 'Pull' system and minimizes errors by continuous testing. Therefore, both terms are often used synonymously as shown in a study in software NPD by Barton (2009).

However, there are also notable differences that distinguish the two concepts. Dall'Agnol et al (2003) suggest that the two concepts address a different audience. Where Agile focuses on the development team, Lean is applied from a top-down management perspective with the goal of

optimization of workflows. This means Lean considers the end-to-end process of NPD, whereas Agile is a bottom-up project management tool with a narrower scope: the fast delivery of a working product in short iterations to the customer (Petersen, 2011). Another difference is that Agile defines methods such as SCRUM whereas Lean does not (Ibid). Conboy (2009) goes even further and states that Lean cannot cope well with variability, whereas it is the fundamental requirement of Agile. Lemieux et al. (2015) on the other hand claim that the combination of the two concepts is essential in NPD, which is referred to as 'Leagile'. This aims at merging the benefits of each concept while finding the right balance to minimize the challenges of each (Wang, Conboy, & Cawley, 2010). Regarding 'Leagile' there occurs to be a difference between the software and hardware domain: where in the software domain literature focuses on introducing Lean into established Agile development processes, in hardware the attention is on introducing Agile principles into established Lean development processes. This can also be seen from the timeline in Figure 5, where LPD is established in NPS projects more than a decade before Agile.

2.5 SCRUM

As mentioned in Section 2.3, Scrum has had the biggest impact on industry practice of NPD (Rigby, Sutherland, & Takeuchi, 2016). Scrum is found on the strategic layer based on the adaption of the St. Gallen management model by Atzberger et al. (2020) as seen in Figure 6. Agile development sits on the top layer answering the normative "WHY", and the operative layer is populated by the tools, techniques, artefacts and events that are included in Scrum.

Originally developed by Sutherland and Schwaber in 1995 (2017), Scrum involves iterative problem-solving cycles based on the Deming Cycle. Scrum is commonly divided into artefacts, roles and events (Schwaber & Sutherland, 2017). A visualization of the process can be seen in Figure 7.

Artefacts: The overall requirements of the product, which are sorted by priority, are found in the Product Backlog (PB). When new information emerges (e.g. new customer requirement), the items on the list are updated. From the Product Backlog the Sprint Backlog (SB) is selected, which are items for the current iteration. It also serves as the plan on how the iteration goal will be achieved. The Sprint Backlog is revised daily to select items and estimate the time required to complete them. The Sprint Burndown Chart shows the amount of work completed and still open for the current iteration (Schwaber & Sutherland, 2017).

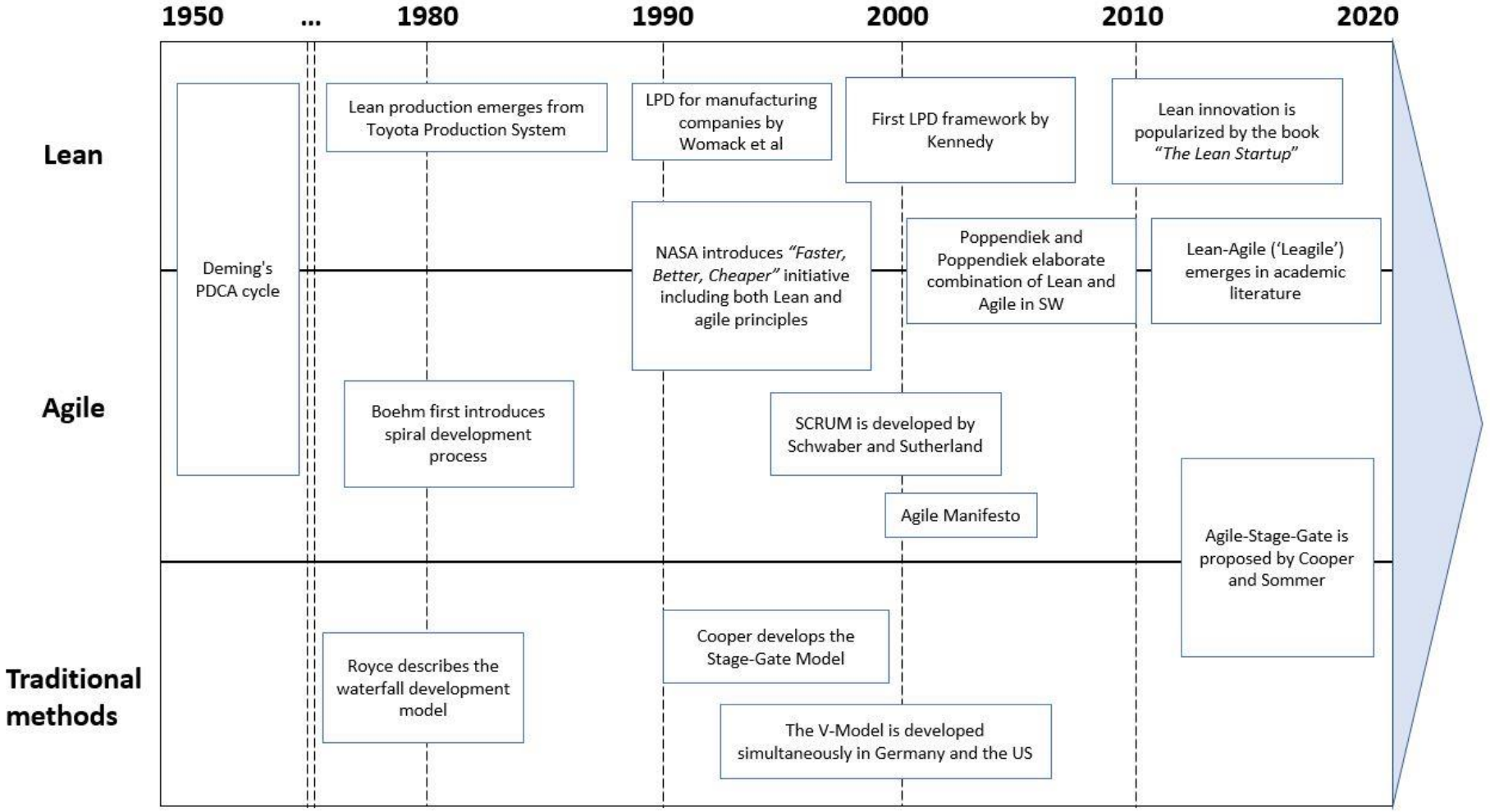

Figure 5: *Timeline of Lean, Agile and Traditional NPD methods*

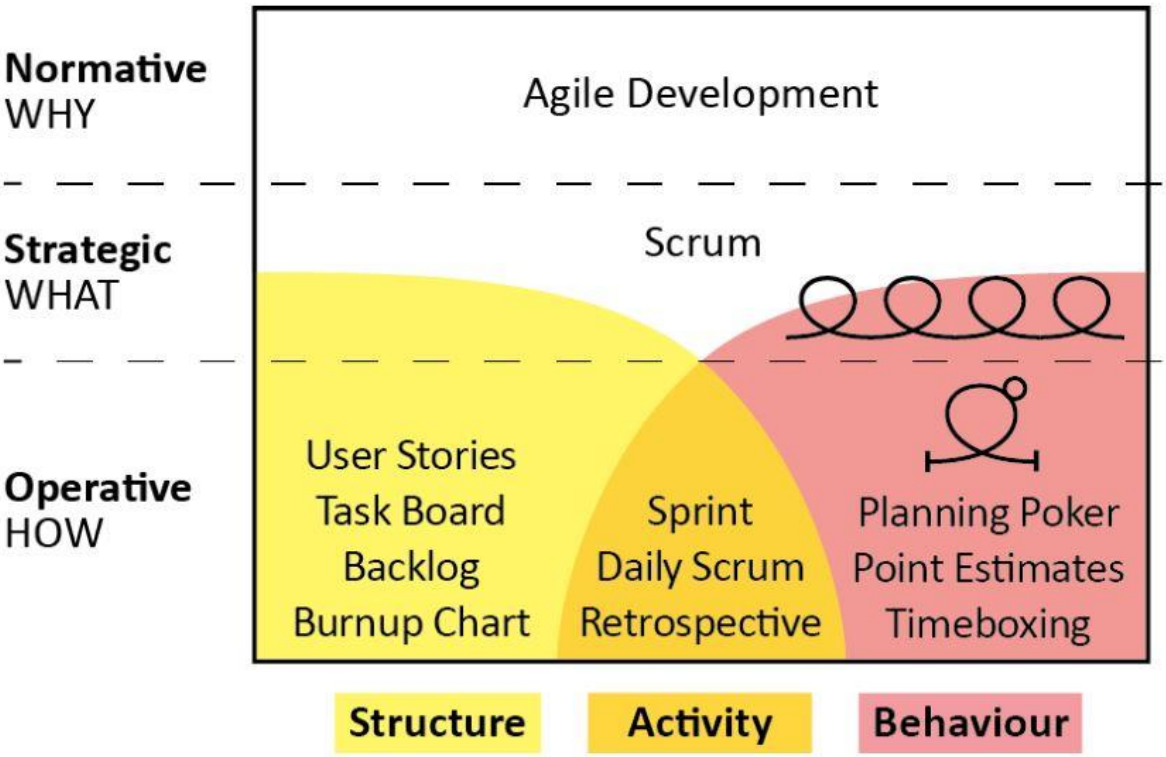

Figure 6: *Classification of Scrum according to Atzberger et al (2020)*

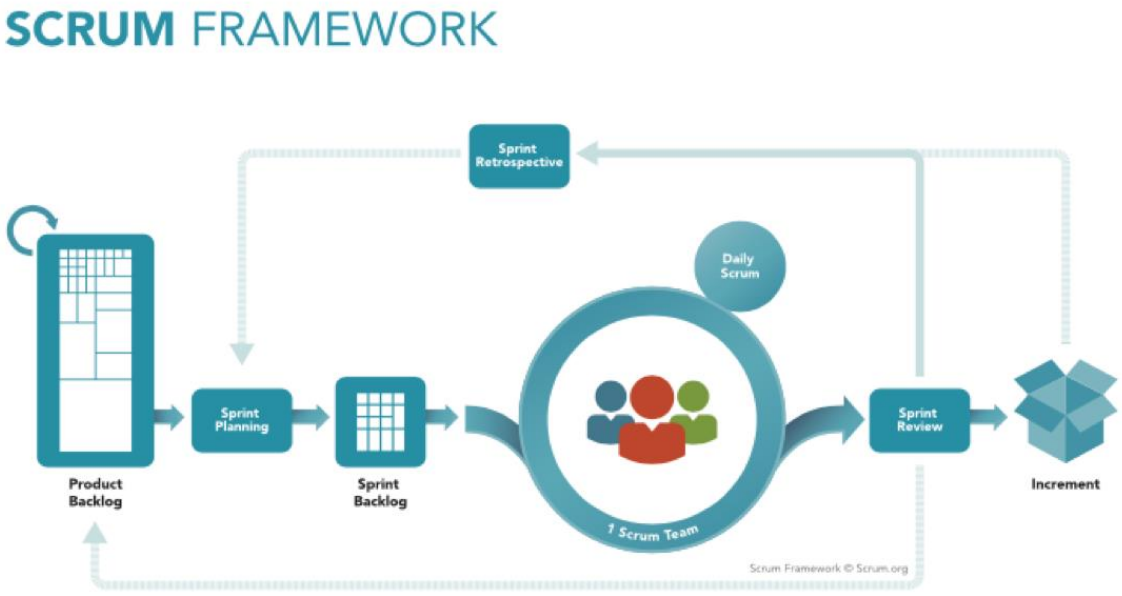

Figure 7: *SCRUM process according to Schwaber and Sutherland* (2020)

Roles: According to Schwaber and Sutherland (2017), the Scrum team consists of a Product Owner (PO), Scrum Master (SM) and the Team consisting of multi-disciplinary professionals. The PO is responsible for defining, managing and prioritizing the PB and therefore serves as the interface between the team and the customer. The SM manages the team, the PO and the process by advising stakeholders on the Scrum process. He/she functions as a coach and is responsible for facilitating the events and eliminating potential issues with the process. Finally, the team is self-organizing and cross-functional.

Events: The basic element of Scrum are the time-boxed iterations, referred to as Sprints. Every Sprint starts with Sprint Planning, where the team selects and assigns the items from the Product Backlog for the Sprint Backlog. During the Sprint, there is a daily stand-up meeting to keep all stakeholders in the loop regarding the progress. After a Sprint is finished, the Sprint Review reviews the results/increment while including customers and potentially other stakeholders. Afterwards, during the Sprint Retrospective the Scrum process is evaluated and improvements to the process are discussed (Schwaber & Sutherland, 2017).

Generally, Scrum is a framework to organise small projects and teams but doesn't consider NPD projects with multiple teams working on different aspects of a product. To accommodate for these products, researchers and industry have developed scaling frameworks.

2.6 Scaling Frameworks

There are various scaling frameworks, which are summarized in Table 1. Amongst the most common scaling frameworks are the Scaled Agile Framework (SAFe), the Large-Scale Scrum (Less) and the emerging Scrum@Scale (Alqudah & Razali, 2016).

***Table 1**: Comparison of Agile scaling frameworks based on Kalenda, Hyna and Rossi* (2018) *and Dolman and Spearman* (2018)

Characteristic	SAFe	Less	Scrum@Scale
Target size	Large to enterprise	Medium to large	Small to large
Based on	Scrum, Extreme Programming, Kanban	Scrum	Scrum
Project control	Top-down approach Distributed ownership of "how"	Centralized prioritization, distributed coordination	Distributed, more "agile"
Industry Adoption	High	Medium	Medium

Advantages	Focus on big picture, very prescriptive	Effective Product Owner scaling, based on suggestions	Lightweight, closest to pure Scrum,
Challenges	Requires extensive training, not as agile as other frameworks	Difficult to implement in large organizations as considered “radical”	Newest framework, still evolving
Team sizes	50-120	10 teams with 7 members each	Varies depending on use case
Complexity	High	Medium, low if Scrum-trained	Medium/low, more around guidelines

2.7 Differences between software and not-purely-software NPD projects

However, Scrum and the scaling frameworks were first introduced and matured in software development. In NPS projects the product does not solely consist of software but exhibits a tangible or physical character. Often, these products involve mechanical, electrical and software aspects and can be referred to as mechatronic or cyber-physical (Atzberger, et al., 2019). This results in some key differences.

According to Eklund and Berger (2017), mechatronic development has significantly longer lead times compared to software development. Also, capital investments are typically committed early in the project due to the disproportionate effect of initial decisions regarding manufacturing processes on the later development (Ahmed-Kristensen & Daalhuizen, 2015). Both these factors result in a long-term vision regarding NPD projects (Ibid). Another difference is the higher product complexity and the involvement of more stakeholders in the process (Schuh, et al., 2017). Furthermore, the interplay between mechanical, electrical and software results in more dependencies, referred to as constraints of physicality. Ovesen (2012) divides these constraints into four clusters:

1. Issues with the separation of the product into deliverables that fit into an iteration length: prototyping and testing something tangible for an increment is more difficult due to these dependencies (Cooper & Sommer, 2016), whereas in pure software development increments can be tested and deployed relatively easily.
2. Issues with the division of development tasks: this results from the fact that domains are more specialized in NPS projects involving mechanical engineers, developers, test engineers, manufacturing engineers, etc.

3. Issues with the estimation of time and resources required for the tasks: in hardware, small design changes can have a large effect on the cost and timeline.
4. Issues with missing flexibility in process and product: this can be for example long supplier lead times (Cooper & Sommer, 2018).

Despite these differences, Eppinger (2019) states that many of the elements of Agile can be adapted for NPS NPD projects. Ultimately, these tenets all aim at merging Agile and sequential practices in hybrid models.

2.8 Hybrid models

The umbrella term for the customization of Agile methods to new environments is called *Agile Tailoring* (El-Said, Hana, & Eldin, 2009). Agile-stage-gate hybrid models are an example of such, combining established stage-gate processes with Agile elements. In a study on Agile in project management in the DACH region it was found that two-thirds of companies that adapt Agile development approaches utilize a selective or hybrid development process (Komus & Kuberg, 2017).

An early approach in integrating both concepts was introduced by Karlström and Runeson (2006). This model states that in systems engineering the software development can be done using Agile, whereas the other domains are managed by the stage-gate process. They concluded the Agile and sequential are compatible, as Agile brings powerful micro-planning and daily operational control and the stage-gate provides the team coordination and communication across stakeholders.

More recent models include the "Agile-Stage-Gate-Model" by Cooper and Sommer (2016), in which Agile development methods are used inside the stages for all subsystems. Yet, the application of the Scrum method requires some adjustments in the context of physical products: first the definition of "done" has to be changed. The authors define a "protocept" – merging prototype and concept – to have something to obtain feedback from customers. Secondly, the approach requires a dedicated, co-located team. Lastly, communication is supposed to be in a diamond pattern, with each member connected to one another. This is in stark contrast to the pure stage-gate process, where there is one central point through which information flows (Cooper and Sommer, 2016). As this model is comparably prescriptive, it can be considered a framework.

A similar model has been suggested by Conforto and Amaral (2010), which revolves around a framework called “Iterative and Visual Project Management Method”. They divide the project into multiple levels: the first level is the high-level stage-gate process with milestones and development phases. For each phase, deliverables for iterative development are defined in level 2. In level 3, the deliverables are broken up into tasks and assigned to team members. In the last level, the key performance indicators (KPI) are measured. The authors emphasize the importance of a project management software to support the framework.

Schuh et al. (2017) take a different approach by discarding the notion of using Agile only inside the stages. While releases of Agile teams and project gates should be in sync, Sprints can be allowed to stretch across gates. Gates function as indicators for the project status and are defined as closing knowledge gaps or key decisions taken to allow for changeable specifications. Releases are aimed at knowledge exchange and validation, and optimally should use minimum viable products (MVP). This model is similar to findings from Ahmed-Kristensen and Daalhuizen (2015) exploring hybrid models in four European manufacturing companies. Krug et al. (2019) build on top of this approach by deriving a framework to find the **project**-specific, optimal proportion of Agile. On the other hand, Schuh et al. (2018) suggest focusing on **product** rather than project scopes in the determination of the optimal hybrid process. For this, they propose a qualitative judgement based on weighted ‘Agile Indicators’, which are categorised in internal and external indicators (Schuh, Riesener, & Diels, 2016).

Internal

- Solution Space
- Resources
- Technology Ability
- Prototype Manufacturability
- Corporate Culture

External

- Market Accuracy
- Market Volatility
- Market Relevance

Currently, hybrid development models are still being validated and tested in industry and academia. There has not been a consensus on one method as with the Stage-gate model in the

1990s (Cooper, 2017). Comprehensive quantitative data and details on industry practices are rarely found in academic literature.

2.9 Industry perspective

As the research area is novel, industry practices are found mostly in case-study based research. An overview of relevant publications including the case-study companies can be found in Table 2. Cases were deemed relevant if they used Agile or elements of it in a NPS NPD project and enough information on the implementation was provided.

In total, 24 case studies were found that were relevant to the primary research areas. To include only the most recent case-studies, only studies published from 2016 onwards were included, which were 14. Ultimately, only the studies with a specific focus on the research topic were chosen on a case-by-case basis, which results in the 10 chosen case studies.

Table 2: *Relevant industry case studies on Agile in NPS NPD since 2016*

Publication	**Case company - Industry**	**Size**	**Implementation in study**
(Cooper & Sommer, 2018)	Chamberlain – Gate Systems/Door Openers	>5.000	Hybrid in large, uncertain development projects (less than 20% of all NPD)
	Danfoss – Industrial Valves	>27.000	
	LEGO – Plastic Toys	>14.000	
	Honeywell – Industrial Automation	>130.000	
	GE - Diversified	>300.000	
	Tetrapak - Packaging	>24.000	
(Cooper, 2016)	Automotive	unknown	Hybrid for all front-end development
	Control Devices	unknown	Hybrid for all NPD
(Böhmer, Hugger, & Lindemann, 2017)	Automotive	unknown	Complete Agile NPD in singular project
(Eklund & Berger, 2017)	Group of 6 companies – Household appliances	2.100-93.000	Transfer of Agile principles beyond software
(Garzaniti, Briatore, Fortin, & Golkar, 2019)	Space/Aviation	unknown	Hybrid for singular component NPD project
(Lindlöf & Furuhjelm, 2018)	SAAB – Military equipment	>15.000	Hybrid for large NPD project

(Könnölä, et al., 2016)	Ericsson – Communication technology	>99.000	Hybrid for project on product upgrade
	Nordic ID – RFID and barcode devices	>50	Hybrid for singular NPD project
	NextFour Group – development agency	>20	Complete Agile for internal NPD project
(Dackhammar & Ek, 2017)	Additive manufacturing	unknown	Hybrid for all NPD
	Welding and cutting machinery	>8.500	
	Outdoor power products	>13.000	
	Medical implants	unknown	
(Edwards, Cooper, Vedsmand, & Nardelli, 2019)	B2B food industry	>140	Hybrid for single project
	Audio equipment	>150	
	Radar systems	>90	
(Ahmed-Kristensen & Faria, 2018)	BMW - Automotive	>120.000	Hybrid for majority of NPD
	Philips – Medical devices	>100.000	
	Hearing measurement devices	>500	
	Excluded as only software NPD	N/A	
	Audio solutions	>5000	
	Jabra GN - Audio	>500	
	Danfoss – Industrial valves	>24.000	
	Medical devices	>2700	

The following description of the case studies in Sections 2.9.1-2.9.3 will reference to the company rather than the author.

2.9.1 Organization

All examined companies used iterations, with sprint lengths between 2-8 weeks. However, there were notable differences in how companies interpret self-organization of teams. Whereas at Danfoss and Saab the project team defines and allocates tasks themselves, at Philips the PO delegates the tasks to the team. At Ericsson, the disciplines break down the requirements into tasks before the sprint planning. The governance of the self-organization was not described in detail in any of the case studies.

Another element of Agile is the increment, which according to the case studies can take various forms in NPS NPD. As each company has their own interpretation of an increment, no common consensus or pattern was found. Some examples include:

- Chamberlain: design drawings or early prototype
- Honeywell: demo-able or integrate-able product increment
- Automotive company from Cooper (2016): protocept. This can be anything shown to customer to seek feedback, test a market-facing hypothesis or seek proof-of-concept.
- Automotive company from Böhmer, Hugger and Lindemann (2017): anything that brings value to customer. This doesn't necessarily have to be anything physical
- Additive manufacturing company: Finished tasks such as order of a component, control of tools, examination of materials and/or testing

2.9.2 Benefits

In all case studies there were reported benefits of using Agile in NPD. Most of these advantages were qualitative soft factors:

- Better information exchange and alignment
- Improved handling of requirements
- Improved coordination
- Better at handling uncertainty
- Higher visibility of progress
- Better team satisfaction/empowerment

Yet, some companies also experienced measurable hard benefits:

- Reduced cycle time: Chamberlain saw a reduction of cycle time by 20-30% due to less redo in the process.
- Faster time-to-market: Danfoss experienced a 30% reduction in time-to-market.
- Faster development: GE reports a reduction of development time from ideation to test from average 3 years to 1.5 years.

However, hard benefits were rare and only found in the case studies done by Cooper and Sommer (2018). Yet, soft benefits were mentioned in every case.

2.9.3 Challenges

The challenges the companies from the case studies faced can be categorized into three groups: constraints of physicality, teams and company context.

Constraints of physicality were introduced in Section 2.7. These lead to challenges as mentioned in the case studies, particularly difficulties in dealing with changes in mechanical components and long supplier lead times.

Looking at the teams, there were three major challenges:

- The teams experienced higher stress levels.
- The employees were unwilling to work in an Agile process or reverted back to established work habits.
- The Agile approach resulted in a lack of coordination between teams.

Finally, the company context (industry, size, organization, etc.) meant that bureaucratic processes hindered the implementation of Agile. Additionally, there were issues related to the distribution of responsibilities from a central to a decentral governance model. The manufacturer of additive manufacturing solutions, for example, mentioned that delegating responsibility down resulted in "*too many chefs in the kitchen*" (p.34).

2.10 Research Gap

The literature covered both academic perspectives and industry case studies to cover the primary domains: Agile development, hybrid models and Scrum. Although some early adopters (SAAB, LEGO, GE, ...) have successfully spearheaded the transfer of Agile from software to NPS NPD, there have only been isolated case studies. Additionally, the case studies are often either longitudinal or only include a small group of cases. According to Ahmed-Kristensen and Faria (2018), there has been a significant increase in the use of Agile in manufacturing companies only in the past few years. This results in the following research gaps:

First, the taxonomy and core characteristics of Agile aren't clearly defined, leading to various interpretations of Agile. Where Cooper and Sommer (2018) interpret Agile as a bottom-up project management tool guided by stages, other researchers such as Böhmer, Hugger and Lindemann (2017) focus on the incremental product delivery.

Furthermore, the understanding of when Agile, hybrid or sequential elements are applicable is still in early stages of industry validation. Though first papers have inductively derived a

systematic approach (see Schuh, Riesener and Diels, 2016) it is not evident how companies evaluate this in practice.

Another research gap is, that publications on the details of Agile implementations across industries are rare. The identified case studies do not describe relevant aspects (such as the role of the customer, changing governance model and requirements handling) in sufficient detail.

Lastly, there have been contradicting findings on the benefits of Agile. As discussed in Section 2.9.2, some studies have found that companies experienced hard benefits whereas other studies have indicated that in NPS there are mainly soft benefits.

2.11 Research Question

The study aims at bridging the gap between academic knowledge and industry practice by answering the following exploratory research question:

When and how do manufacturing companies use Agile development practices in not-purely-software new product development?

The above research question was broken down into 5 sub-questions, each corresponding to a research gap as seen in Figure 8.

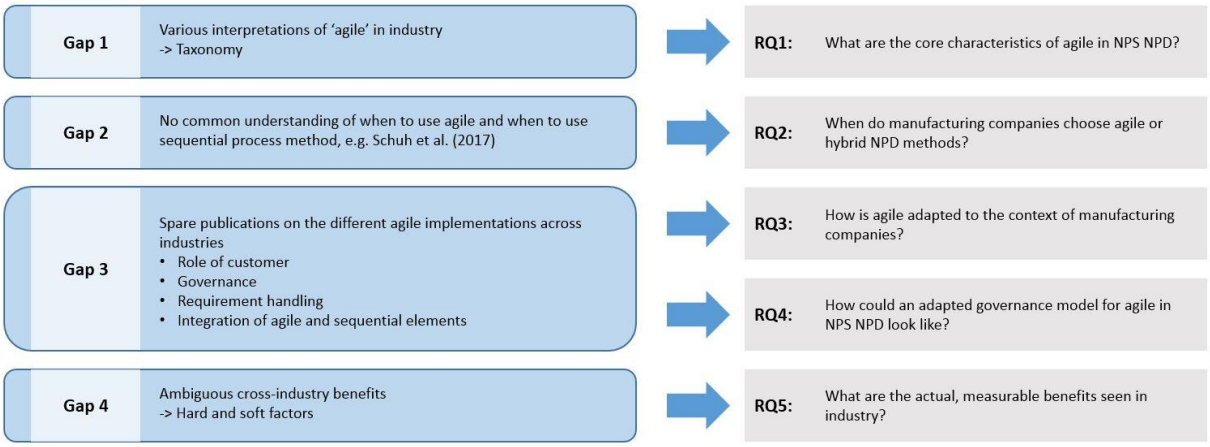

Figure 8: *Research gaps and resulting research sub-questions. Research question is abbreviated as RQ.*

3 Research Methodology

3.1 Research Project Design

Based on the identified research gap and research question, a suitable research method must be formulated. The section follows a top-down approach as shown in Figure 9, starting with the most outer layer philosophical position down to details of the data collection and analysis.

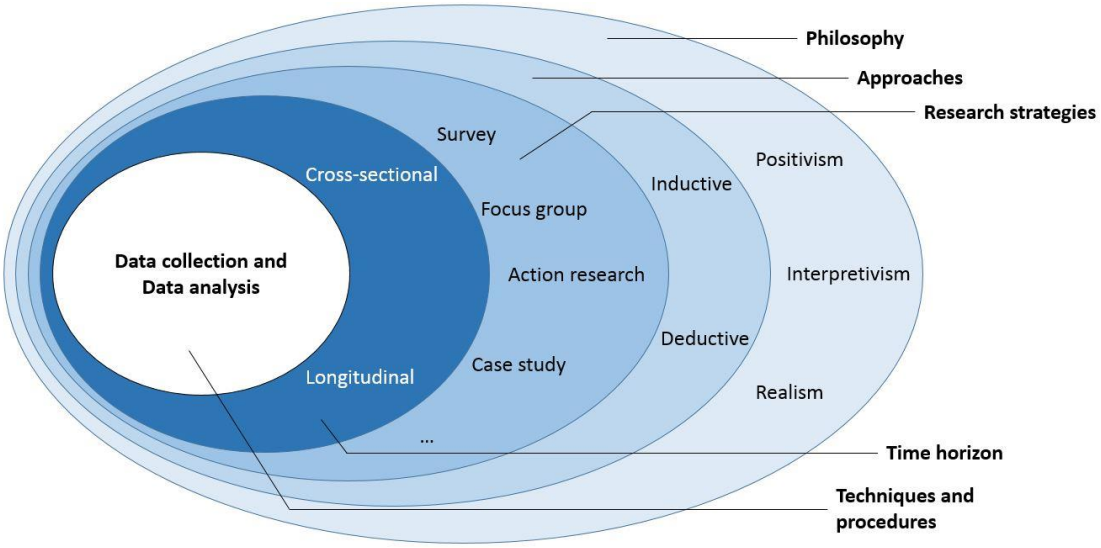

Figure 9: *Research onion adapted from Saunders, Lewis and Thornhill* (2009)

To analyse the research questions effectively, first the nature of the research must be understood. The research project is designed to be empirical, which is common in studies in business and management as it aims to describe real world problems (Easterby-Smith, Thorpe, & Jackson, 2015).

In the context of empirical research there are three major philosophies, which are summarized in Table 3.

Table 3: *Philosophies adapted from Easterby-Smith, Thorpe and Jackson (2015)*

Characteristic	**Positivism**	**Realism**	**Interpretivism**
Research aim	Discovery	Exposure	Invention
Starting Point	Hypothesis	Suppositions	Meanings
Outcome	Causality	Correlation	Understanding
Interpretation	Verification/Falsification	Probability	Sense-making
Approach	Deductive	Inductive/Deductive	Inductive

This study is on a complex and dynamic topic and the findings based on perspectives of people are inherently subjective. Additionally, the research area is relatively novel and still focused around exploratory understanding. The results are interpreted with regards to sense-making of the Agile implementations. Therefore, **Interpretivism** is the main philosophical position. This results in the research approach being **inductive**, meaning findings will be interpreted open-mindedly, without hypothesis, by the researcher. Another implication is that the collected evidence is qualitative in nature to answer the 'When' and 'How' question as seen in the research question (Denzin & Lincoln, 2011).

Furthermore, the research strategies need to be determined. Relevant research strategies and their characteristics are shown in Table 4.

Table 4: *Research strategies adapted from Yin* (2014)

Data collection strategy	**Characteristics**	**Type of question**	**Control over behavioural events**	**Contemporary event focus**
Survey	Collecting large quantities of data using questionnaires	Who, What, Where, Where, How	NO	YES
Case study	Study of established evidence to gain an understanding of a situation	How, Why, When	NO	YES
Action research	Active involvement of the researcher to solve a problem in an organization	Who, How, Why	YES	YES
Focus group	Discussion among group of people on a specific topic	Who, How, Why	YES	YES

To improve confidence in the findings methodological triangulation was used, which refers to utilizing more than one research strategy (Saunders, Lewis, & Thornhill, 2009).

The first research strategy was collective **case studies**, which is an in-depth inquiry into a phenomenon within its real-life setting (Yin, 2014). Case studies set out to understand the

dynamics of the topic and lead to rich, empirical descriptions and the development of theory (Ibid). After finishing the case studies, another selected strategy is a **focus group** in the form of a workshop. The workshop aimed at validating the findings and interpretations derived from the case studies and to foster a discussion amongst participants. This strategy is valuable as it results in an understanding of the various interpretations of the specific topic, in this case the findings from the case studies (Liamputtong, 2011).

As the research question required a multitude of companies and perspectives to investigate the current state-of-the-art, a **cross-sectional** time horizon was selected. That means the current use of Agile in NPS NPD at multiple case companies was analysed, rather than following the process of introducing Agile for a single case.

The research topic is novel and knowledge on industry practices is limited, so the research was exploratory in nature. Hence, the focus is on understanding reasons for decisions, attitudes and opinions. Additionally, the data collection should be flexible to going into unexpected directions. In this context it is also important to emphasize the trust required through personal contact, for example when discussing opinions. For this reason, **interviews** were chosen as the primary data collection technique for the case studies. Regarding the focus groups, a **questionnaire** and **documentation** of discussions were the data collection methods. This combination of exploratory interviews in case studies, supplemented by workshops with questionnaires have been used in similar studies (Ahmed-Kristensen & Daalhuizen, 2015; Könnölä, et al., 2016; Sommer, et al., 2015).

Finally, the main analysis method was grounded theory. Grounded theory was used to derive main conclusions from the literature review and the case studies. This qualitative technique is used to break down data into smaller components, label them as categories and compare them to understand variations in the data (Corbin & Strauss, 2008). To ensure a structural approach, the interview transcripts were analysed using a conceptually ordered display based on Sommer et al. (2015). The answers were clustered along the main research topics and then cross-analysed. This enabled an understanding of similarities, differences and recurring patterns.

With the research methods elaborated, the research design follows the 6 stages as seen in Figure 10. Limitations of this research design will be discussed in Section 6.3.

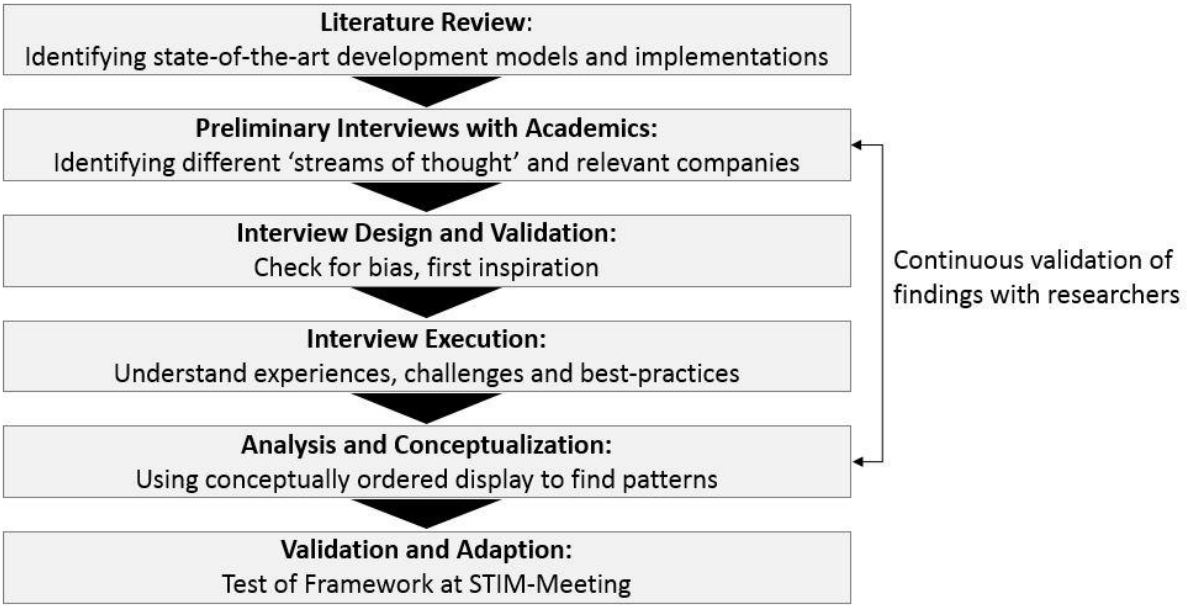

Figure 10: *Final research design*

3.2 Case selection

To conduct cross-sectional case studies, relevant companies must first be identified. The participating companies must have made first experiences using Agile methods (e.g. SCRUM) or elements of it in one or more NPD projects involving not only software development. In this study NPD included both the development of a completely new product from scratch as well as product upgrades of existing products.

The companies were identified and contacted through two means:

1. The company/employees indicated interest at the STIM-Consortium meeting at the University of Cambridge.
2. The company/employee is part of LinkedIn groups about Agile development in hardware contexts.

Based on these criteria and search modes, the companies as seen in Table 5 were selected. It is important to note that some companies are large, which means the findings from this study only reflect the situation of the analysed department specifically, as different Agile implementations can exist simultaneously in different business units of one company.

The case companies vary significantly in size, country of origin and industry. This is due to the exploratory and open-ended nature of the study. This heterogeneity allows to identify cross-industry patterns and feeds multiple perspectives into the interpretations of the data. One outlier

is the pharma/life-sciences company, which uses Agile in their technology development rather than in NPD. Therefore, this company was taken for inspiration and validation but not as a data source for the analysis and discussion in Section 5.

Table 5: *Summary of case companies: in the case of 'industry' and 'country' the context of the interviewees and their departments was taken. The values for employees and revenues are as of 2019.*

Company	**Employees**	**Revenue**	**Country**
Aerospace & Defence 1	>1,700	~£2.6B	UK
Aerospace & Defence 2	>130,000	~€70.5B	Germany/Spain
Agricultural vehicles	>70,000	~$37.3B	Germany
Automation systems 1	>88,000	~$18B	US
Automation systems 2	>750	Unknown	Spain
Automotive	>130,000	~€104.2B	Germany
Automotive start-up	>20	Unknown	US
Automotive supplier 1	>27,000	~€6.9B	Germany
Automotive supplier 2	>29,000	~$10.5B	Canada
Automotive supplier 3	>180,000	~€42.6B	UK
Engineering services	>20	Unknown	Canada
Food & Beverage	>100,000	~$37B	UK
Industrial furniture	>900	~$250m	US
Jewellery	>7,000	~$2.2B	India
Pharma/Life Sciences	>99,000	~£33.75B	UK
Research & Technology Organisation (RTO)	>500	Unknown	UK
Ventilation systems	>3,000	~€644m	The Netherlands

The interviews followed a semi-structured qualitative process, lasting between 40-90 minutes using videoconferences. To facilitate the interview effectively, interview guidelines were derived from the research questions as seen in Figure 11. The interview is split into four parts:

1. The first section is to set the context of the interviewee, as this shapes the perception especially for the reflective part of the interview. The three main elements of interest are the company and interviewee background, and the product or project that was/is developed using Agile NPD.
2. Afterwards, the current Agile implementation is discussed in detail. This starts off with an open-ended question to see what area the interviewee has the most expertise/interest in. Then, the guidelines follow the framework based on SCRUM as introduced in Section 2.5, which splits up Agile into the elements roles, artefacts and events. Even though not all companies follow a SCRUM method, this conceptualization of Agile is generalisable and enables a structured analysis (Cooper & Sommer, 2016).
3. Based on the detailed understanding of their Agile implementation, the reflection section focuses on three major topic areas: challenges and advantages, potential ideas for improvement and the discussion of when to select which NPD approach. Depending on the previous part, further topics can be explored.
4. The last part focuses on governance. Sometimes governance can already be introduced in the second section, but here the interviewee's opinion on effective governance in Agile is discussed in particular.

The interviews were recorded and automatically transcribed using the app Otter.ai, after receiving permission, and notes were taken throughout.

3.3 Researcher interviews

To ensure constant validation and relevance of the interview findings, a group of leading researchers were interviewed throughout the project as seen in Table 6. These interviews were conducted unstructured and focused on the exchange of opinions. This allowed to dive deeper into topics the researcher was experienced with and to receive feedback on emerging findings (Saunders, Lewis, & Thornhill, 2009).

3.4 Workshop design

The workshop was split into two parts. First, a presentation introduced initial findings and included a poll to validate them. In the second half of the workshop, a focus group discussed interpretations to receive feedback and ideas for improvements. The content of the workshop was derived from the findings of the case studies.

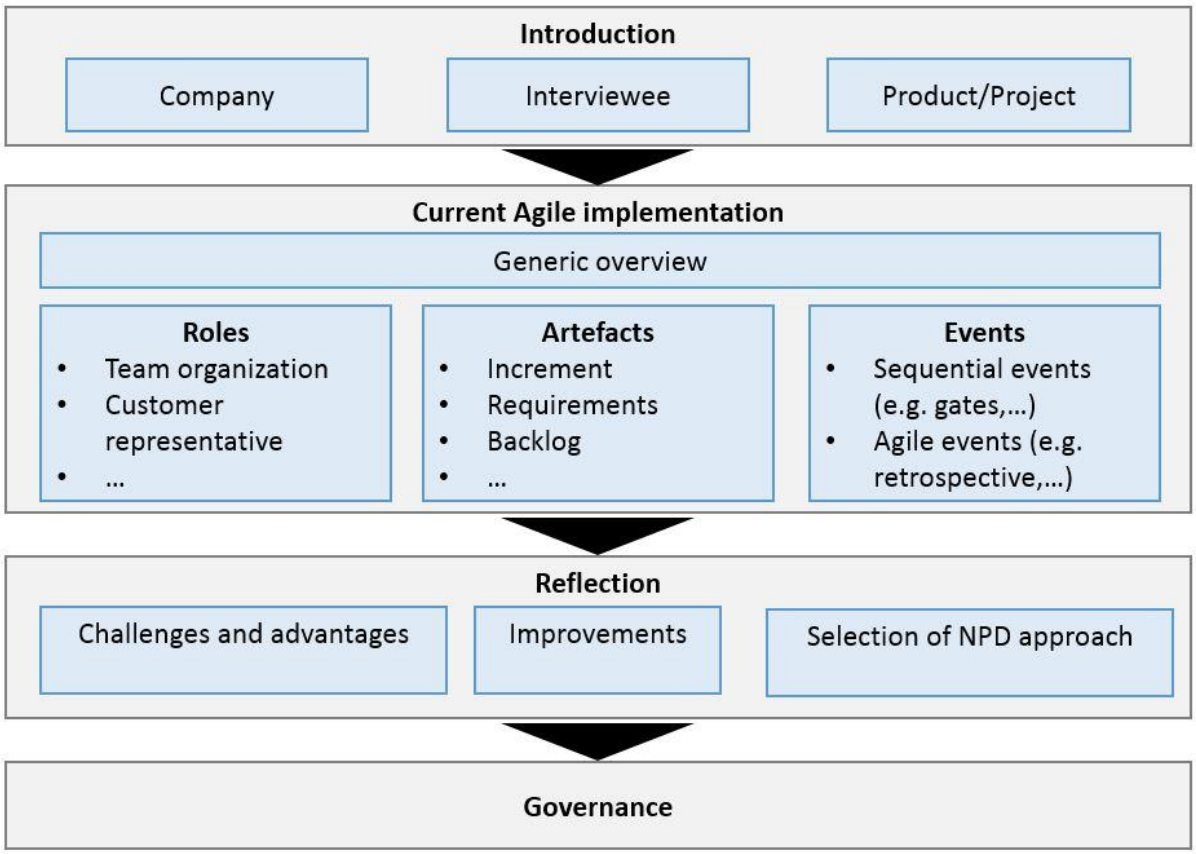

Figure 11: *Interview guidelines for semi-structured interviews*

Table 6: *Interviewed researchers*

Country	**University**	**Focus area**
Germany	University of Armed Forces Germany	Conducting annual study on Agile in NPS NPD in Germany
Germany	RWTH Aachen	Conducting a study on best-practices in NPS NPD based of 100+ German companies
United Kingdom	University of Cambridge	Digital transformation and strategic roadmapping
United Kingdom	The Open University	PhD on using Lean and Agile approaches in roadmapping for a fusion start-up
United Kingdom	University of Cambridge	Postdoctoral researcher, conducted a study on Agile transformation process in NPS NPD with 3 companies

4 Data Collection Summary

In total, 30 interviews were conducted with industry practitioners from a variety of backgrounds. Table 7 provides contextual information on the case companies, such as their product/project and software content, and a high-level description of each company's specific use of Agile. It is important to note that some companies, such as 'Automation Systems 1' and 'Aerospace and Defence 2' have two separate cases each. As the use of Agile significantly varied between different products of the same company, they were split up and analysed independently.

Potential sources of bias resulting from the data collection are discussed in Section 6.3.

5 Analysis and Discussion

First, an understanding of the different interpretations of Agile build the foundation of the shapter (Section 5.1). This is as the interpretations of Agile influence when to use Agile (Section 5.2) and how to use Agile (Section 5.3). To facilitate the Agile implementation, an appropriate governance model will be discussed (Section 5.4). Finally, the advantages of Agile and how companies measure them (Section 5.5) conclude the discussion.

5.1 Research Question 1: Interpretation of Agile

Generally, it became evident that the specific context of the product and industry (for example governmental regulations or certification) results in a need for a customization of Agile methods to the development process for each case. An additional factor was the differences in how Agile was interpreted. Only four of the companies use an adapted theoretical framework, namely the Agile-stage-gate hybrid model by Cooper and Sommer (2016), SAFe, SCRUM@Scale and lastly the pure SCRUM framework. The other companies use customized Agile tools based on Agile principles to a varying degree, rather than following an Agile framework.

As the company context is relatively rigid, the interpretation of Agile must be examined in more detail. A cross-case study analysis revealed recurring themes in four mutually inclusive clusters, from which a conceptual framework was derived as seen in Figure 12. Agile frameworks can be located in the middle grey area, comprising all four interpretations simultaneously.

Table 7: *Summary of data collection.*

Company	Agile implementation	Agile since	Product/Project	Software content	Team size	Time-boxing (weeks as w)
Aerospace & Defence 1	Some Agile elements in stage-gate	This year	Aerospace components	None	6	Varying, flexible
	Extensive use of Agile elements	This year	Medical ventilators	High	8	Varying
Aerospace & Defence 2	SAFe Framework	2018	Commercial airplanes	Medium	10	2-4 w Sprint, 6 w PI
			Airplane component upgrade	High	10-12	
Agricultural vehicles	Use of Agile elements in sequential model	2011	Complete tractors	Medium	8-10	Varying, <2 months
Automation systems 1	As part of SW team, using SAFe framework	Few years on individual basis	Process systems	Very high	5	2 w Sprint, 10 w PI
	Agile elements in stage-gate	Q3 2019	Control process valves	High	varying	3 months
Automation systems 2	Agile elements in stage-gate	2016	Automation systems/lines	low	6-8	2 w
Automotive	Trial of Agile teams in wider stage-gate process	Apr. 2019	Complete car	Medium	6-8	2 w Sprint, 6 w major review
Automotive start-up	Complete Agile organization	2011	Complete car	Low	-----	2 weeks
Automotive supplier 1	SCRUM@Scale framework	2018	Breaking and steering systems	High	<8	2-3 w, 3 months PI
Automotive supplier 2	Use of Agile elements in stage-gate	2018	Automotive inverters	High	7-10 (not cross-functional)	2 w
Automotive supplier 3	Agile elements in hybrid model	2018	Small hardware parts	None	>7	No time-boxing
Engineering services	Self-developed Agile framework	March 2019	Varies, e.g. wheelchair	Varies, mostly low	4-5	2-4 w Sprint 1-3 months PI
Food & Beverage	Agile-stage-gate	2018	Pet food	None	3-6 core, 10-12 total	2-6 w
Industrial furniture	Agile elements in trial project	Few months	Dental chairs	Low	18	4 w Sprint, 3 months PI
Jewellery	Extensive use of Agile elements	2016	Wedding rings	None	10	2 w
Pharma/Life Sciences	Trial of Agile elements	Few months	Technology Development	---	---	---
RTO	Agile as philosophy, extensive use of Agile elements	Multiple years	Varies; example project on sintering machine	Medium	10	No time-boxing
Ventilation systems	Agile-Stage-Gate	2017	Commercial radiators	Low	<9	2 w

1. **Team collaboration**: Every company understood team collaboration as a main pillar of Agile. The focus here is on bringing people from multiple departments together and foster product/project ownership for an Agile team throughout the whole development process. Another aspect included under this categorization is the notion of self-organizing teams and increased team autonomy. Overlaying this interpretation is an Agile governance model, which will be discussed in Section 5.4.
2. **Customer integration**: Some companies focused their efforts on involving the customer more. This didn't necessarily coincide with incremental development, but solely getting the customer on board throughout the development process. An automation systems company, for example, said they used to evaluate their progress with their customers only at one of three major design reviews and have now shifted towards meeting on a weekly basis. Here, it is important to distinguish between contract and commercial work regarding the role of the customer in the process, which is discussed in detail in Section 5.3.1.
3. **Task management**: Another major interpretation of Agile was as a bottom-up project management tool to organize tasks while maintaining a constant rhythm. The time-boxing is used to evaluate progress and prioritize tasks more frequently. The automotive company, for example, used a 2-week time-boxing and subsequently only evaluated the accomplished tasks and prioritized work for the next two weeks, with no customer involvement or early prototyping.
4. **Iterative prototyping**: Here, Agile is interpreted as a method for failing fast and learning from failures using prototypes. These prototypes can be either physical or digital. Interestingly, companies who focused on this interpretation, such as the RTO and one aerospace & defence company, tended not to use time-boxing. The RTO, for example, said they did not hesitate to show the customer a proposed mechanism using a LEGO build to receive quick feedback.

This conceptualization aims to simplify the understanding of how companies interpret Agile. Additionally, the following aspects are derived from each respective interpretation:

- For which products/projects is Agile suitable?
- Should the NPD process follow a framework?
- If not, what Agile tools are applicable for the interpretation?
- What KPIs should be measured to understand the benefits of Agile?

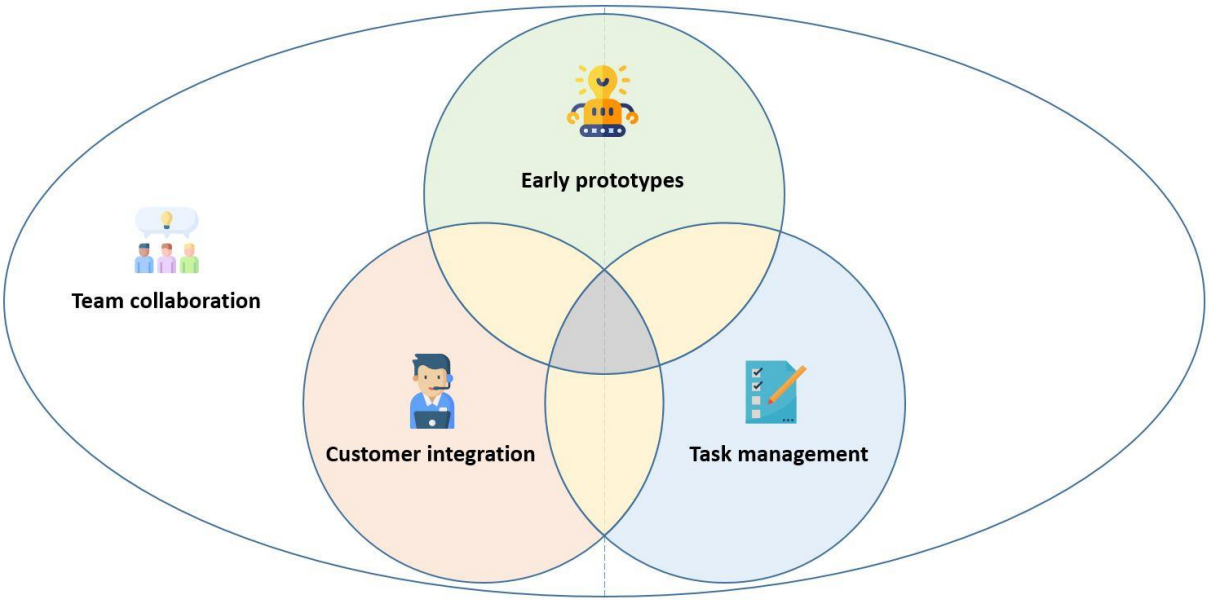

Figure 12: *Interpretations of Agile*

As an example, if a company decides to focus solely on Agile as task management, it would not make sense to implement an Agile framework or to measure its success by prototype maturity.

As seen in Figure 13, feedback from the workshop poll showed 10 out of 22 participants could allocate their company in the framework, with 6 being unsure and 2 not being able to identify their company in any of the categories. The follow-up discussion with the focus group revealed that there was not enough time given for the poll in the presentation, resulting in confusion over the differences between some of the interpretations. Looking at the practicality of the framework, 14 of the 22 participants said they "strongly agree" or "mostly agree" that the framework is easy to apply in their context. However, there were still two participants indicating they "mostly disagree" with the statement. Possible explanations from the focus group indicate that for some product-groups there are constraints that make distinguishing between the interpretations difficult. Furthermore, the workshop participants suggested that they were not given enough time to ask questions and understand the conceptualization fully, resulting in confusion. Regarding consistency, the framework was validated by 19 of 22 participants claiming they "strongly agree" or "mostly agree" with the statement that the framework is logical.

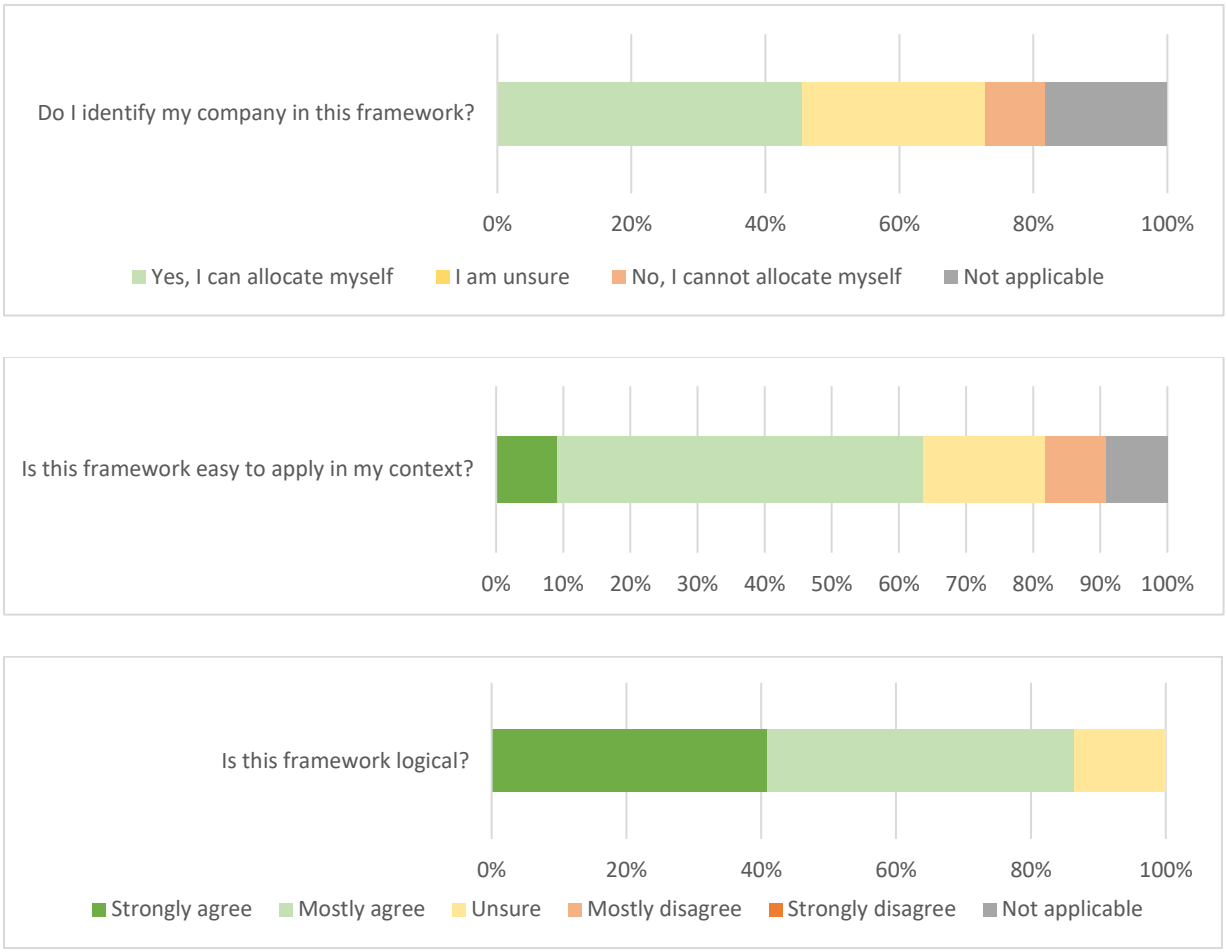

Figure 13: *Poll results*

Abstracting from the conceptual framework, the case studies displayed some of the similarities of Lean and Agile as discussed in Section 2.4. The pharma & life-sciences company mentioned that they implemented Agile tools using their continuous improvement framework based on Lean. A director said that they are incorporating Agile principles "*to actually inform how we should work together as a team, rather than having something formalized as in 'here's the product owner', 'here's the Scrum master' and so on.".* Additionally, Agile is considered an enabler for continuous process improvement by the automotive start-up. However, apart from these two companies none of the cases mentioned Lean or 'Leagile' explicitly nor implicitly. There could be three possible explanations for this:

1. The company implicitly sees Agile as part of their Lean initiative
2. The company sees Lean and Agile transformations as separate parallel initiatives
3. The company does not use Lean methods/initiatives and only considers Agile

The overlap between Lean and Agile raise the question of the applicability of Lean tools in Agile in NPS NPD. An example could be using the Lean tool Quality-Function-Deployment as

a tool to capture customer needs and derive requirements. However, these explanations are subject to speculation and have neither been studied in detail in academic literature, nor in this study.

5.2 Research Question 2: When to use Agile

As explained in the previous section, there are four interpretations of Agile which result in different perceptions on when to use Agile. Overall, there were two opposing opinions:

1. Agile should only be applied in specific scenarios or for specific products
2. Agile can be used in all NPD projects, only the tools must be selected and adjusted for each individually

The majority of the case companies supported the first opinion and only 5 suggested using elements of Agile for every project. Two main factors could account for these differences: first, the companies using Agile for every NPD project tend to be smaller companies doing contract work. Hence, they frequently work on individual NPD projects that are significantly different from one another. Secondly, the companies always using Agile change their interpretation of Agile as the project progresses. For example, the industrial furniture company suggested using Agile throughout the whole project, but later in the certification stages keeping only the tool of time-boxing to maintain a rhythm (thereby using the task management interpretation).

Looking at the cases suggesting a targeted use of Agile, three main clusters of conditions crystallised as seen in Table 8. These are compared to the 'Agile Indicators' proposed by Schuh, Riesener and Diels (2016).

Comparing the conditions proposed by the case companies to the 'Agile Indicators' show that the case companies tend to neglect some internal factors such as the availability of resources (knowledge, machining, budgets), the manufacturability of prototypes and the corporate culture. Yet, two process-related factors identified in the case studies aren't included in the 'Agile Indicators'. These are "necessity for integration into software process" and "including many stakeholders".

Interestingly, most case companies do not have a formal approach to determine when to use Agile but decide informally project by project on an ad-hoc basis. Yet, some companies determine the applicability of Agile using a 2D-plane to plot relevant metrics, similar to the Stacey Matrix used in software development, as seen in Figure 14.

Table 8: *Comparison of identified conditions for using Agile with 'Agile Indicators' by Schuh, Riesener and Diels (2016)*

Category	Condition	'Agile Indicators'
Market	High uncertainty of requirements	~Solution space
	High market volatility	~Market volatility
	Customer willingness	~Market accuracy
Product / Technology	No confidence in technology	~Technology ability
	Every project different / customization	~Solution space
	Flagship products	~Market relevance
	Strategic initiatives	~Market relevance
Process	Necessity for integration into software process	N/A
	Process has an element of experimentation	~Solution space
	Including many stakeholders	N/A

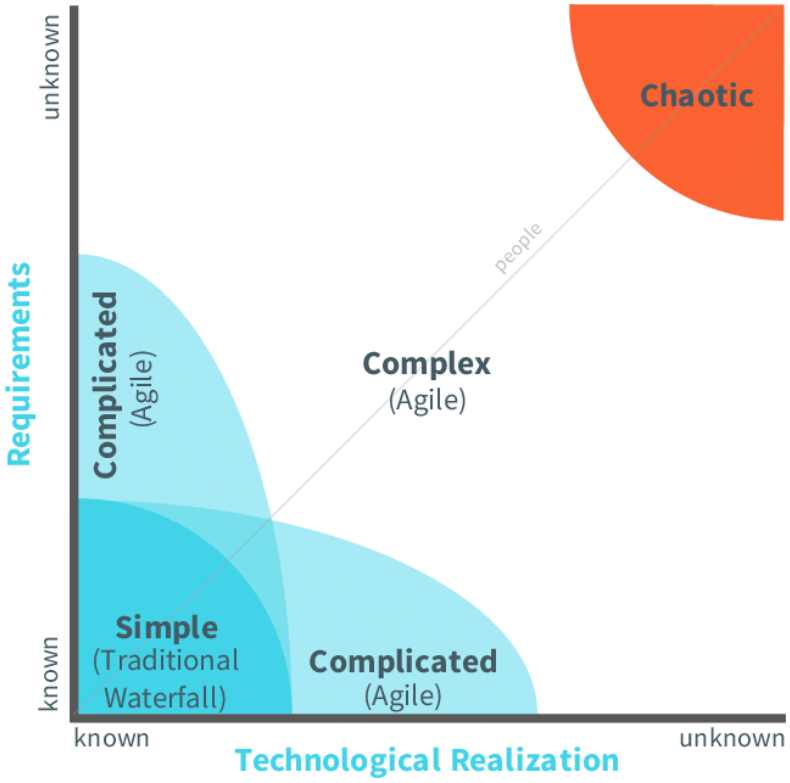

Figure 14: *Stacey matrix according to Uludag, Harders and Matthes* (2019)

The case ‘aerospace & defence 2’, for example, plots flexibility of requirements over the team experience. Another case, the manufacturer of breaking and steering systems, considers complexity (Have we used the technology before? Do we know the market/customer?) over team willingness to determine the applicability of Agile.

5.3 Research Question 3: Adaptions of Agile in NPS NPD

Assuming that the company decides to use Agile, the main question becomes how they use it. Except the automotive start-up which was launched as an Agile organisation, all other companies used an existing sequential process around the stage-gate and/or the V-model. In this context, there were three general approaches companies had when implementing Agile as seen in Figure 15.

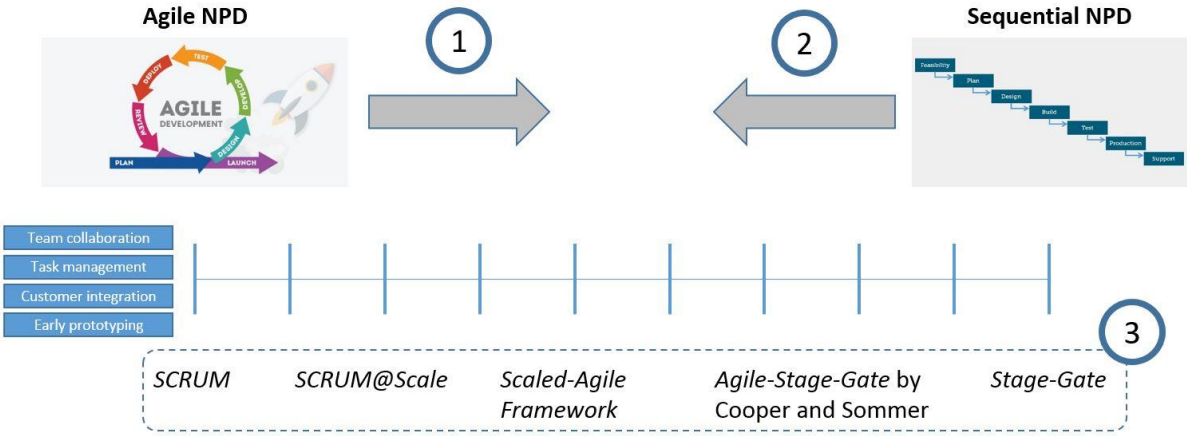

Figure 15: *Approaches to integrating sequential processes with Agile*

The first approach is to learn about the Agile principles, understand the pure Scrum process and then evaluate how to amend this process to fit the constraints. The other approach is to analyse the current sequential process and review which Agile tools can be utilized to reap the benefits of Agile. The last option is to simply use an existing Agile framework. Some companies used multiple approaches throughout their transformation journey. The manufacturer of commercial airplanes, for example, started using SCRUM in certain parts of their NPD since 2016 and then decided to use the SAFe framework in 2018 to scale across the whole product development.

As explained in Section 2.5, Agile implementations can be divided into three mutually-exclusive elements: roles, artefacts and events. This conceptualization also used for the following analysis.

5.3.1 Roles

As is common in software development, most case companies also utilize cross-functional teams to form an Agile team (see exact team sizes in Section 4). Products with higher complexity (such as commercial airplanes or agricultural vehicles) tend to include systems engineers, domain experts (structural, mechanical, electrical, etc.) and test engineers. Low complexity products focus more on domain experts, as systems engineering becomes of less importance and testing can be done by the domain experts. Additionally, the engineering manager of an aerospace & defence company emphasized the importance of up-skilling employees into a T-shape: "*If you could train them up as a T-shaped engineer, you could have a designer who could do stress analysis or do some qualification*." Therefore, the engineer is specialized in his/her domain (depth) but can also support other functions (breadth).

Another important finding was the difficulty of achieving a high team dedication. This varied notably between different case companies but was usually below 70% for each project. Two mentionable exceptions with full dedication were the medical ventilator NPD due to its urgency and the jewellery manufacturer due to its fast development time of two weeks. Some companies solve that issue by having one team work on multiple projects simultaneously. Another proposed solution is to have working agreements with functional departments to ensure high commitment. However, this wouldn't solve the issue that the need for some domains (e.g. manufacturing, procurement) fluctuates significantly throughout the different phases of an NPD project. Multiple companies for this reason apply a shared-services approach adapted from SAFe, which can be seen in Figure 16. In this approach, there is a core team of 3-4 members that are fully dedicated throughout the whole project. The advisors/shared-services are members that flexibly join and leave specific phases of the project with high dedication.

Another aspect of Agile roles is the SCRUM Master or process facilitator. Unsurprisingly, companies using frameworks always have a dedicated and trained SM, but there were mixed findings in the other companies. Generally, it was found that larger companies tend to have a dedicated SM whereas smaller companies usually use the PO/PM as SM. Looking at the importance of having a SM, there were many opposing opinions specific to the interviewees background and job title. Hence, no pattern was found there.

Lastly, the role of the customer is an essential part of Agile. Here, the nature of the case companies must be split into contract-work (NPD for one specific client) and commercial work (NPD for a market).

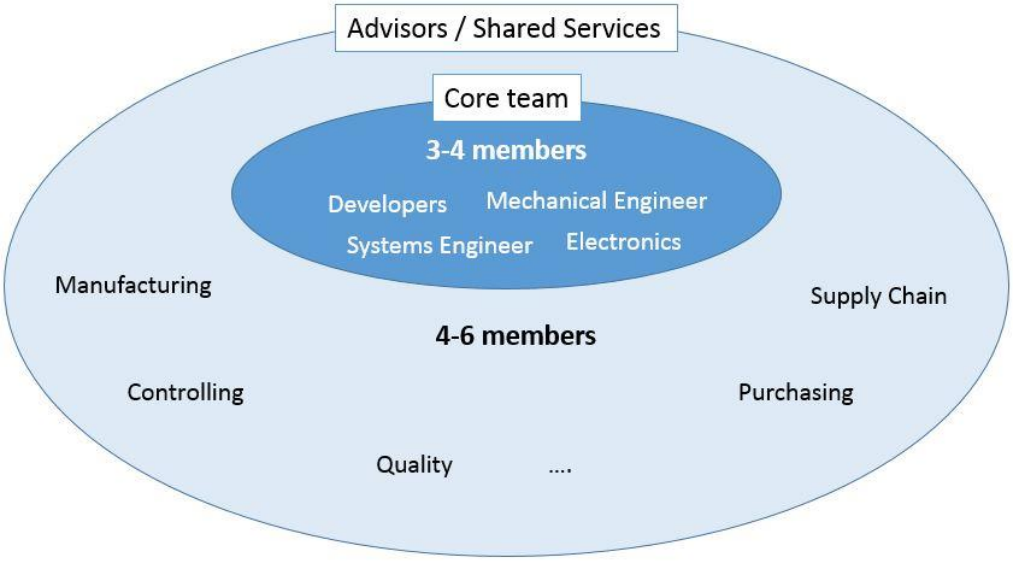

Figure 16: *Agile team set-up*

Regarding contract-work, the companies involve the customer directly and sometimes co-develop. If the customer isn't willing to integrate into the Agile process, then senior leadership takes over the role of the customer.

Regarding commercial-work there are different implementations, each with their own reasoning:

- Marketing
    - Assess progress of product based on market research
    - Plan marketing activities
- Customer service
    - Enable new business models
    - Design-for-serviceability
- Product/Program management
    - Understand product progress
    - Align with other projects/program
- Senior management
    - Understand product progress
    - Increase acceptance of Agile in leadership

5.3.2 Artefacts

Backlogs in varying forms are utilized by all examined companies. JIRA, an Agile PM software tool to organise the PB and SB, is currently only used by five companies. Other companies use MS Office tools or the collaboration software Smartsheet.

Another aspect is the definition-of-done (DoD) for an increment. Here, the constraints of hardware become evident, as all case companies struggle to have a usable and tested increment after every Sprint. This is in line with academic literature and previous case studies. Based on this study, the DoD can have multiple forms:

- Accomplished tasks
- Digital mock-up (rendering)
- Physical prototype
- Data pack
- Product maturity level
- Supporting documents

One finding from cross-analysing the differences showed that the interpretation of Agile is important: the automotive manufacturer, for example, focuses on Agile as task management and therefore interprets the DoD as accomplished tasks. Also, all case companies agreed that the DoD changes throughout the project and should be specified at the beginning of each Sprint, which is in line with the findings from Cooper and Sommer (2018).

As seen in the data collection, a group of companies suggested distinguishing between Sprint deliverables and product increments as seen in Figure 17. This is similar to the model introduced by Eklund and Berger (2017) as well as SAFe. In these cases, the DoD of the PI is a testable and usable product increment and the sprint deliverables are pulled from the requirements of the PI. One automotive supplier proposed planning the testing into the PI, for example having the last Sprint before a PI solely dedicated to testing.

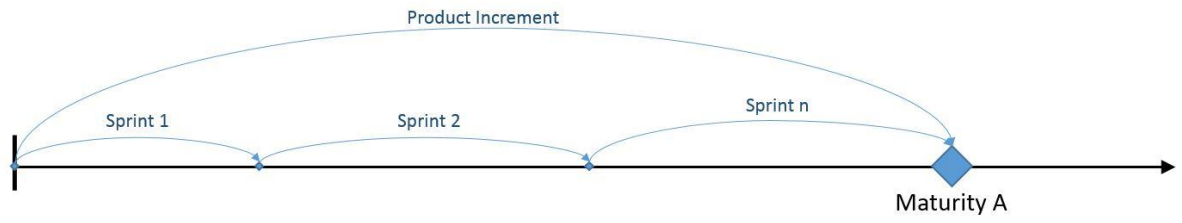

Figure 17: *Difference between sprints and product increments*

5.3.3 Events

Agile events are used in the vast majority of case companies, as seen in Figure 18. This indicates that companies put an emphasis on events as a tool for implementing Agile. This supports findings from earlier case studies as discussed in Section 2.9.

Figure 18: *Events used by the case companies*

5.4 Research Question 4: Governance model

Governance is defined by Bekker and Steyn (2006) as a set of management systems, protocols, relationships, rules and structures that serve as the framework within which decisions are made to accomplish the business or strategic motivations. Regarding product development, governance systems include several governance assets (Weill & Ross, 2004):

- Physical facilities
- Financial structures
- Information systems
- Reward system
- Roles and responsibilities

As noted by Sommer, Dukovska-Popovska and Steger-Jensen (2014) only roles and responsibilities are well described by existing frameworks. This study therefore focused on this factor of governance to understand how Agile roles and responsibilities need to be amended to fit the constraints in not-purely-software environments.

Sequential NPD project generally have a steering committee (e.g. program management), a project manager and the project team (Müller, 2009). The steering committee has the

responsibility for strategic decisions (WHY, WHAT) and the project manager has responsibility of tactical (WHAT) and operational decisions (HOW). The project team executes assigned tasks with no decision-making authority. The customer is in contact with the steering committee.

However, this system must necessarily change under the team collaboration interpretation of Agile, which was followed by every case company. Particularly regarding self-organization there is a conflict between maximizing team autonomy and alignment with the rest of the company. The manufacturer of agricultural vehicles, for example, works with a system of self-management but not self-direction. Another example is the automotive supplier of inverters that stresses the importance of a clearly defined safe space for the Agile team to operate in. Based on the findings from the case studies, a novel governance model is proposed as shown in Figure 19.

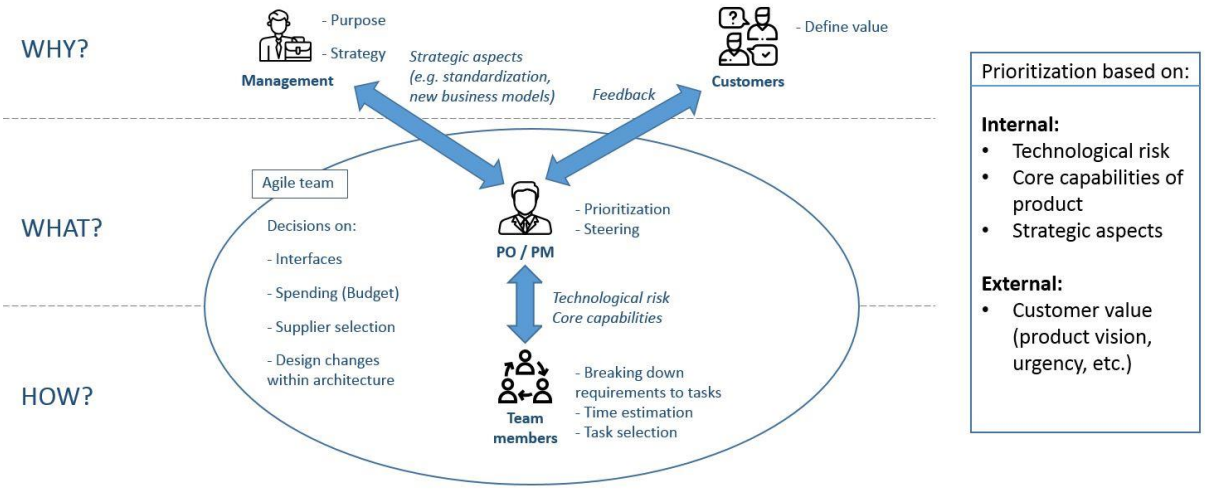

Figure 19: *Proposed governance model for Agile teams*

Compared to traditional roles and responsibilities, there are several changes:

- **Agile team:** The Agile team has a clearly defined decision autonomy. This should vary from product to product, as dependencies and company-specific constraints can make a generalisable approach difficult. The team should either way have clearly defined interfaces and autonomy in design changes within specified boundaries. Additionally, the team could receive a spending budget and the freedom to choose suppliers themselves to allow for quick procurement without lengthy approval processes.

- **Role of PO/PM:** The PO/PM serves as the interface between the Agile team and the management and customers. He/She is responsible for steering the project and prioritizing tasks. Rather than just representing the voice-of-customer as prescribed in Agile in IT, he/she combines the voices of the customers (value), management (strategic considerations, alignment with other projects, standardization) and the team (technological risk, team capabilities). Hence, the PO/PM doesn't receive orders from the management to be broken down into work packages but sees the management as a voice to consider when steering the project.
- **Role of the customer:** The customer doesn't communicate with the management which then delegates to the PM, but the customer is in direct contact with the PO/PM.
- **Team empowerment:** The team has the responsibility of breaking down the prioritized requirements into tasks, estimating the time for each task and finally allocating the tasks to the team members.

The focus group validated the applicability and practicality of the model but said there is still some way to go to achieve a similar governance model. Embedding this model with existing governance models and corporate governance occurred to be the greatest inhibitor.

5.5 Research Question 5: Measurable benefits of Agile

Every case company reported benefits of using Agile, even though there were notable differences in the prevalence of these. A summary of the reported advantages based on the categories "soft factors" and "hard factors" from Atzberger et al. (2019) can be found in Figure 20. One thing that became evident from the analysis is the predominant occurrence of soft benefits compared to hard benefits. While "More communication" and "Increased employee satisfaction and empowerment" was mentioned by 14 and 15 companies respectively, hard benefits such as "Less documentation" was only mentioned by 2 companies. This is in line with current academic literature (Atzberger, et al., 2019; Ahmed-Kristensen & Faria, 2018) but deviates from suggested advantages seen in the software industry in terms of faster time-to-market and productivity (Benefield, 2011). However, as shown in a large study by PMI in 2013 effective communication to all stakeholders was found to be the most important success factor in project management. Based on this observation using Agile occurs to have a positive impact on NPD.

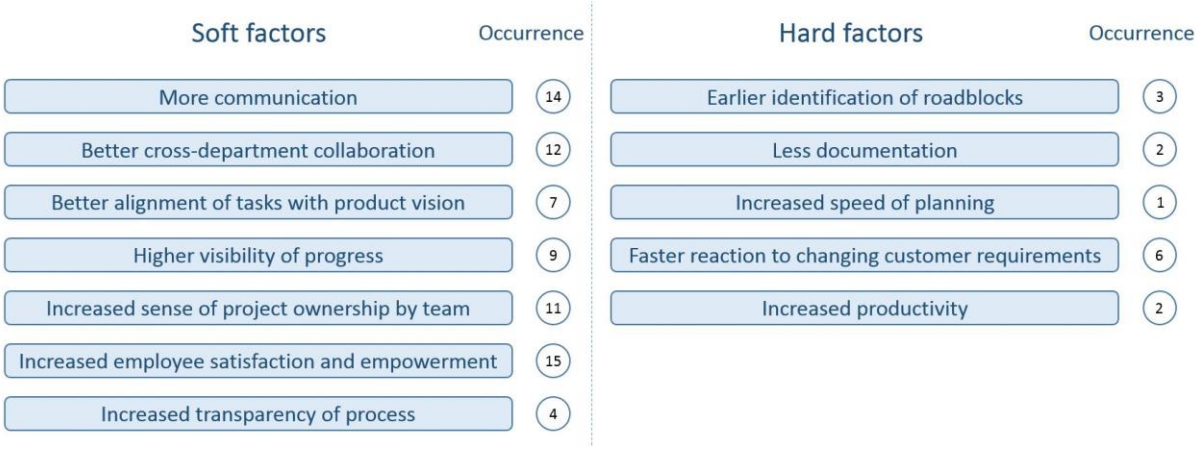

Figure 20: *Advantages of using Agile*

The findings raise the question how some companies could achieve hard benefits while others couldn't. A cross-case analysis shows the following pattern of companies realizing hard benefits:

1. Large companies that have been using Agile in NPD for longer than the other case companies
2. Companies using complete frameworks to reap benefits from all four interpretations

Particularly the companies that have just introduced Agile elements this year experienced mainly soft benefits, indicating that these are quick wins when introducing Agile. Another explanation was provided by an aerospace & defence company mentioning that they haven't experienced any hard benefits simply because it is still too early to measure them.

The mentioned benefits are rarely structurally measured through key performance indicators (KPIs). As mentioned in Section 5.1, it is important to note that deciding on how to measure the effectiveness of Agile depends on the interpretation. Hence, examples of KPIs for each interpretation can be seen in Table 9. However, determining appropriate KPIs and collecting the necessary data seemed to be an issue faced by almost all the case companies. There occurs to be a gap between the proposed benefits of Agile and the measurable, actual benefits experienced by the case companies.

Table 9: *Example of KPIs measured for each interpretation of Agile*

Interpretation of Agile	Benefit measured by	Example companies
Team collaboration	Internal survey on happiness, stress, etc.	Engineering services, Pet food
Customer integration	External customer survey, e.g. Net Promoter Score	Automotive supplier 3
Task management	Velocity	Automation systems 1, Automotive supplier 1
Early prototyping	Acceptance rate at testing	Jewellery

6 Conclusions and Future Research

This Section highlights the key findings and assesses the contribution to knowledge from both a theoretical and practical perspective. Then, limitations of the study are explained and recommendations for potential future research are provided. The research question was:

When and how do manufacturing companies use Agile development practices in not-purely-software new product development?

6.1 Summary

Based on a structured literature review and the resulting research gaps, the research question and five sub-questions were derived. An appropriate research method using case studies and a focus group was selected and adjusted to collect relevant data. In total, 17 case companies from different industries were analysed to provide the required breadth. The findings were then discussed with a small focus group to provide depth.

RQ1: What are the core characteristics of Agile in NPS NPD?

To answer this question a conceptual framework was developed to cluster common themes obtained from the case studies. Overall, there were four mutually-inclusive interpretations:

- Agile as a method for team collaboration
- Agile as a method to integrate the customer into the NPD process

- Agile as a method to manage tasks
- Agile as a method to learn through early prototyping

It is important that companies understand which interpretations they follow as it affects the questions when to use Agile, which elements of Agile to focus on and which KPIs to measure.

RQ2: When do manufacturing companies choose Agile or hybrid NPD methods?

There were two opposing opinions: the majority of companies suggested using Agile only for specific NPD projects. These must fulfil certain conditions which can be categorized as market, product/technology and process conditions. On the other hand, some companies proposed to always use Agile and simply select and adjust tools as required. This second group of companies tended to be smaller, contract-work companies and also changed their interpretation of Agile throughout an NPD project.

RQ3: How is Agile adapted to the context of manufacturing companies?

Due to the constraints in physical environments, companies need to customize the use of Agile to their context. There are three approaches: Adapting the 'ideal' SCRUM process to fit the NPS NPD constraints, adapting the existing sequential process with Agile elements or using an Agile framework. Regarding the details of the process, the analysis was split up into roles, artefacts and events:

- *Roles*: Cross-functional teams were used by almost all companies. There are issues with achieving high team dedication, which companies solve using working agreements, having one team work on multiple projects or a shared-service approach. A dedicated SM was uncommon and often combined with the role of the PO/PM. The customer role was taken by a variety of departments, including marketing, product management or customer service.
- *Artefacts*: Backlogs were used by all case companies, but there were differences in the DoD depending on the interpretation of Agile.
- *Events*: Agile events were common in all case companies.

RQ4: How could an adapted governance model for Agile in NPS NPD look like?

Introducing Agile necessarily has to be accompanied by a change in governance to allow for more team autonomy. A first governance model based on roles and responsibilities was derived based on the analysis of the case companies. The WHAT needs to shift down from the

Management to the PO/PM, and the HOW needs to shift down to the team which selects and estimates its own tasks. The PO/PM functions as the interface of the Agile team to receive inputs from management, customers and the team to steer and prioritize the project rather than just receiving orders from the management. The Agile team needs a clearly defined safe space based on spending (budget), design changes, purchasing autonomy, etc.

RQ5: What are the actual, measurable benefits seen in industry?

The case companies mainly experienced soft benefits such as increased communication, whereas hard benefits such as increased productivity remained the exception. Additionally, the vast majority of examined companies struggled to identify suitable KPIs and collect required data. Some examples include NPS, velocity (taken from Scrum) and acceptance rate at testing.

6.2 Contribution

The research contributes to bridging the gap between academic literature and industry practice both from a theoretical and a practical perspective. An addendum is provided to participating companies to share identified best-practices.

Theoretical contributions are

- This research provides a structured and comprehensive conceptualization of Agile in NPS NPD based on cross-industry patterns.
- The theoretically proposed ‘Agile Indicators’ were mostly validated in this study, with two additional indicators identified.
- A novel governance model was proposed to allow Agile practices to be effective in manufacturing companies.
- The study builds academic knowledge on the current state of Agile in NPS NPD.

Practical contributions are:

- The conceptualization helps company navigate the broad topic of Agile and focus their efforts.
- A better understanding of how companies from multiple industries use Agile in their NPD process both from the literature review and the case studies.
- The governance model gives companies a basic model which can be adjusted to each company’s context

6.3 Limitations & Future Work

This paper has limitations relating to both the chosen research method as well as the context of the study.

First, given the current pandemic, many companies didn't have the resources to participate in the study and only the ones that could afford it participated. This also resulted in difficulties receiving access to potential interviewee partners, and a heterogenous group was interviewed. Therefore, the case studies sometimes only included one perspective, whereas for others there are multiple people from different backgrounds. This bias was minimized through actively accounting for this context in the interpretation.

Additionally, there could be a bias from the researcher in the formulation of the interview guidelines and during the interviews or the workshop. This was accounted for by validating the interview questions with academics from other universities researching the same topic and continuously validating findings. Given that the interviews had to be conducted over video, there is also a limitation in what the interviewee is willing to share. This could be sensible company information or challenges faced. This bias was diminished by anonymizing interviewees and case companies.

Another source of bias could result from the poll questions in the workshop. To avoid these biases, the questions were validated with the author's supervisor and included an uneven number of answers.

Additionally, another limitation is that the case companies were mostly still in an early stage of using Agile. Therefore, many findings are preliminary, and interpretations might change in the future. Especially results for RQ2 and RQ5 should be considered preliminary and need to be observed in the future to track any developments.

Lastly, while the analysis has revealed some cross-industry patterns which means the interpretation is generalisable, there could still be industry- or company-specific constraints that mean the conceptualization or the governance model does not apply. While the theory has been validated by the focus group, further testing is needed to assess the generalizability of the interpretations.

The analysis and discussion raised some questions, which should be answered in future research:

- Extending the derived conceptualization to include which Agile tools are suitable for which interpretation
- Extending the governance model to incorporate more factors than roles and responsibilities, such as physical assets
- Understanding the applicability of Lean tools and methods to support Agile in NPS NPD
- Analysing the best method to embed software and hardware teams in NPD of mechatronic systems
- Conduct in-depth analysis of Agile implementations focused on one industry or product group

7 References

Abrahamsson, P., Warsta, J., Siponen, M. T., & Ronkainen, J. (2003). New Directions on Agile Methods: A Comparative Analysis. *IEEE 25th International Conference on Software Engineering*, 244-254.

Ahmed-Kristensen, S., & Daalhuizen, J. (2015). Pioneering the combined use of agile and stage-gate models in new product development - cases from the manufacturing industry. *Innovation & Product Development Management.* Copenhagen, Denmark.

Ahmed-Kristensen, S., & Faria, L. (2018). *Hybrid Agile-Planned product development processes: Preparing the manufacturing sector for industry 4.0.* Copenhagen: Industriens Fond.

Alqudah, M., & Razali, R. (2016). A Review of Scaling Agile Methods in Large Software Development. *International Journal on Advanced Science, Engineering and Information Technology*, 828-837.

Atzberger, A., Gerling, C., Schrof, J., Schmidt, T. S., Weiss, S., & Paetzold, K. (2019). Evolution of the Hype around Agile Hardware Development. *IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*.

Atzberger, A., Wallisch, A., Nicklas, S., & Paetzold, K. (2020). Antagonizing Ambiguity – Towards a Taxonomy for Agile Development. *30th CIRP Design 2020 (CIRP Design 2020)*.

Barton, B. (2009). All-Out Organizational Scrum as an Innovation Value Chain. *42nd HawaiiInternational Conference on System Sciences.* Waikoloa.

Beck, K., Beedle, M., Van Bennekum, A., Cockburn, A., Cunningham, W., Fowler, M., . . . Kern, J. (2013). Manifesto for agile software development.

Bekker, M., & Steyn, H. (2006). Project governance for global projects. *IEEE Technology Management for the Global Future*, 2195-2202.

Benefield, G. (2011). Rolling out Agile at a large Enterprise. In J. Sutherland, & K. Schwaber, *The Scrum Papers: Nut, Bolts, and Origins of an Agile Framework* (pp. 35-45).

Boehm. (1976). Software Engineering. *IEEE Transactions on Computers*, 1226-1241.

Boehm, B. W. (1986). A spiral model of software development and enhancement. *ACM SIGSOFT Software Engineering Notes*, 22-42.

Böhmer, A. I., Hugger, P., & Lindemann, U. (2017). Scrum within Hardware Development - Insights of the application of Scrum for the development of a passive exoskeleton. *2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, (pp. 790-798). Madeira, Portugal.

Browning, T. R., & Ramasesh, R. V. (2007). A survey of activity network-based process models for managing product development projects. *Production and Operations Management*, 217-240.

CollabNet VersionOne. (2019). *13th State of Agile Report.*

Conboy, K. (2009). Agility From First Principles: Reconstructing the Concept of Agility in Information Systems Development. *Information Systems Research*, 329-354.

Conboy, K., Coyle, S., Wang, X., & Pikkarainen, M. (2011). People over process: Key challenge in agile development. *IEEE Software*.

Conforto, E. C., & Amaral, D. C. (2010). Evaluating an agile method for planning and controlling innovative projects. *Project Management Journal*, 73-80.

Cooper, R. G. (1990). Stage-Gate Systems: A New Tool for Managing New Products. *Business Horizon*, 44-54.

Cooper, R. G. (2011). *Winning at new products: Creating value through innovation.* Basic Books.

Cooper, R. G. (2016). Agile-Stage-Gate Hybrids. The Next Stage for Product Development. *Research-Technology Management*, 21-29.

Cooper, R. G. (2017). Idea-to-Launch Gating Systems. Better, Faster and More Agile. *Research-Technology Management*, 48-52.

Cooper, R. G., & 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*, 17-26.

Cooper, R., & Sommer, A. F. (2016). The Agile-Stage-Gate Model: A Promising New Approach and a New Research Opportunity. *Journal of Product Innovation Management*, 1-14.

Corbin, J., & Strauss, A. L. (2008). *Basics of qualitative research.* Thousand Oaks, CA: Sage.

Dackhammar, N., & Ek, J. (2017). Combining Agile methods and a Stage-Gate model within the product development process - A multiple case study. *University of Gothenburg Thesis*.

Dall'Agnol, M., Janes, A., Succi, G., & Zaninotto, E. (2003). Lean Management - A Metaphor for Extreme Programming? *Proceedings of the 4th International Conference XP2003*, 26-32.

Denzin, N. K., & Lincoln, Y. S. (2011). *The Sage handbook of qualitative research.* Sage.

Dolman, R., & Spearman, S. (2018). *AgileScaling.org.* Retrieved from Agile Scaling Knowlegde Matrix: http://www.agilescaling.org/home.html

Easterby-Smith, M., Thorpe, R., & Jackson, P. R. (2015). *Management and business research.* Sage.

Edwards, K., Cooper, R. G., Vedsmand, T., & Nardelli, G. (2019). Evaluating the Agile-Stage-Gate Hybrid Model: Experiences From Three SME Manufacturing Firms. *International Journal of Innovation and Technology Management*.

Eklund, U., & Berger, C. (2011). Scaling Agile Development in Mechatronic Organizations - A Comparative Case Study. *IEEE 39th International Conference on Software Engineering: Software Engineering in Practice Track*, 173-182.

Eklund, U., & Berger, C. (2017). Scaling Agile Development in Mechatronic Organizations - A Comparative Case Study. *IEEE/ACM 39th International Conference on Software Engineering: Software Engineering in Practice Track (ICSE-SEIP)*.

El-Said, S. M., Hana, M., & Eldin, A. S. (2009). Agile Tailoring Tool (ATT): A Project Specific Agile Method. *IEEE International Advance Computing Conference*, 1659-1663.

Eppinger, S. (2019, 06 20). *10 agile ideas worth sharing*. Retrieved 05 18, 2020, from MIT Sloan Management School: https://mitsloan.mit.edu/ideas-made-to-matter/10-agile-ideas-worth-sharing

Eversheim, W., & Schuh, G. (2005). *Integrierte Produkt- und Prozessgestaltung.* Berlin: Springer.

Garzaniti, N., Briatore, S., Fortin, C., & Golkar, A. (2019). Effectiveness of the Scrum Methodology for Agile Development of Space Hardware. *IEEE Aerospace Conference*, 1-8.

Gaubinger, K., Rabl, M., Swan, K. S., & Werani, T. (2015). *Innovation and Product Management - A Holistic and Practical Approach to Uncertainty Reduction.* Heidelberg: Springer Verlag.

Goevert, K., Gökdemir, A., Peitz, C., & Lindemann, U. (2017). Challenges of agile development implementation in mechatronic development processes. *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 701-705.

Grönlund, J., Sjödin, D. R., & Frishammar, J. (2010). Open innovation and the stage-gate process: A revised model for new product development. *California management review* , 106-131.

Hruschka, P., Rupp, C., & Starke, G. (2009). *Agility kompakt. Tipps für erfolgreiche Systementwicklung.* Heidelberg: Spektrum Akademischer Verlag.

Kalenda, M., Hyna, P., & Rossi, B. (2018). Scaling agile in large organizations: Practices, challenges, and success factors. *Journal of Software: Evolution and Process*.

Karlström, D., & Runeson, P. (2006). Integrating agile software development into stage-gate managed product development. *Empirical Software Engineering*, 203-225.

Komus, A., & Kuberg, M. (2017). Studie Status Quo Agile 2016/2017. *GPM - Deutsche Gesellschaft für Projektmanagement*.

Könnölä, K., Suomi, S., Mäkilä, T., Jokela, T., Rantala, V., & Lehtonen, T. (2016). Agile methods in embedded system development: Multiple-case study of three industrial cases. *The Journal of Systems and Software*, 134-150.

Krug, M., Ays, J., Sauermann, F., Prote, J.-P., & Schuh, G. (2019). Synchronization of Scrum and Stage-Gate in Hybrid Product Development Projects of Manufacturing Companies. In J. Wulfsberg, W. Hintze, & B.-A. Berhens, *Production at the leading edge of technology* (pp. 421-430). Berlin, Heidelberg: Springer Vieweg.

Lemieux, A.-A., Lamouri, S., Pellerin, R., & Tamayo, S. (2015). Development of a leagile transformation methodology for product development. *Business Process Management Journal*, 791-819.

Liamputtong, P. (2011). *Focus Group Methodology: Principles and Practice.* Sage.

Liker, J. K. (2004). The 14 Principles of the Toyota Way: An Executive Summary of the Culture Behind TPS. In J. K. Liker, *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer* (pp. 35-41). New York: McGraw-Hill.

Liker, J. K., & Morgan, J. M. (2006). The Toyota way in services: the case of lean product development. *Academy of management perspectives*, 5-20.

Lindlöf, L., & Furuhjelm, J. (2018). AGILE BEYOND SOFTWARE - A STUDY OF A LARGE SCALE INITIATIVE. *INTERNATIONAL DESIGN CONFERENCE - DESIGN* , 2055-2062.

Mathur, S., & Malik, S. (2010). Advancements in the V-Model. *International Journal of Computer Applications*.

Müller, R. (2009). *Project Governance.* Surrey, England: Gower Publishing.

Ovesen, N. (2012). *The challenges of becoming agile: Implementing and conducting SCRUM in integrated product development.* Department of Architecture and Design, Aalborg University.

Petersen, K. (2011). Is Lean Agile and Agile Lean?: A Comparison between Two Software Development Paradigms. In K. Petersen, *Modern software engineering concepts and practices: Advanced approaches* (pp. 19-46). IGI Global.

PMI. (2013). *The Pulse of the Profession: The High Cost of Low Performance.*

Poppendiek, M., & Poppendiek, T. (2003). *Lean Software Development: An Agile Toolkit* . Addison-Wesley Professional.

Ries, E. (2011). *The lean startup: How today's entrepreneurs use continuous innovation to create radically successful businesses.* Crown Books.

Rigby, D., Sutherland, J., & Takeuchi, H. (2016). Embracing Agile. *Harvard Business Review*, 40-48.

Rother, M. (2009). *Toyota Kata: Managing People for Improvement, Adaptiveness and Superior Results.* McGraw-Hill Education.

Royce, W. W. (1970). Managing the Development of Large Software Systems. *Technical Papers of Western Electronic Show and Convention (WesCon).*

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students.* Pearson Education.

Schmidt, T. S., Weiss, S., & Paetzold, K. (2018). *Agile Development of Physical Products: An empirical study about motivations, potentials and applicability.* Munich: University of the German Federal Armed Forces.

Schrof, J. I., Atzberger, A., Papoutsis, E., & Paetzold, K. (2019). Potential of Technological Enablement for Agile Automotive Product Development. *IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, (pp. 1-8). Valbonne Sophia-Antipolis, France.

Schuh, G., Dölle, C., Diels, F., & Kuhn, M. (2018). Methodology for determining agile product scopes in development projects. *IEEE Portland International Conference on Management of Engineering and Technology (PICMET)*, 1-9.

Schuh, G., Rebentisch, E., Riesener, M., Diels, F., Dölle, C., & Eich, S. (2017). Agile-waterfall hybrid product development in the manufacturing industry—Introducing guidelines for implementation of parallel use of the two models. *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*.

Schuh, G., Riesener, M., & Diels, F. (2016). Structuring highly iterative product development projects by using HIP-Indicators. *Industrial Engineering and Engineering Management*, 1171-1175.

Schwaber, K., & Sutherland, J. (2017). *The SCRUM guide.*

Schwaber, K., & Sutherland, J. (2020). *Scrum.org*. Retrieved 05 21, 2020, from What is Agile?: https://www.scrum.org/resources/what-is-scrum

Sommer, A. F., Dukovska-Popovska, I., & Steger-Jensen, K. (2014). Agile Product Development Governance – On Governing the Emerging Scrum/Stage-Gate Hybrids. *IFIP International Conference on Advances in Production Management Systems*, 184-191.

Sommer, A. F., Hedegaard, C., Dukovska-Popovska, I., & Steger-Jensen, K. (2015). Improved product development performance through Agile/Stage-Gate hybrids: The next-generation Stage-Gate process? *Research-Technology Management*, 34-45.

Sommerville, J., Craig, N., & Hendry, J. (2010). The role of the project manager: all things to all people? *Structural Survey*.

Stacey, R. D. (1996). *Complexity and creativity in organizations.* Berrett-Koehler Publishers.

Steffen, D., & Jilg, K. (2009). Kundenorientierte Produktentwicklung. *Automobilelektronik*, 56-58.

Sutherland, J. (2011, 10 22). *Takeuchi and Nonaka: The Roots of Scrum*. Retrieved 05 16, 2020, from SCRUMinc.: https://www.scruminc.com/takeuchi-and-nonaka-roots-of-scrum/

Uludag, Ö., Harders, N.-M., & Matthes, F. (2019). Documenting Recurring Concerns and Patterns in Large-Scale Agile Development. *24th European Conference on Pattern Languages of Programs*.

Wang, X., Conboy, K., & Cawley, O. (2010). "Leagile" Software Development: An Experience Report Analysis of the Application of Lean Approaches in Agile Software Development. *The Journal of Systems and Software*.

Weill, P., & Ross, J. (2004). IT governance on one page. *CISR WP*, 349.

Yin, R. K. (2014). *Case Study Research Design and Methods.* Thousand Oaks, CA: Sage.

Zhang, L. (2013). Managing Project Changes: Case Studies on Stage Iteration and Functional Interaction. *International Journal of Project Management*, 958-970.

Author biographies

Linus Gerdes is a postgraduate researcher at the University of Cambridge reading Industrial Systems, Manufacture and Management at the Institute for Manufacturing. He holds a First Class Honours BSc degree in industrial engineering and previously studied in Berlin, Munich and Sydney. Before joining the University of Cambridge, he gained work experience at Siemens Energy in South Korea and Detecon Management Consulting.

Dr Robert Phaal joined the Centre for Technology Management at the University of Cambridge in 1997. As a Principal Research Associate he conducts research in the field of strategic technology management. Areas of interest include the emergence of technology-based industry and the development of practical management tools. Rob has a mechanical engineering background, with a PhD in computational mechanics from Cambridge (1990). He is a Chartered Engineer, with industrial experience in technical consulting, contract research and software development at TWI, a leading UK research and technology organisation.

Dr Valerie Lynch is researching as an industrial visitor on a part time basis at the University f Cambridge, working on the BATP valuation project with CTM until September 2006. In October 2006 she registered for a PhD. She started her career with British Telecom and worked in the UK and overseas on a variety of telecoms related projects before setting up AND Technology Research where she remains CEO. AND Technology Research, specialises in embedded computing technologies and provides R&D services for electronic product development and ambient computing. The success of the company has been recognised with awards for enterprise, technology and innovation.