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Rapid Product Development and R&D

Welcome to the March issue of the Technology Innovation Management Review. We invite your comments on the articles in this issue as well as suggestions for future article topics and issue themes.

Technology Innovation Management Review

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Overview
The Technology Innovation Management Review (TIM Review) provides insights about the issues and emerging trends relevant to launching and growing technology businesses. The TIM Review focuses on the theories, strategies, and tools that help small and large technology companies succeed.

Our readers are looking for practical ideas they can apply within their own organizations. The TIM Review brings together diverse viewpoints — from academics, entrepreneurs, companies of all sizes, the public sector, the community sector, and others — to bridge the gap between theory and practice. In particular, we focus on the topics of technology and global entrepreneurship in small and large companies.

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Editorial: Rapid Product Development and R&D

Iivari Kunttu, Charles Camarda and Antti Perttula

Welcome to the March issue of the *Technology Innovation Management Review*. As guest editors, it is our pleasure to introduce this month's editorial theme covering a variety of topics on agile and rapid approaches in product development. As indicated by this collection of scholars in fields of management studies, R&D is a key source of competitive advantage for high-technology organizations. At the same time, investments in R&D and innovation can be risky and costly, since typically only a minority of industrial R&D projects yield a commercial product or service. For this reason, new agile, rapid, and flexible approaches for R&D are critical to enable shorter product development cycles, allow for unexpected changes, and facilitate parallel development alternatives. Moreover, in today's world with rapidly changing customer and consumer expectations, networked interaction with external stakeholders such as customers, suppliers, and research institutes is essential for R&D organizations.

This special issue contributes to the theme of rapid development of products and services with both practical and scientific importance. The issue consists nine papers all having their own viewpoint on this general theme. The rapid product development theme brings together product and service ideas and methodologies. Both technology and business development viewpoints are covered in the papers. In a similar manner, the special issue contains papers focusing on stakeholder interaction, including various forms of customer, user, and university collaboration in rapid R&D. Some of the papers originate from conference papers presented in previous ISPIM events in Ottawa, Canada (*ISPIM Connects*, April 2019), and Florence, Italy (*ISPIM Innovation*, June 2019).

The first set of three papers give a practical introduction to the theme of rapid development of products and services from the viewpoint of development methods and processes. The paper written by **Charles Camarda et al**., *"Rapid Learning and Knowledge-Gap Closure During the Conceptual Design Phase – Rapid R&D"*, focuses on rapid product development strategies. It follows the principles of set-based design as a way to provide improved ways of addressing knowledge gaps in alternate design concepts. The paper describes how this methodology may construct knowledge that can accelerate knowledge capture that is critical for developing solutions to extremely challenging R&D problems. The methods are practically illustrated by case examples from NASA technology development.

The paper by **Tuomas Huikkola** and **Marko Kohtamäki**, *"Agile New Solution Development in Manufacturing Companies"*, proposes a new agile solution development model for technology and manufacturing companies. The proposed model presents a way for manufacturing companies to consider ideas related to new product, service, process, and business model development. This in turn may help companies to strategically renew themselves faster for turbulent product-service markets.

Antti Perttula and **Joni Kukkamäk**i's paper, *"Enabling Rapid Product Development through Improved Verification and Validation Processes"* has a particular focus on verification and validation (V&V) processes in rapid product development that applies the principles of agile development. The paper shows how product development cycles can be made faster and more flexible by implementing the V&V in each phase of agile product development. This is placed in contrast with the traditional approach in which V&V takes place only at the end of the product development process.

The next four papers concentrate on collaboration practices in industrial R&D by showing how internal and external relationships may facilitate innovation and R&D processes. The paper authored by **Johan Simonsson** et al., *"Organizing the Development of Digital Product-Service Platforms"*, focuses on the role of digital product-service platforms in manufacturing companies. The paper identifies challenges that these companies may face when they develop digital service platforms as part of a servitization process. The empirical part of the paper presents interesting outcomes from the Swedish industrial manufacturer Husqvarna Group.

The paper by **Jari Jussila et al**., *"Rapid Product Development in University-Industry Collaboration: Case Study of a Smart Design Project"*, contributes to the area of rapid product development by presenting a case study of developing prototypes in university-industry collaboration. It is facilitated by a Design Factory concept. The paper highlights key design principles involving stakeholders such as teachers, business representatives, and students working together in collaborative project design.

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The paper written by **Leena Kunttu** and **Yrjö Neuvo**, *"The Role of academics, Users, and Customers in Industrial Product Development"* also considers university-industry collaboration with special emphasis on the involvement of users and customers in networked collaboration between academia and industry. Based on a case study comprising five long-term university-industry relationships in Finland, the paper demonstrates collaborative practices through which the academic actors, users, and industrial customers may actively take part in industrial innovation and R&D processes.

Janne Kuivalainen et al.'s paper, *"Agile Product Development Practices for Coping with a Learning Paradox in R&D offshore Units"*, focuses on the recent trend of R&D offshoring. The paper presents a case study revealing how agile product development approaches greatly help the managers of globally dispersed R&D offshore units in coping with tensions that involve conflicts related to project performance and innovation.

The paper authored by **Mikko Mäntyneva**, *"Company Offers to Meet the Needs of Business-to-Business Customers: Strategies and Orientation"*, presents a qualitative analysis of customer-driven R&D. The paper investigates whether companies' offers to meet customer needs can be supported by customer strategy and orientation. In this task, the paper provides guidelines on how firms can align their R&D activities to consider the company's existing customers, with both their current and potential needs and requirements.

Finally, **Daniel Viberg** and **Mohammad H. Eslami**'s paper, *"The Effect of Machine Learning on Knowledge-Intensive R&D in the Technology Industry"*, concentrates on the integration of tacit and explicit knowledge in an industrial R&D context. The paper shows how machine learning can be applied to knowledge integration in organizational contexts, and in particular for knowledge-intensive high-technology organizations.

The contributions included in this special issue of the TIM Review provide a covering insight into the actual viewpoints of agile and rapid product development, not only from the perspective of industrial R&D methodologies and concepts, but also from the viewpoint of service development, collaboration networks, stakeholder involvement, strategy work, and learning. For this reason, we hope that the content of this issue will be of the interest to the TIM Review's regular audience, as well as for scholars and practitioners contributing to the area of agile and rapid product development.

Guest Editors
Iivari Kunttu, Charles Camarda, and Antti Perttula

The TIM Review currently has two Calls for Papers on the website. See the Upcoming Themes on the website for further information for prospective authors. For future issues, we invite general submissions of articles on technology entrepreneurship, innovation management, and other topics relevant to launching and scaling technology companies, and solving practical problems in emerging domains. Please contact us with potential article ideas and submissions, or proposals for future special issues.

Managing Editor
Gregory Sandstrom

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Rapid Learning and Knowledge-Gap Closure During the Conceptual Design Phase —Rapid R&D

Charles J. Camarda, Stephen J. Scotti, Iivari Kunttu, Antti Perttula

"You don't learn to walk by following rules. You learn by doing, and by falling over."

Sir Richard Branson
Founder/Virgin Group

New product development strategies, such as set-based concurrent engineering design (SBCED) or set-based design (SBD), have demonstrated improved ways to address knowledge gaps in alternate design concepts prior to the decision to select a single concept for development. Most of the corpus in this field addresses engineering product development that relies on systems and subsystems with years of prior experience in testing, development, and operation. These often have known or existing solutions, and use state-of-the-art (SOA), or near SOA technology. In addition, most papers do not dive into the details of how knowledge was attained to rapidly close critical knowledge gaps. This paper attempts to explain how a research-based method to construct knowledge can accelerate the knowledge capture critical for developing solutions to extremely challenging problems. This rapid R&D methodology enables a rapid acquisition of critical knowledge to understand potential failure modes of concepts in a set-based way. Thus, it enables intelligent decisions for the selection of the final concept as well as the continuous maturation of parallel concepts. The continuous, parallel maturation of multiple concepts enables effective off-ramps in the design process as requirements and new knowledge arise in the course of the development program, without incurring excessive rework, cost growth, and schedule creep. The goal of this paper is to describe a method that accelerates the generation of critical knowledge early in the conceptual design phase, as a way to close knowledge gaps quickly, and thus enable intelligent design decisions and concept selections early in the product development cycle. The methodological descriptions are illustrated with case examples from NASA technology development.

1. Introduction

Research and development (R&D) is a key source of competitive advantage for high-technology organizations (Artz et al., 2010). However, investments in R&D and innovation development can be risky and costly. Research has shown that only one of four R&D projects is successful (Evanschitzky et al., 2012). One essential reason for this is the lack of flexibility in traditional R&D approaches, which are typically based on waterfall development processes. In these sequential processes, the contribution of each functional department (for example, mechanical, electrical, packaging, manufacturing, quality control) is done one after the other. These methods seem to work for the development of products that rely on systems and subsystems having years of prior experience in testing, development, operation and known solutions that use state-of-the-art (SOA) or near SOA technology. Yet these methodologies fail miserably for situations where there is no known solution and/or the problem is complex (Mitchell, 2009; Camarda et. al., 2019).

Set-based concurrent engineering (SBCE) or set-based design (SBD) is a product development strategy (Singer et al., 2009). It transcends traditional point-based solution methods by looking at broad "sets" of functional solutions that are constrained by broad "ranges" of design requirements and specifications in parallel, as the design space is explored and understood. For example, the root cause of excessively dropped keystrokes in a manufacturer's keyboard that passed all automated quality validation tests but failed with human test subjects was found to be the humans' perception of "feel" that the keys had been deflected sufficiently (Cloft et al., 2018). Once the root cause was identified, very simple force-deflection structural models of the keyboard could be used to rapidly evaluate numerous material and structural design alternatives to select a viable, optimum solution. However, complex, transdisciplinary engineering problems, like the cause of premature failure of a Space Shuttle's thermal protection system (TPS) tiles prior to launch, require a tiger team of subject matter experts and lengthy study, in order to identify the root cause, which in this case was a highly coupled transdisciplinary problem (Cooper & Holloway, 1981; Camarda, 2014a; Camarda et. al., 2019). After the root cause was understood and a satisfactory solution of densifying a small bottom layer of the fragile fibrous TPS tile prior to bonding developed, it still required over one year to solve the problem. This delayed the launch of the first Space Shuttle. The R&D knowledge construction methods were adequate to solve this problem, however, are there ways this process can be significantly accelerated?

This paper will discuss in detail the knowledge construction process used by NASA research teams to understand and rapidly solve the on-orbit repair of a damaged Space Shuttle wing leading edge (Camarda, 2007; Camarda, 2014b; Camarda et. al., 2019). It will compare and contrast this new method of R&D knowledge capture with other Space Shuttle case studies, which used more traditional programmatic methods. The rapid R&D approach used is a blend of set-based design and intelligent fast failure (failing and learning smart, fast, small, cheap, early, and often) (Matson, 1996). The key to this methodology's success is the incorporation of a network of teams, or Team-of-Teams approach, using open and effective communication, and a flat organizational structure (McChrystal, 2015).

2. Rapid R&D

2.1 James Starnes' View of Research, Design, and Knowledge Construction

NASA Langley Research Center (LaRC) in Virginia, USA, is a research organization that had a culture where failure was not only tolerated; it was accepted and expected. NASA LaRC historian, James Schultz, described Langley's greatest gift as its "permission to try and try again" ("permission to fail"). He noted that, "Learning by repeated attempts may appear cumbersome, but failures indicated areas where further research was needed to improve the understanding of flight phenomena. At Langley, the mistakes were just as important as the successes, for they sowed the seeds of future accomplishment" (Schultz, 2003).

Dr. James Starnes was a world-renowned structural mechanics expert at LaRC who espoused a view of research and design (Camarda, 2009) illustrated in figure 1, on the left diagram. We begin with a physical observation, then attempt to model that observation as best we know how analytically/mathematically. We evaluate our representation of that observation by a test/experiment. More often than not, we either "fail," or our model of the problem's physics is found to be lacking. It could be our experimental representation of the "real" observation (initial conditions, boundary conditions, physical properties, etc.) or the errors could lie in our simplified, mathematical model (simplifying assumptions, numerical model, etc.). We iterate in these two worlds of experiment and analysis (double-ended arrows), until we understand the discrepancies and can correlate our analytical representation of behavior with what we observe in the laboratory to within some level of accuracy.

Dr. Starnes always stressed the importance of *testing to failure*, and it is a critical part of his philosophy of how research in structures should be done. The true test of our understanding of structural concepts occurs when we are able to anticipate every significant failure mechanism, and can accurately predict when failure will occur. Once we believe we truly understand the physics of a problem, we proceed to step into the world of design.

We can now use our analytical or numerical representation of the problem to rapidly and systematically vary design variables and wander through design space, avoiding constraints (that is, boundaries of regions in the design space where failure will occur), until we arrive at a design that satisfies all constraints (avoids failure) and produces an "optimum" solution to our function. We then go back to the laboratory to determine if we can reliably predict the behavior and failure of our "optimum" design. Once again, we may fail and, in the process, discover or learn that we have exceeded our understanding of the problem by moving beyond the bounds of applicability for our prior assumptions about the design space, or we have encountered an unanticipated "failure mechanism" that needs to be included in our analytical/numerical representation. This process is repeated many times. Each time we fail, we also learn. Thus, we develop a much better understanding of the problem and, more

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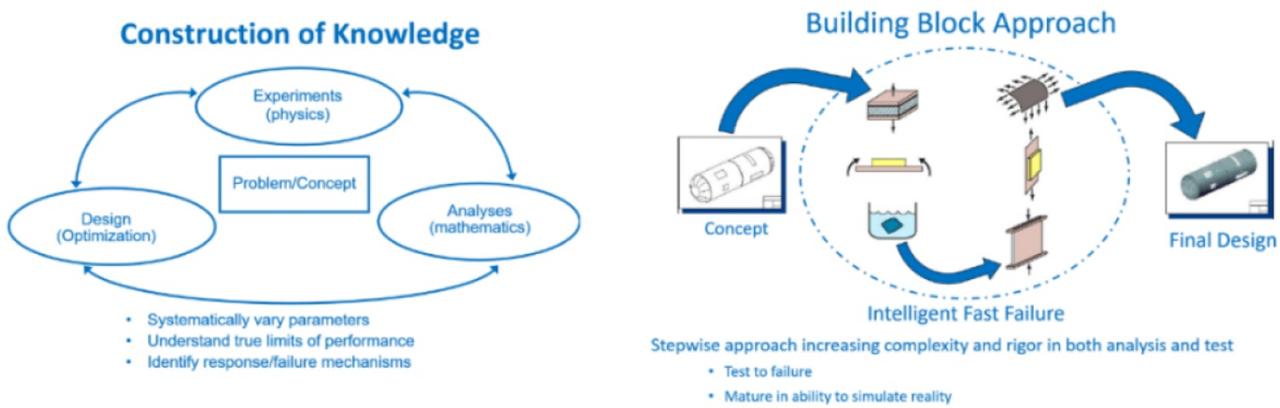

Figure 1. Knowledge construction methods used in Rapid R&D (Camada et. al., 2019).

importantly, an understanding of our limitations in predicting the behavior of an actual, imperfect artifact, given the use of an idealized, and also imperfect, model.

In Dr. Starnes' research philosophy, one cycles through a structural concept at ever-increasing scales, starting with the simplest of material property tests of coupons, and proceeding, in a building-block fashion, to sub-element, component, full-scale section, and finally to a full-scale test article (right-hand illustration in Figure 1). Research engineers use a building-block approach at a very elemental level to understand basic principles which can be observed with very simple experiments. The observations made during these simple experiments are then compared with very simple initial models of the problem, which are modified until they agree, and the analyses and tests can be said to be correlated. This validates that the simple analytical model is sufficient to accurately describe the behaviors witnessed in the experiment. More complex tests of these simple structural elements combined into a larger-scale structure are designed to explore the potentially nonlinear effects of interactions between simpler elements when integrated together. It leads to an improved physical understanding that is more complete, such that eventually a full-scale representation of the real, full-scale problem can be accurately modeled. These tests may include interfaces between multiple components, attachments, and manufacturing details. The closer the test article approaches the real embodiment and operational use of the concept, the more rigorous the analysis must be in order to not only predict behavior/performance, but also to predict failure.

Because the problems we are attempting to solve are complex and can have undetermined results as we integrate at larger and larger scales, the resulting outcomes cannot be predicted from only running small-scale tests. It is therefore terribly important that we follow a stepwise building-block process, even within a single discipline such as structures. When a new and multidisciplinary concept or application is the focus of development, the team of researchers must be adept at working collaboratively, in a converged, transdisciplinary way, in order to understand all the potential interactions of key disciplines that can be highly coupled and lead to premature failure.

An example of such a transdisciplinary team was the Thermal Structures Branch (TSB) at NASA LaRC. It was much more than a conventional integrated product development team (IPDT). Rather, it was a collection of subject-matter-experts with cross-disciplinary skills in multiple key domains related to hypersonic vehicle structures and related systems, and subsystems such as TPS, cryogenic tankage, hot, passive, and cooled structures. We call this type of research team or branch, an integrated systems research branch (see Figure 2). The collection of team members with cross-disciplinary skills (shown by the dashed oval) are connected, in a *"team-of-teams"* (McChrystal, 2015), with an integrated network of key subject-matter-experts (SMEs) in each individual discipline to rapidly assess potential failure mechanisms and anomalies. The success of this network of teams and the open and rapid collective learning and dissemination of knowledge is a function of many factors. Due to the length limitations of this paper, only a few will be highlighted.

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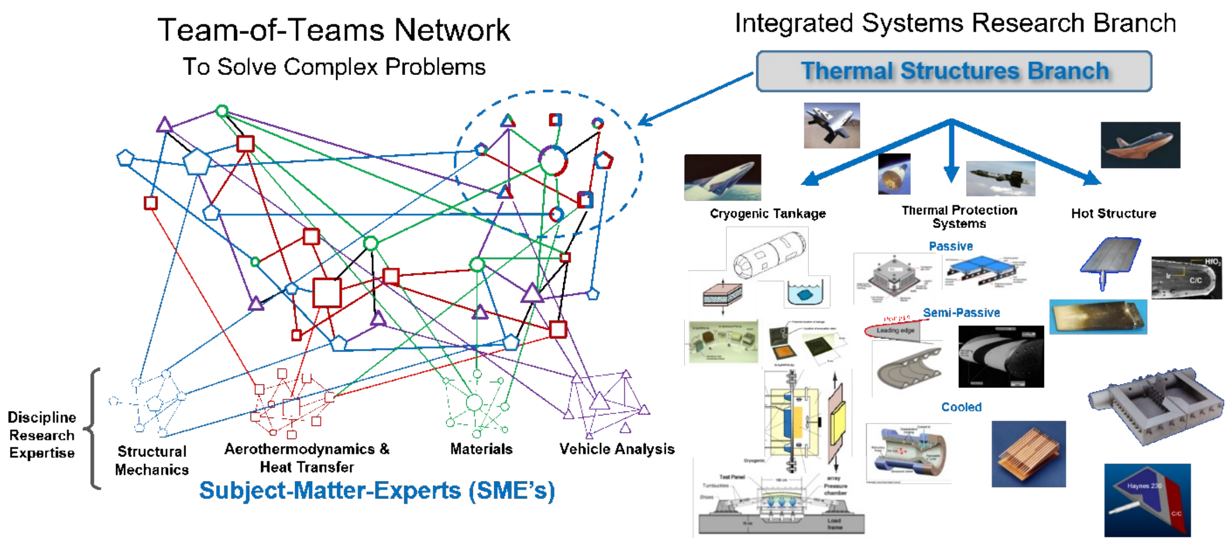

Figure 2. Definition of an integrated systems research branch and a team-of-teams network to solve complex problems.

The seemingly subtle differences in what we are describing as a converged, transdisciplinary team, or integrated systems research branch, will become evident when we compare the methodologies used by such a team with more traditional "groups" assigned to mature complex systems and/or to identify root causes of complex problems.

2.2 NASA Case Study: Space Shuttle Thermal Protection System (TPS) Tile Development Anomaly

The Space Shuttle was an amazing and unique spacecraft that transported crewmembers, supplies, equipment, experiments, and large payloads to and from low Earth orbit (LEO) (Camarda, 2014a). The history of the Space Shuttle Program (SSP) clearly demonstrates the drawbacks of a serial, point-based design approach to designing a complex technical product. Among the technical, scientific, political, and programmatic challenges during its development were ambiguous and everchanging design requirements, multiple stakeholders (NASA, military, industry, civilian, and scientific communities) to satisfy to secure sufficient funding and support, severe budget constraints, and schedule pressures. It was hoped that this very complex, highly sophisticated space vehicle could usher in a new era of safe, low-cost access to space, which would enable effective commercial and private usage in space for everyone.

The engineers, scientists, and program managers that helped develop the thousands of components, sub-systems, and systems for the Space Shuttle, used a reductionist approach to functionally decompose the problem. They then used conventional systems engineering principles to relate the elements and to predict the integrated behavior as if it was a "complicated", deterministic problem as opposed to a "complex" problem (Mitchell, 2009).

Prior to the launch of Space Transportation System-1 (STS-1) on April 12, 1981, after flight profiles and air loads were refined, it became apparent that while the TPS material satisfied loading requirements, the TPS as a "system" had inadequate tensile strength as illustrated at the bottom of Figure 3. This meant that many of the Shuttle tiles would exceed structural limits and fail. At the time, Rockwell had already installed over 24,000 tiles on the vehicle before the root cause of problem was finally discovered, and a solution found. In fact, on the Shuttle ferry flight from Palmdale, California where the Shuttle was built, to its launch site in Florida at Kennedy Space Center (KSC), a large number of tiles fell off. In an actual mission, loss of even one TPS tile in a critical location could cause a burn through of the aluminum structure that would lead to loss of the vehicle during the high heating phase of entry. This Shuttle TPS anomaly was discovered late in the program and is notionally shown in Figure 3 by the steep increase of the "Knowledge Gap" (Kgap) curve. Because the anomaly was unanticipated, it caused delays, redesign and rework (which is called an engineering "loop-back" and illustrated by the blue arc denoted by 1000x) in the Shuttle development effort. NASA created a "Tiger Team" led by Dr. Paul Cooper at LaRC, which included

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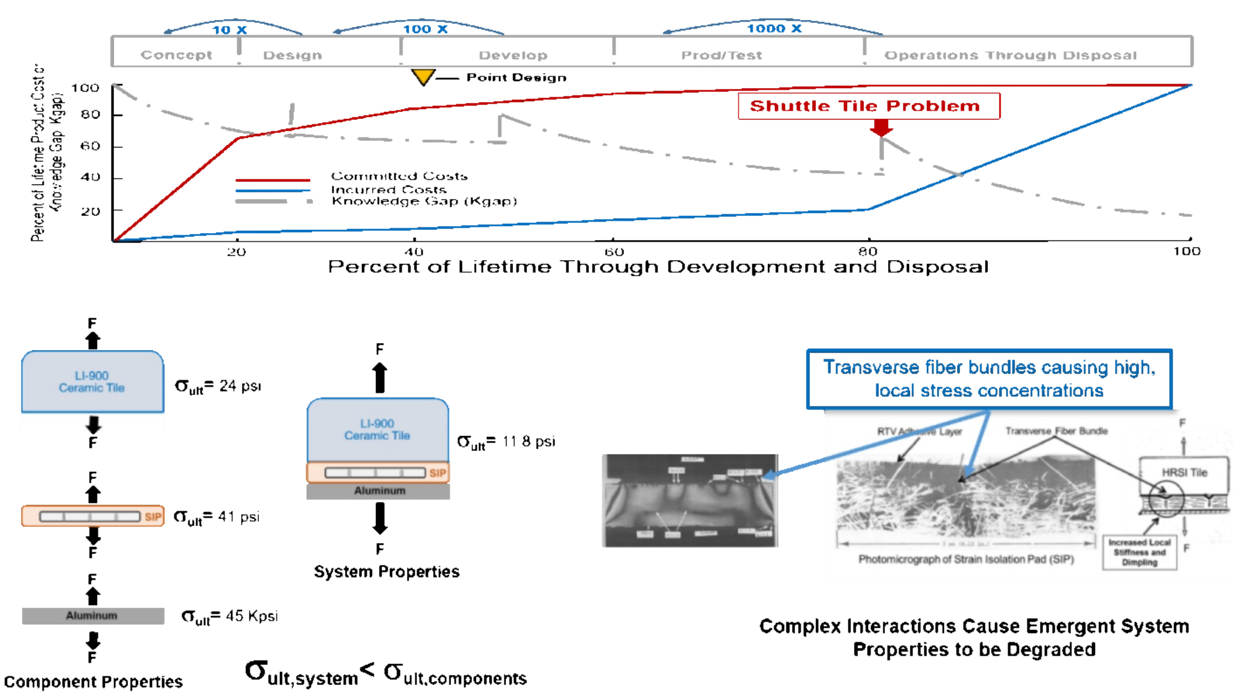

Figure 3. Space Shuttle TPS bonding issue caused by complex systems interaction and subsequent property degradation, identified late in the product development life cycle (just prior to the first launch).

scientists and engineers from multiple NASA Centers, to determine the root cause of this very serious problem and recommend a solution (Cooper & Holloway, 1981). It is very important to emphasize that it required a small team of key SMEs in distinct areas of materials science, structural mechanics, structural dynamics, material and geometric nonlinear behavior, and advanced experimental techniques (in this case photoelasticity), to identify the elevated stress concentrations caused by the transverse fiber bundles of the strain isolator pad (SIP) material (Figure 3), which was the root cause of the reduction in transverse ultimate load of the bonded system. Only then was it possible to conceive a solution (in this case the densification of a thin layer of the tile adjacent to SIP) and conduct the necessary validation and verification testing. The real question, however, should have been: how could teams of professional thermal-structural and materials scientists and engineers not test the complete system of LI-900 ceramic tile, bonded to the strain isolator pad (SIP), and the aluminum structure of the Shuttle? A very simple and inexpensive pull test of the complete system, as part of a building block approach described earlier, would have rapidly and inexpensively identified the complex interactions which caused the emergent system properties to be degraded by over 50%.

The case study above serves to highlight the drawbacks of a point-based design, phased-gated approach to product development with a NASA Space Shuttle design problem. It also highlights the value of an effective analysis/experiment building block approach to fail and learn as effectively as possible. The case study which follows, also taken from NASA experiences, provides some additional examples of experienced NASA research engineers raised in an R&D culture using principles of a SBCE/rapid research and development approach.

2.3 Knowledge Construction for Rapid R&D. Reinforced Carbon-Carbon (RCC) R&D Repair Effort Post Space Shuttle Columbia Disaster

2.3.1 Early Exploration Phase Rapid R&D

After the loss of the Space Shuttle Columbia, one of the Columbia Accident Investigation Board (CAIB) recommendations for future flights was for NASA to develop methods to repair on-orbit damage similar to that which led to tragedy (Gehman, 2003). Damage to the reinforced carbon-carbon (RCC) wing leading edge (WLE) resulting from impact of insulation foam on ascent was believed to be the damage that led to the loss of the vehicle and crew during Earth entry on February 1, 2003 (Gehman, 2003; Camarda, 2014b).

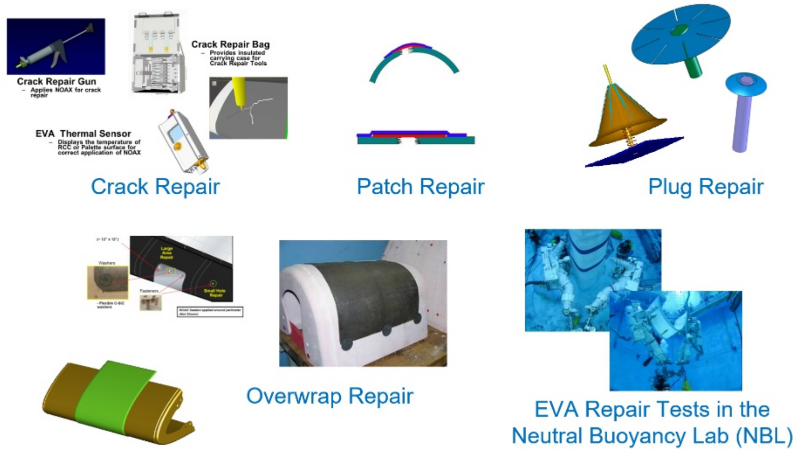

Figure 4. Categories of types of reinforced carbon-carbon (RCC) wing leading edge on-orbit repair concepts.

A Technical Exchange Forum (TEF) was held at NASA Johnson Space Center (JSC) June 3-4, 2003 to investigate ideas for on-orbit repair of the Shuttle WLE. Numerous repair concepts and methods were suggested in multiple categories related to the size and type of damage and the suggested repair method. The SSP was interested in repair ideas that spanned the smallest possible critical damage (for example, small cracks, holes, and/or SiC coating losses) to very large holes typical of the tests reported in (Camarda, 2014b) (approximately 16 in. [41 cm] square). For small damage, a spreadable pre-ceramic polymer was eventually developed that could be applied over a damage site by astronauts during a spacewalk (more correctly called an Extra-Vehicular Activity or EVA). The polymer would adhere to the damaged surface and cure on orbit, and then convert to a high-temperature ceramic barrier that would protect the surface from heating during entry. For larger damage (small to medium size holes or cracks), a "patch" that could be bonded to the outer surface, or a "plug" that would be mechanically attached to the surface of the RCC WLE and conform to the WLE outer moldline were developed (Camarda, 2007). The program also evaluated ideas for repairing larger holes, but discontinued pursuing them as they were deemed impractical. Some of these on-orbit, RCC WLE repair concepts and categories are shown in Figure 4.

In early June 2004 (over one year after the accident), it became obvious that the formal program TPS repair teams were struggling to develop concepts for on-orbit tile or RCC repair that would survive Earth entry. Charles Camarda approached the Orbiter Project Manager with a plan for developing a team to brainstorm new ideas for solving the problem. He also convinced astronaut Don

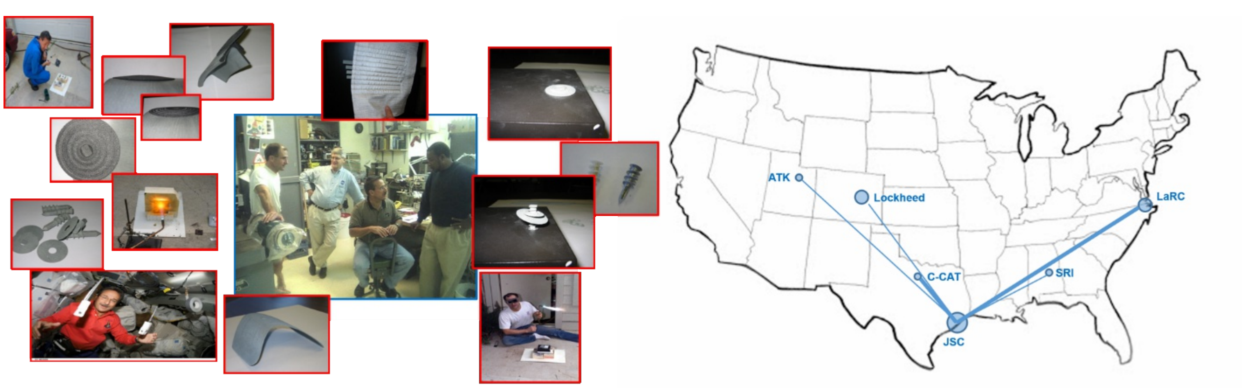

Figure 5. Covert exploratory on-orbit thermal protection system (TPS) design activity.

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Pettit (friend and fellow NASA astronaut classmate) to begin exploring ideas in secret in his garage/laboratory, and to work together in their spare time, while not interfering with their primary duties as Astronauts (see Figure 5).

This duo expanded into a very small team of key SMEs in the areas of high-temperature structures, materials, and TPS from other government, industry, and academic connections. This network helped to provide not only key ideas (for example, Francis Schwind of C-CAT, a carbon-carbon [C-C] material manufacturer, had the idea for drilling and tapping a hole in the C-C, and filling it with a C-C fastener and/or plug). Using this network, the team rapidly obtained materials, built and tested numerous leading edge wing and tile TPS repair concepts. They also explored approaches to drill holes in C-C and a doubly-curved, thin C-C plug, which would conform to numerous curvatures on the leading-edge surface. The size of the circles in the network diagram in figure 5 relate to the number of team members and the thickness of the lines is the relative communication traffic and/or strength of collaboration. This network was called the "Friends of Charlie" (FOC) network because it relied on trusted SMEs with whom Dr. Camarda had many years of experience working with, as well as a detailed understanding of personnel, and both the knowledge and experiences that each person had related to a specific domain (the "know who with the know how", from Larsson, 2005).

The next phase of the rapid R&D effort called for the creation of a larger, more technically rigorous repair concept development team to close critical technical and manufacturing knowledge gaps. A two-and-a-half-day innovative design workshop was held at NASA LaRC in June 2004, with a small group of key researchers, engineers, designers (see Figure 6) from around the USA. The approach used in this workshop later developed into a curriculum that became the foundation for the Innovative Conceptual Engineering Design (ICED) methodology (Camarda et al., 2010). The goal of the meeting was to exchange knowledge —each participant shared essential information from their perspective — and to define a broad design space by brainstorming concepts that could be used in a repair. Because of the varied backgrounds of the attendees, a good "cross-pollination" of ideas occurred.

The workshop was held at a facility experienced at such meetings, and it supplied floor-to-ceiling white boards, A/V equipment, computer capabilities, supplies, IT support, and a facilitator. The meeting first reviewed the current status of the RCC Repair Project, summarized the design requirements (for example, cost, schedule, technical requirements, constraints), presented the technology challenges with respect to several key disciplines (for example, aerothermodynamics, thermal, materials, and structures, etc.), reviewed the status of several key concepts such as crack repair and plug repair, and presented a short review of effective techniques for enhancing innovative thinking, such as

Name	Organization	Area of Expertise
Donna Phillips	NASA LARC	Workshop facilitator
Aaron Matheson	ATK Thiokol	Material testing
Ali Yousefiani	Boeing HB	High temp. materials & processes
Brian Sullivan	MR&D	Materials/structures
Bruce Steinetz	NASA GRC	High temp. seals-TPS and turbine engines
Charlie Camarda	NASA JSC	Thermal structures, heat pipes, Crew
Clark Thompson	Boeing	EVA systems
David Glass	NASA LARC	High temp structures and materials, heat pipes
Don Curry	NASA JSC	Thermal protection systems – RCC material
Don Pettit	NASA JSC	Chemical engineering, Crew, EVA
Francesco Iannetti	Design Ideas, Inc.	Design concepts
James Reeder	NASA LARC	Material mechanics
Jim Nesbitt	NASA GRC	Oxidation, high-temperature coatings
Joel Alexa	Lockheed Martin	Plasma spray
John Koenig	SRI	Materials/testing
Ken Cooper	NASA MSFC	Fabrication non-metallics
Mike Gubert	MSFC/Sverdrup	Thermal protection system
Pete Hogenson	Boeing HB	M&P TPS
Peter Gnoffo	NASA LARC	Aerothermal environment
Steve Hales	NASA LARC	Metals and plasma spray
Steve Scotti	NASA LARC	Thermal structures
Suraj Rawal	Lockheed Martin	C-C/C-SiC materials; TPS passive/active
Tom Horvath	NASA LARC	Aerothermal environment
Wallace Vaughn	NASA LARC	C-C/C-SiC materials

Figure 6. Diverse team of participants for a 3-day R & D On-Orbit Repair Workshop at NASA Langley Research Center (June 4, 2004).

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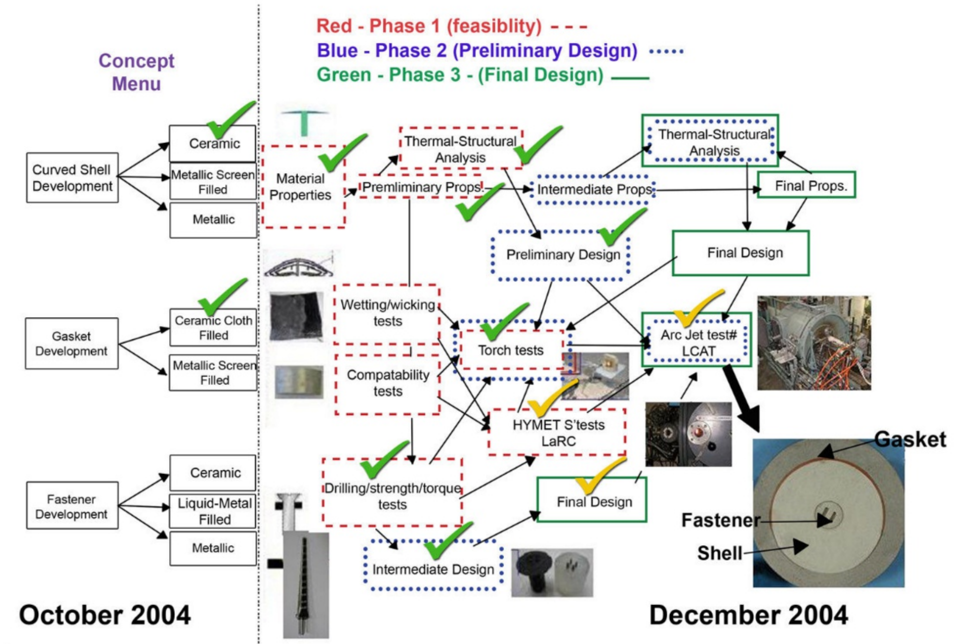

Figure 7. Rapid concept development efforts of one concept for Space Shuttle on-orbit wing leading edge repair.

brainstorming and TRIZ (Altshuller, 2001). Several brainstorming sessions were then held to identify potential repair approaches. To build the comradery needed for effective group dynamics, social activities such as dinners with keynote speakers were also included. As a result, over 70 individual repair concepts were generated in real time, with another 30 added the following week. These concepts were later categorized into classes having specific salient features in common.

Following the innovative design workshop at LaRC, a program team, called the R&D Repair Team, was formed with Dr. Stephen Scotti as its leader. The team then worked virtually and interacted several times a week to identify the critical knowledge gaps for each concept class, and to define and begin to execute the tasks necessary to close the gaps.

Categories of repair concepts resulting from the workshop included metallic and ceramic shells that could deform to fit different surface curvatures, large flexible refractory metal and ceramic sheets that could cover the largest damage areas, soft gaskets and pastes to prevent hot-gas ingress though gaps, and many different types of fasteners and means to drill and tap holes in the leading edge. The critical knowledge gaps for each class were identified, both during the meeting and afterwards, and separate teams that “championed” a given class of repair concepts were formed to close the knowledge gaps. The most critical knowledge gaps dealt with were: 1) how a repair concept could be installed and verified by a space-walking astronaut, 2) whether or not the concept could withstand the temperatures and pressures of reentry, and 3) whether the concept could prevent the hot plasma formed during reentry from entering the interior of the leading edge.

Concept “gates”, defined as simple tests and analyses that establish concept feasibility, were established for each repair concept that provided goals for each team’s efforts. Within each concept class, the set-based design philosophy of eliminating the “weaker” solutions was performed within the team championing the concept. Weaker solutions were determined in several ways. They could have inferior performance as demonstrated by a quantitative metric, such as maximum operating temperature, they could have a larger number of knowledge gaps that could not be easily addressed, or they could have less applicability to the different damage scenarios than other alternatives within the class. However, when a solution was also applicable to teams outside their development team, such as a high temperature fastener that could be used with several repair concepts, it was not eliminated. Each repair class team was allowed to continue their development in

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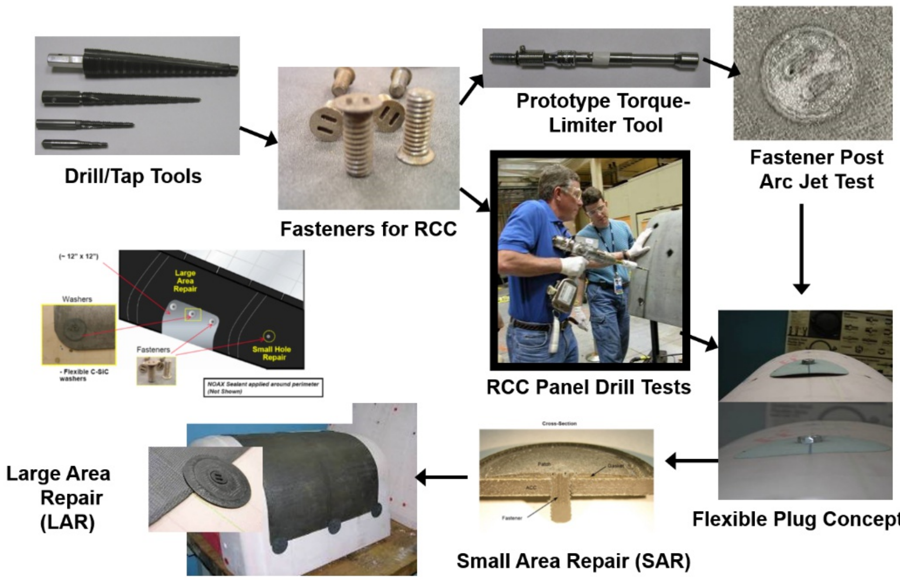

Figure 8. Assorted technologies and concepts developed by the R&DR Space Shuttle Wing Leading Edge Repair Team to repair small to large on-orbit damage to the reinforced carbon-carbon (RCC) wing leading edge.

parallel as long as possible because the teams didn't all proceed at the same pace, and a "show-stopper" in one class could be revealed late in the development.

Following this approach, the network shown in Figure 6 was reconfigured several times during the effort to include additional participants (such as C-CAT mentioned earlier), as well as to "prune" branches that worked on approaches which were found infeasible. Some illustrative examples of team products for one repair concept, and of the many gaps that were closed, are shown in Figure 7. The rapid, set-based design approach utilized allowed the feasibility of this concept to be fully evaluated in only 3 months. Additional technologies and repair concepts that were developed by the team are shown in Figure 8. The development of these innovations followed the methodology described above. The R&D Repair Team closed the capability gap for repairing a large leading edge hole, a capability desired by the Shuttle program but initially believed to be infeasible, and a contingency repair kit flew on the Space Shuttle for the Hubble repair mission (STS-125).

3. Discussion and Conclusions

In this paper, we have presented how set-based methods in product development may significantly improve product development, production, and quality assurance, as well as sophisticated problem solving in challenging environments. This paper relies on case studies from design challenges faced by NASA.

The two case studies from NASA's real-world design activities highlighted several lessons-learned that illustrate the value of a set-based design approach for challenging and complex problems. In particular, they showed the value of starting with a broad design space, understanding the knowledge gaps (Kgaps) that characterize each potential design solution, using a systematic approach to closing the Kgaps (for example, the building block approach), and the pitfalls of selecting a point-design before the Kgaps are closed (for example, Space Shuttle Design). Also, it was shown that for situations where there is no known solution, and/or the problem is complex, the most significant Kgaps require understanding the root cause of failures so that a design can be tailored or modified to close them.

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Dr. Charles Camarda received his undergraduate degree in Aerospace Engineering from the Polytechnic Institute of Brooklyn in 1974. Upon graduation, he began work at NASA's Langley Research Center (LaRC), received his M.S. from GW in Mechanical Engineering in 1980 and a Ph.D. in Aerospace Engineering from VPI in 1990. He was Head of the Thermal Structures Branch at LaRC and led the structures and materials efforts of two programs: The National Aero-Space Plane (NASP) and the Single-Stage-to Orbit Program. He was selected to be an Astronaut in 1996 and flew on the return-to-flight mission of Space Shuttle following the Columbia Accident, STS-114, in 2005. He was selected Director of Engineering at JSC in December 2005 and was the Sr. Advisor for Innovation and Engineering Development at NASA's Langley Research Center. He is currently the Founder and CEO of the Epic Education Foundation, a 501 (c)3 nonprofit seeking to transform education and plug the leaky science, technology, engineering, and math (STEM) pipeline.

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Agile New Solution Development in Manufacturing Companies

Tuomas Huikkola, Marko Kohtamäki

"When GDP is growing by 4% a year, no business is hard. When GDP is growing by 1% a year, no business is easy, so you've got to be percolating new and different ideas."

Jeff Immelt
GE's former CEO

This conceptual paper proposes a new agile solution development model for technology and manufacturing companies. The flexible model consists of five key phases: 1) new idea screening, 2) idea nurturing, 3) conversion of ideas into "good enough" solutions, 4) solution productization, and 5) solution revamping. These phases are iterative by nature and follow partial stage model logic, hence combining elements of both the waterfall and agile methods. For technology and manufacturing companies, the new model presents a new way to consider ideas related to new product, service, process, and business model development. It is framed in contrast with older models that are typically product oriented, which potentially restrict companies in the ability to strategically renew themselves fast enough in turbulent product-service markets.

Introduction

Technology and manufacturing companies nowadays are moving towards services and solutions (Luoto et al., 2017; Rabetino et al., 2018) to escape the commoditization trap (Neu & Brown, 2005; Huikkola et al., 2016). This phenomenon has generally been called business "servitization" (Vandermerwe & Rada, 1988; Baines et al., 2017) and has been studied from many theoretical perspectives (Rabetino et al. 2018; Raddats et al. 2019). The existing servitization literature has identified many reasons for this business transition (Fang et al. 2008; Josephson et al., 2016). For instance, Gebauer and Fleisch (2007) identified three basic reasons why manufacturing companies attempt to servitize: 1) financial reasons (increased profits and more stable revenues), 2) strategic reasons (differentiation benefits), and 3) marketing reasons (image and reputation advantages). The extant servitization literature has quite thoroughly studied organizational-level antecedents and factors that facilitate servitization (Rabetino et al., 2018; Raddats et al., 2019), but lacks studies and conceptual frameworks on how those sellable, productized solutions (combinations of products, services, expertise, and software; see Vandermerwe & Rada, 1988; Nordin & Kowalkowski, 2010; Kohtamäki, et al., 2019) are initially developed in manufacturing and technology companies (Kowalkowski & Ulaga, 2017; Sjödin et al., 2020). Studies have called for research acknowledging the paradoxes and tensions that hamper solution development and servitization (Kohtamäki et al., 2020).

The aim of this conceptual paper is to gain deeper understanding of the process of agile solution development, that is, how new solutions emerge in practice. As most of the attempts (80%) to generate wealth from solution businesses fail (Reinartz & Ulaga, 2008; Ulaga & Reinartz, 2011), there is a constant need to improve the solution development process in order to reap significant economic and strategic benefits from services and solutions (Fang et al. 2008; Kohtamäki et al., 2013). This paper provides insight into different phases regarding solution development, and addresses the following question: *What are the preconditions needed to develop a novel integrated solution?* In this study, we present five key phases of agile solution development, namely, 1) new idea screening, 2) new idea nurturing, 3) conversion of ideas into "good enough" solutions, 4) solution productization, and 5) solution revamping. These phases, and related innovation practices, are discussed in more detail throughout the paper. For managers of servitized manufacturing companies, this conceptual study provides a new perspective on how to

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manage the solution development process in an agile manner.

Theoretical Background

Business servitization

Servitization is not a completely new phenomenon in the business world. For instance, Michelin developed its Fleet Solution concept (Michelin sells driven miles instead of products) more than 100 years ago. Motor vehicles have to be maintained regularly to keep them running, and likewise elevators and escalators have to be serviced based on regulations. A well-known Finnish elevator and escalator manufacturer, KONE Oyj, has been making money from servicing elevators, escalators, and automatic doors since the 1920s (Simon, 2010; Michelsen, 2013). However, servitization has garnered more attention among business scholars and practitioners since the millennium began. The number of servitization-based studies skyrocketed, especially in the 2010s, when differentiation through pure products and technology became harder, and when rivalry, especially from East Asian economies, stiffened and made competition in product markets truly global (Baines et al. 2008; Luoto et al., 2017; Rabetino et al., 2018; Raddats et al., 2019).

Servitization (also known by other terms, such as service infusion, service business development, servicizing, tertiarization, service transition, and value migration in the literature; while in this study, we use the general term "servitization" henceforth to describe the business phenomenon where the relative amount of services increases in manufacturing sales) refers to a company's attempt to strategically renew itself by starting to sell an increased number of services and customer solutions to its clients (Tuli et al., 2007). Some researchers have described manufacturers as having gone downstream and becoming closer to the end customer (see Wise & Baumgartner, 1999), while others have claimed that this is reminiscent of synchronized development (Töytäri et al., 2018) that requires development activities in parallel between suppliers and customers (Huikkola et al., 2013). The existing literature has acknowledged how to structure services and solutions within a firm (Oliva & Kallenberg, 2003; Gebauer et al., 2010), how to sell more of them (Reinartz & Ulaga, 2008), what types of capabilities are needed to provide those solutions (Ulaga & Reinartz, 2011; Kindsröm et al., 2013; Huikkola et al., 2016; Visnjic et al., 2018) and what kind of organizational processes are needed to effectively bundle products and services into solutions (Storbacka et al., 2013; Huikkola & Kohtamäki, 2018). However, the extant literature is relatively silent on how these sellable services and solutions are initially developed within manufacturing companies, as stated in the previous literature (Kowalkowski & Ulaga, 2017).

New service development (NSD)

New service development (NSD) has gained attention especially among service marketing scholars. Researchers have identified key differences between new product and service development processes (Kowalkowski & Kindström, 2012; Kowalkowski & Ulaga, 2017). New product development (NPD) is typically back-heavy, meaning that it requires back-end capabilities in technology development and prototyping, whereas NSD is considered front-heavy, calling for customer-related capabilities during the market introduction and piloting phases (Kowalkowski & Ulaga, 2017). Some studies have described general frameworks for NSDs. For instance, Zeithaml and Bitner (2003) developed a model consisting of two major phases, namely, front-end planning, and implementation. In front-end planning, companies address questions regarding their overall mission and strategy when generating new ideas.

In concept development and feasibility analysis, companies should know the potential market demand and address the following question: is the new service feasible from a business perspective? During the implementation stage, companies have to consider all the factors affecting service delivery through prototypes and market testing. When introducing new services/solutions to markets, firms should understand the potential or problems that may occur in service delivery and customer adaptation. Design thinking literature (for example, Plattner et al., 2010) has expanded our understanding why NSDs typically fail, namely a lack of desirability, feasibility, and viability. In a traditional development model, feasibility is overemphasized, whereas two other dimensions (desirability and viability) are taken better into account in agile development models.

While solutions are described as bundles of products, services, and software (Vandermerwe & Rada, 1988; Nordin & Kowalkowski, 2010; Ulaga & Reinartz, 2011; Kohtamäki et al. 2019), their development requires logic and principles that support their intertwined development (Bäck & Kohtamäki, 2015). Particularly important is to notice the meaningful role of software, when operating at the age of digitalization (for example,

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IoT, A.I. and connectivity). Existing NSD models typically consist of sensing, exploring, and ideation phases, a conceptualization phase, a test-building and development phase, and a deployment phase. New services are developed in collaboration with customers, thus following a feedback loop and joint sense-making of the novel, co-developed solutions (Huikkola et al., 2013). Hence, developing novel solutions requires balancing between traditional process-oriented models and modern agile methods (Sjödin et al., 2020a; Sjödin et al., 2020b).

Agile New Solution Development

Even though researchers are not unanimous about the term "agile" (Abrahamsson et al., 2002) and there exist different terms to describe the same phenomenon (for example, light methods), Abrahamsson et al. (2002) conclude based on previous literature that agile development is "when software development is incremental (small software releases, with rapid cycles), cooperative (customer and developers working constantly together with close communication), straightforward (the method itself is easy to learn and to modify, well documented), and adaptive (able to make last moment changes)." This is aligned with a later definition by Conboy (2009): "the continual readiness of an information systems development (ISD) method to rapidly or inherently create change, proactively or reactively embrace change, and learn from change while contributing to perceived customer value (economy, quality, and simplicity), through its collective components and relationships with its environment". Agile methods featured in agile development, refer to specific methods used, such as extreme programming (XP), Scrum, Kanban, or lean software development, just to name a few (Takeuchi & Nonaka, 1986; Abrahamsson et al., 2002; Lei et al., 2017).

In this paper, we present five general phases regarding agile solution development: 1) new idea screening, 2) new idea nurturing, 3) conversion of ideas into good enough solutions, 4) solution productization, and 5) solution revamping. During each of these phases, there are questions that manufacturers need to address before rolling into the next stage. The framework is also iterative by nature. In the ideation phase, ideas are iterated within the company through cross-functional collaboration (sometimes involving interfirm collaboration as well). In the conceptual phase, the concept is iterated between pilot customers and the focal company. In the solution phase, the solution is iterated first internally, and then, when the solution has been delivered to clients, externally. In the following chapters, we explain the key features of each phase.

New idea screening

New ideas are fuel for any organization that attempts to thrive through innovations. For instance, Amazon has described itself as "the world's biggest laboratory", indicating that there must be enough ideas in the pipeline that eventually lead to sellable offerings. The rule of thumb is that 1-2% of the overall ideas will eventually be converted into sellable solutions. Hence, to obtain 10 solutions that will be sold in the future, there must initially be approximately one thousand ideas in the pipeline. Thus, most ideas will be rejected, and there must be rules, reasons, and guidelines about when to continue with an idea or abandon it.

To obtain enough ideas, manufacturers must encourage personnel to share their initial ideas. Moreover, manufacturers have increasingly moved towards open innovation practices (see Chesbrough, 2003, 2011), hence involving external parties such as customers, suppliers, and research institutions for contributions to the ideation phase. In new idea screening, it becomes important not only to generate those novel ideas inside and outside the organization, but also to provide information about the progress of the idea (and possibly to give a brief explanation of why the idea was rejected) to the initiator (when contact information is available).

There are several ways to enable people to share their ideas. Establishing traditional suggestion boxes is one way to generate various new development ideas. In global organizations, this method can be seen as relatively rigid and old-fashioned (but still often very useful and effective). Until recently, manufacturers have established several social media tools, both to generate new ideas and to review ideas online. Through web-based tools, it is now easier to obtain instant feedback on an idea and facilitate a faster process for reviewing the idea's validity and novelty, as people can vote and comment on ideas without extensive rounds of review.

Our proposal for the question of whether to proceed or reject an idea in the new idea screening phase is as follows:

> Q1. *Has the idea enough potential value that it is worth investigating further?*

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At this point, ideas can overlap, that is, they may be duplicates, vague or even inferior. The key feature is that initiators can follow how their ideas proceed, learn about why they proceed, or why they have been abandoned. People's willingness to contribute to ideation is hindered more by lack of awareness than by information that the idea was abandoned for a reason than can somehow be justified. The justification for abandoning and idea becomes vital, as the majority (almost 98-99%) of ideas are typically rejected during the innovation process.

Idea nurturing

Idea nurturing refers to the optional phase that gives additional resources and capabilities for idea development within the focal company. In this phase, the key target is to validate the idea from two main perspectives: 1) is this idea good from the customer's perspective (is there real demand for the idea?), and 2) is it good from the focal company's perspective (is it economically viable and profitable?). One way to test the idea is to engage in sprints, that is, rapid experiments with the concept to reduce development cycles based on good enough information regarding the potential adaptation. In larger organizations, cross-functional development teams from different parts of the organization (for example, finance, HR, marketing, technology, sales) are typically established to obtain additional know-how for development, and to reduce the solution's potential bottlenecks. The idea is similar to the lean start-up method (see Ries, 2011) that enables organizations to try new ideas faster, making overall development cycles shorter through rapid experiments. Similarly, the initial target of the lean start-up method is to shed wasteful practices and improve chances of success, by collecting instant feedback and focusing on elements as lightly as possible that customers value most(Sarvas et al., 2017). To make progress during this stage, manufacturing companies need to answer the following question:

> Q2. *Has the idea been validated both internally and externally to build a minimum viable product (MVP)?*

The overall aim of this phase is to increase a company's agility through a faster learning curve that is enabled by allocating additional resources and capabilities for development. At this stage, greater involvement is needed from many parties, both within and outside the company. As with the other phases too, many organizations struggle to develop a "license to fail" culture, given that many engineering companies have not accepted this type of attitude in their approach. Nevertheless, "scaling fast or failing fast" is quite different than simply not making something properly in the first place. The key question is whether the development has been done properly enough.

Conversion of an idea into a "good enough" solution

This phase revolves around the initial conceptualization of an idea. In practice, companies develop a minimum viable product (MVP) at this point to test and pilot it with real customers. In digital solutions, building an MVP is much easier and less costly than building large-scale physical products. Some practitioners have referred to this phase as building a "good enough" solution, as a way of developing a minimum sellable product (MSP) (see Winton, 2017), or even minimum lovable product (Sarvas et al., 2017; Pulkkinen et al., 2019). The initial idea is to obtain specific feedback about the concept from real customers and users of the solution. In practice, companies can use simulations and prototypes to build a showcase.

One problem during this phase is that for testing, manufacturers often use old, established customers, and potentially leading customers in their fields. In general, this approach is very natural and fruitful (demanding customers tend to force suppliers to give their best effort). But if a firm is trying to bring a good enough solution or disruptive concept to markets, this approach is simply wrong, as stated by Clayton Christensen in his famous "Innovator's Dilemma" book. With these types of solutions, according to the theory of disruptive innovations, test customers should be noncustomers or low-end customers (Christensen et al., 2015) in the field. At this stage, manufacturing companies should address the following question related to their business viability:

> Q3. *Has the MVP been validated internally and externally to continue larger-scale development?*

The aim of developing a good enough solution is to obtain instant feedback from potential customers, by piloting and testing the solution in real-life situations. These pilots, through the testing of prototypes, provide insight for manufacturing companies regarding whether or not they should take the concept into the productization phase. However, special attention should be devoted to the selection of customers at this stage, as they should be the same as the customers to whom the solution is directed.

Solution productization

As previously mentioned, only a minority of all ideas will lead to sellable, productized solutions. When solutions are productized, they need to be priced and trained within an organization. In this phase, the company plans how it will start to bundle, sell, and deliver the solution in practice. There must already be a clear customer segment chosen for this solution. Often, a separate team responsible for productization issues is in charge of this initiative. The following question is presented after deciding that the solution will be produced:

> Q4. *Has the solution been priced and trained to be sold and delivered effectively to clients?*

When a company has addressed this question, a new solution is ready to be distributed to markets. Even though only a small portion of ideas will reach this phase, not all sellable solutions become success stories, despite promising indicators for success. However, this is just beginning of the journey. Solutions need continuous development and revamping as customer preferences change. The competitive landscape may also change, and solutions may contain some issues that need further development (teething problems). After the solution has been productized and sold, focal companies then start to consider processes to redevelop the solution based on accumulated expertise.

Solution revamping
Once the solution has been productized and sold to clients, there will most likely be issues requiring further development based on customer feedback and usage experiences. Solutions are thus continuously revamped based on customer feedback and problems arising in use. This learning loop benefits both the manufacturer and its clients. In manufacturers' strategic accounts, there may be several practices that companies use to increase their mutual learning. For instance, Huikkola et al. (2013) found that manufacturers make relationship-

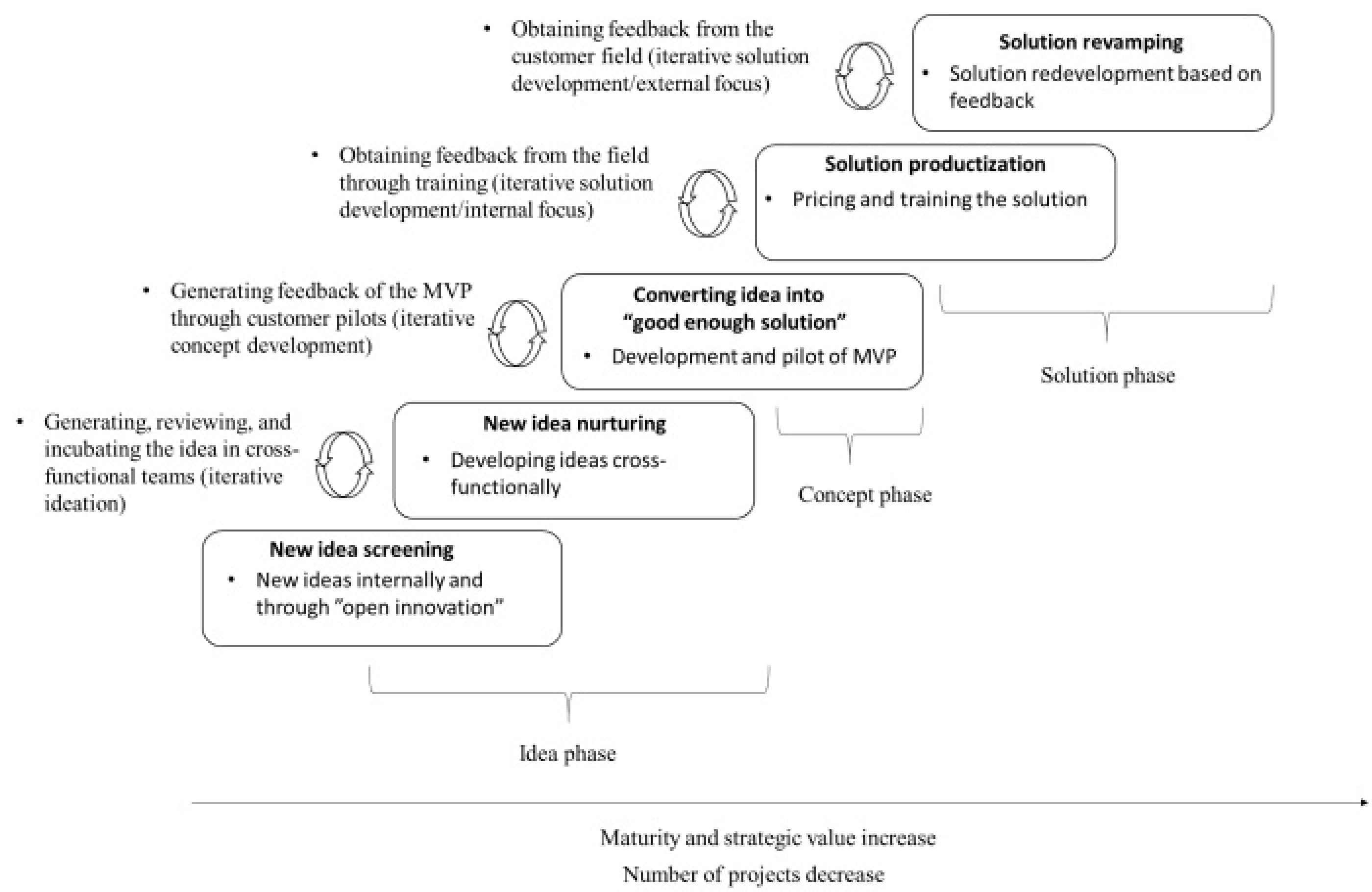

Figure 1. Key phases of agile new solution development for manufacturing companies.

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specific investments in sites, tools, and people to enable mutual learning between parties. Moreover, they establish relational structures such as joint ICT systems, steering groups, and development teams to facilitate joint learning among separate companies. The following question is presented when the solution has already been sold to markets:

> Q5. *How does the solution need to be revamped after it has been sold and delivered?*

Solutions are under continuous development, and there may be a need to revamp the solution's technical features, quality, business model, or other issues. As today's business is considered a never-ending game (see Ritakallio & Vuori, 2018), companies need to be able to adjust their operations to changing environments, which may be caused by changes in customer preferences, competitive situations, or the general business environment. Through the increased digital elements of today's solutions, it is now possible to generate faster feedback loops and follow how customers actually use solutions in real life. Given that such information has historically been lacking, the recent notion that "data is the new oil" (see Marr, 2018), indicates the importance of collecting data for deeper understanding of customers.

Figure 1 above summarizes the key phases of agile new solution development for manufacturing companies. As manufacturers move ahead with this partial stage model, the number of projects naturally decreases while both the project's strategic value and its maturity increase. Notably, using this agile model, ideas lead to concepts, concepts eventually lead to solutions, and there are different rounds between the phases.

Practical Implications

Managers across industries can benchmark this conceptual model when developing new customer solutions. This practical framework facilitates solution development through a "one-size-fits-all" approach. Hence, instead of using established NPD models to develop services and solutions, we suggest that one general framework could be beneficial to boost several types of innovations (for example, product, service, digital service, business model, and process innovation). Of course, NPD can still utilize established models. Nevertheless, people developing new services and business models need not be forced to utilize development models that target traditional product development work, as is the case in many manufacturing companies today (Kowalkowski & Ulaga, 2017).

To thrive in a culture of innovation, managers in manufacturing companies should ensure that people make notable contributions by offering ideas, instead of discouraging them from doing so. Digital tools and social media types of digital solutions can be helpful when collecting and reviewing ideas easily and cost-effectively. In smaller companies, physical suggestion boxes may still have their place for generating and sharing ideas. This model helps managers to divide solution development into phases, and present key questions and rules regarding whether to proceed with an idea or reject it.

When developing MVPs, managers need to ponder the lightest MVP version. Is it reminiscent of only an idea that can be somehow presented to the customer (photo or image of an idea)? Should it be a minimum sellable product (rough draft that helps to sell the idea), or a minimum lovable product (bare bones that make customers to fall in love with a solution; see Sarvas et al., 2017)? All in all, the idea is to develop the lightest possible version of the solution that could be introduced to clients or customers. For manufacturers and engineers, this phase may cause embarrassment through experiencing failures, yet at the same time is mandatory for reducing waste and helping them to focus on the most relevant issues during the innovation process.

Conclusion

The development of novel solutions has, perhaps surprisingly, received relatively little attention in the existing servitization literature. The agile solution development model presented in this paper is an attempt to pursue a better conceptual understanding of the challenges related to new solution development. Even though conceptual models have their challenges, this framework presents general phases and guidelines on how manufacturing companies can potentially progress from idea screening to solution revamping.

Future studies should study this phenomenon empirically and identify practices that manufacturing companies have found helpful when developing novel solutions. Moreover, research can investigate potential challenges and rigidities related to solution development. Further studies may also examine the

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different types of solution development processes and their characteristics. Future research could, for example, investigate how solutions that contain many digital elements differ from solutions that are based more on physical/hardware elements.

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Enabling rapid product development through improved verification and validation processes

Antti Perttula and Joni Kukkamäki

“Requirements analysis is critical to the success or failure of a systems or software project.”

Abran Moore and Bourque Dupuis,
Editors of The Guide to the Software Engineering Body of Knowledge

Fierce competition in consumer electronics market has raised a lot of challenges for product development. Products now must enter to the market as fast as possible. Th e verification and validation (V&V) process is normally the most resource-demanding activity in product development (PD), and thus also has huge potential for improvement. The V&V process is traditionally executed near the end of the development process, and is one of the most critical activities because it identifies design errors. Error correction for a nearly complete product is often difficult and therefore can cause unexpected delays in product delivery. Performing V&V activities in early phases of the PD process and utilising V&V methods other than testing has proven to be a good approach to reduce risks associated with taking a long time to reach the market. However, V&V can only be carried out when verifiable requirements exist. This paper focuses on the importance of moving V&V activities to each phase of PD by defining the requirements for components and modules. In addition, we explore how some of product-level requirements can be verified before a product has been integrated, and explain the difference between definitions of verification and validation requirements. Finally, we present the idea of changing the focus of verification activities from being set-based in the early phase of development, to being point-based when the product is close to completion.

1. Introduction

Companies are facing increasing demands to improve their product development (PD) efficiency because of tough competition in the consumer product market. Newer and more innovative products and services must be brought to market earlier than competitors, which means a need for continuously shorter design cycles. In their studies, McGrath (1998) and Mahadevan (2009) claimed that bringing products to market earlier than competitors brings many benefits, including larger sales volumes and longer sales period. Current changes in the business environment, with a fast time to market and demands to decrease PD costs, have increased the importance of having an efficient product creation processes.

Verification and validation (V&V) are usually the most resource-demanding activities in PD, which makes is possible to find remarkable resource savings in them. The traditional way of carrying out PD has placed V&V as the last activity before product delivery to customers. According to Reinertsen (2009), this timing plan is problematic because, typically, V&V are used to detect errors in product designs, which makes it a critical activity. Correcting errors can be a resource-demanding and time-consuming task, hence, it can lead to delayed delivery or delivery of products with low quality (Kelkar, 2012).

Several examples exist of PD projects that have failed because V&V was not carried out properly, for example, Motorola’s Iridium Communication System (Millard, 2017) and the Hubble Space Telescope (Redd, 2017). Both projects caused the development organisation to incur billion dollar-level extra costs because V&V was done too late. The Iridium System development was performed according to plan and passed most verification tests. However, complet validation was not done until the system was finished. This meant that customers didn’t adopt the system into actual use. In other words, validation failed, which led to the company’s eventual bankruptcy (McIntyre, 2009). In the Hubble Space Telescope project, some requirements related with the primary mirror’s surface were not met during the development phase, which caused blurred pictures (Goodwin, 1993). Later, image quality was improved by installing corrective optics to the telescope in space with estimated additional cost of one billion US dollars (Cohen, 2009). This paper describes both the purpose of V&V and also how to move their implementation to all phases of the development process, as a way to improve PD efficiency. In short, it means that requirements must be created for all the phases of development where V&V is to be carried out.

2. Definitions of Verification and Validation

Verification has been widely understood as a method to prove a product's compliance with specifications. These are not only user requirements for the finished product, but also requirements for components and subassemblies. Mooz, Forsberg and Cotterman (2003) noted that it is not well-known that verification can actually be determined, in addition to testing, inspection, demonstration, and analysis.

The aim of validation is to prove that users are satisfied with the end product. Validation answers the following question: "Is this product behaving as the customer anticipates?" Validation involves the evaluation of customer requirements against their needs and expectations in the most representative environment achievable. According to Stevens, Brook, Jackson, and Arnold (2000), "validation" is sometimes defined as an end-to-end verification process that aims to show that the whole system meets its requirements under operational conditions. The Institute of Electrical and Electronic Engineers Computer Society (2017) defined V&V as "processes that are used to determine whether the development products of a given activity conform with the requirements of that activity, and whether the product satisfies its intended use and user needs".

2.1 Product Requirements

Product requirements are the foundation of the whole PD process. Defining the product-level requirements is basically a straightforward task. First, we ask the customer or anticipate their wants and needs. Second, we transfer the customer's input into exact engineering requirements. Finally, we check with customers that the requirements are right. In addition to these, there are many requirements for products defined by legislation and type approval regulations. When the requirements are clear, we can then attempt to make a product that meets these requirements.

The major problem in PD is the time delay between the definition of requirements and the product's launch to market. During this time period, a customer's needs and wants may change. When the product is finally launched, however, it may happen that customers do not want the product anymore, signifying that product validation has failed. Some system development models, such as Extreme Programming (XP), have tried to minimise the risks associated with validation through the continuous task of customer input and requirements definition. However, according to Paulk (2001), these kinds of agile development models cannot be applied to all kinds of PD. Similarly, Cobb (2019) stated that it may be difficult to apply an agile method, such as Scrum, to large and complex projects.

As normally practiced, product verification can start after the requirements are defined and a product is integrated to market. In practice, this means a lot of work in the late development phase, when errors found at this point can cause unexpected delays in the product's launch. However, many of product-level requirements rather guide the component and module development than influence the final PD. Hence,

Table 1. Some of the product level requirement can be verified at earlier development phases

Product Requirement	*Level, where verification should be done and the method used*			
	Product level	Sub-system level	Component level	Material level
1) Lead-free				*Do not use lead in any materials*
2) One million key pressings		*Verify that a keyboard is functional after a million pressings*	*Select the right components*	
3) TA	*TA testing for the product as required by the authorities*	*TA testing for modules*		

several product-level requirements can be verified at the component and module level. The following requirements shown in Table 1, for example, can be verified partly or completely before a product is integrated into market.

2.2. Technology Requirements

Because of the continuous demand to reach for a shorter time to market, sufficient time often cannot be spent on thorough verification at the product level. Product level requirements must therefore be verified as early as possible, as discussed in the previous chapter. If we make modular products and want to move even more of the verification process away from the product level, then we must be able to define the technology requirements, including components and module requirements. In this case, technology means any kind of technical solution for a complete product.

The definition of technology requirements is normally more complex than the definition of product requirements because customers are often not able to give input to them. In other words, technologies, modules, and components in a product are not always visible to the customers. In fact, there is a definite difference between product and technology requirements and the linkage between them is rarely straightforward. However, as usual, technology (including components and module) requirements are developed from product and customer requirements, which is a sensible approach. The importance of the designer's competence, along with existing technological possibilities, design rules, and guidelines when defining requirements, must not be forgotten.

In the simplest cases, subsystem and component requirements can be copied from product requirements. For example, if a product must function normally in temperatures between20˚C and +40˚C, then we can simply define the same requirements for its components and modules. However, there may be heat sources inside the product, which can increase the internal temperature. In some areas, the temperature can reach +80˚C, which may require increasing the upper-temperature limit of the components accordingly. This may, however, be expensive to produce, while some technologies may not be functional at such high temperatures. In such a case, it would be beneficial to create a temperature simulation model for the product before the physical prototype is made, so that temperature-sensitive components can be placed in cooler locations.

The definition of technology requirements is often difficult because the linkage to product requirements is not always solid. For this reason, the designer plays an important role based on their competences, together with the existing technological possibilities. Requirements for the same module may also vary depending on the designer's competences and the existing technological possibilities. Combined, these can strongly affect the probability that the module will function properly under conditions of product exposure. Because of this, the technology requirements cannot alone guarantee that the module or technology will survive when being integrated into a product.

We have noticed that definitions of technology and subsystem requirements often include many different, and sometimes, unmeasurable inputs. Figure 1 describes the five main inputs to definitions of technology and subsystem requirements.

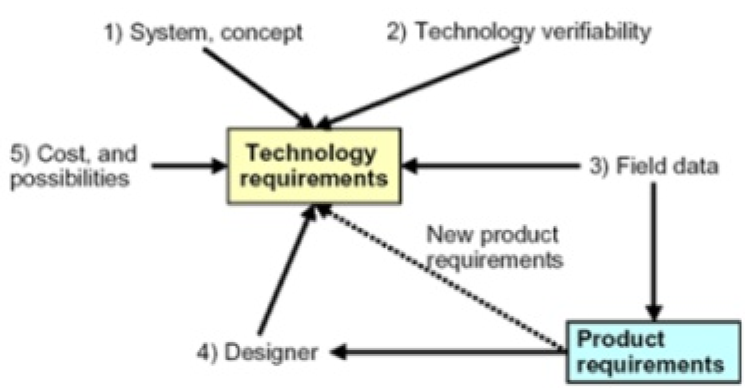

Figure 1. Inputs to definitions of technology requirements, (Perttula, 2007).

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Inputs to define technology requirements include the following:

1 The system and concept that is to be built roughly defines the level and set of requirements.

2) Like any other requirements, technology requirements must also be verifiable with the resources, equipment, and cost that producers can afford.

3) Field data is an important source of input both for technology requirements and product requirements. If we notice that similar technology is failing in the field, we must input this information into new requirements. Also, if a technology is used in other PD projects and seems to be risky, this should be included as input as well.

4) The designer's competence and possibilities are probably the most important inputs.

5) The last inputs are the costs and possibilities of a technology, which must be in line with each other.

Although a solid link between the product and the technology requirements may not be present, information about developing new product requirements could come directly from defining a technology's requirements. Although defining a technology's requirements is not an easy task, it is crucial that it is completed in order to be able to carry out verification before the integrated product phase.

2.3. Definition of verification and validation requirements

Figure 2 describes the new process of defining V&V requirements. Inputs (on the left-hand side of the picture) are general requirements, such as standards and legislation, as well as anticipated and true future customer needs and expectations. The deliverable specific requirements inputs are anticipated future customer requirements, along with anticipated future technology requirements. The deliverable specific requirements together with general requirements form the total set of requirements. From this set, the true verification and anticipated validation requirements will be developed. Validation requirements cannot be accurately defined in the early stage because customer needs and expectations are not yet known. This means that there is always a risk in customer validation, with the level of risk being strongly correlated to PD time. Because of this, PD time should be decreased by all possible means.

3. Modified V-model in Platform-Based Product Development

The V-model created by Harold Mooz and Kevin Forsberg is widely used in PD projects to highlight V&V activities (Mooz & Forsberg, 1991). This model is used in both software and hardware development. Our ambition here is to help move relevant product level verification activities to earlier development phases in order to decrease the workload at the product level. This kind of approach can be called "incremental verification". We illustrate this method below using the idea of the V-

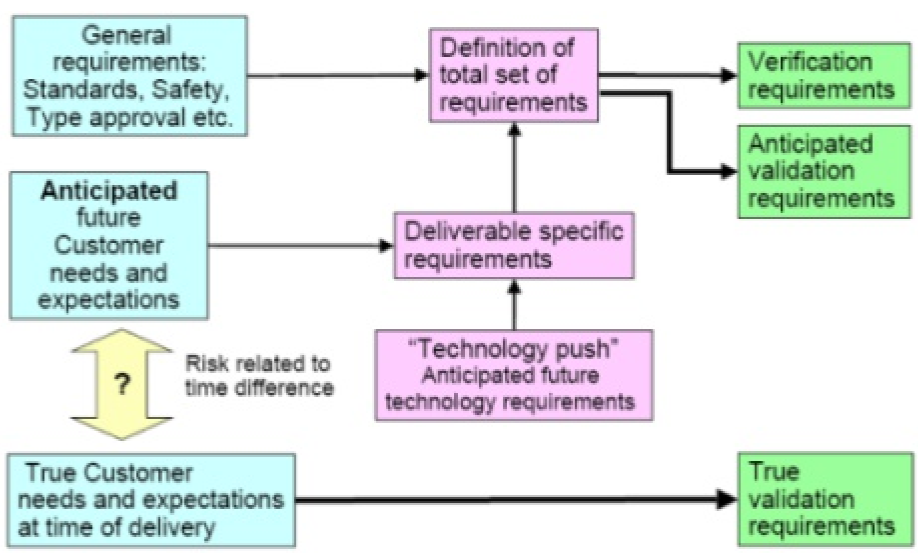

Figure 2. Defining the verification and validation requirements (Perttula, 2007).

model.

The idea of incremental verification is to decompose the product requirements to smaller ‘subrequirements’, develop ‘subitems’, and verify them against these subrequirements separately. Suitable requirements for incremental verification often cover broad areas, such as those relating to product usability and type approval. By developing and verifying these subitems at an early stage, only some of the verification efforts will be needed at the product phase, which also means fewer risks. Typically, subitems are simulation models, modules, and components.

On the left-hand side of the V-model, product requirement A is decomposed into three sub-requirements. Based on these sub-requirements, three sub-items are developed and then verified separately. When these verifications are completed, then the product level requirement A will be verified. Before decomposition can start, product requirement A must be understood as being composed of lower-level requirements.

Our aim is to complete the technology, components, and module V&V before an integrated physical product is available. In practice, this means that we need to apply other types of verification methods beyond only physical testing, as often as possible. For example, we can replace product level drop testing and thermal analysis for finished products by extensive simulations, before the physical samples are produced. By focusing on early V&V, we can save time and select the right technology for further product integration. This will reduce risks at the product phase, and ultimately improve PD efficiency.

In platform-based development, products are made of modules and components, which are usually completed before product integration. The subsystems are then integrated into several future products. One of the major challenges with platform-based development is how to build platforms for future products. Figure 4 shows the traditional way of utilising platforms in PD.

Customer requirements flow through the product programme to platform development. Platforms are developed based on these requirements and are delivered to the product programme that makes use of them. This approach makes sense when there is no serious time pressure during the PD phase, and itis possible to wait until the platform is complete for product integration. PD projects in such cases must wait

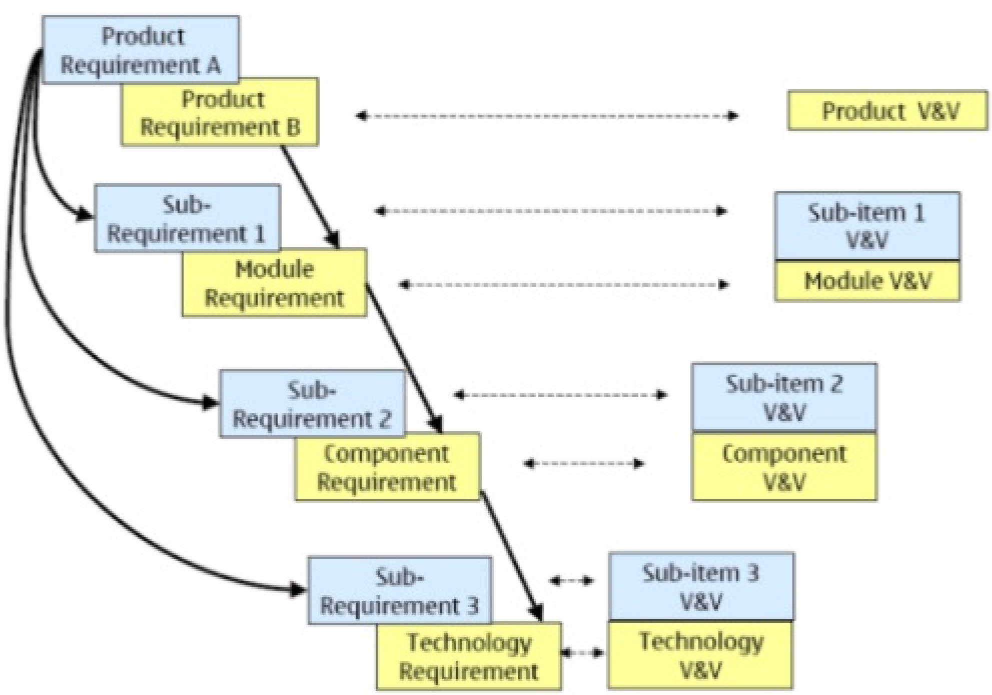

Figure 3. Incremental V&V of some product-level requirements.

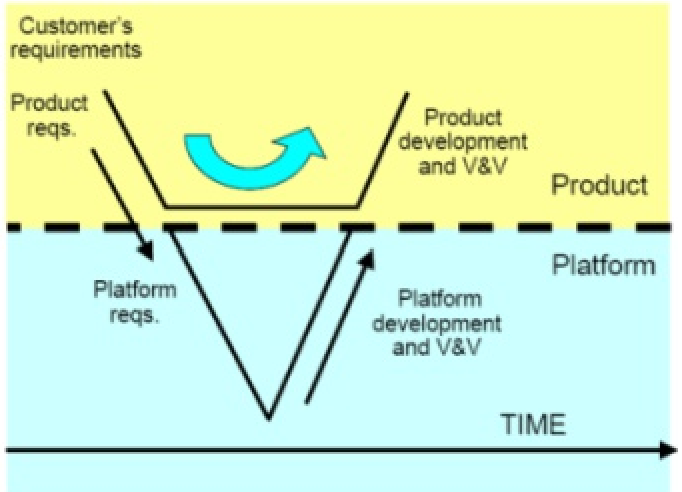

Figure 4. A typical way of utilising platforms in product development.

for platform development to be completed. The thick curved arrow in Figure 4 displays the waiting period. This can be reduced by starting platform development before actual PD. We have further elaborated on the idea of the V-model to describe platform-based PD when there is a time constraint during the PD phase. Figure 5 describes platform development taking place before the PD phase.

At the beginning of the platform development phase, customers' requirements for the product are not necessarily yet known. The technology development organisation must first anticipate these missing requirements, develop the platform, and finally both verify and validate the platform before forwarding it to PD. The PD process shown in Figure 4 is straightforward; product requirements are developed from customer requirements, then the product is developed, and finally verified and validated.

Missing customer requirements at the early development phase present new challenges for platform creating organisations. Adequate knowledge and competence are needed to anticipate future customer requirements for a product, along with readiness to adjust the requirements over the course of time. In the

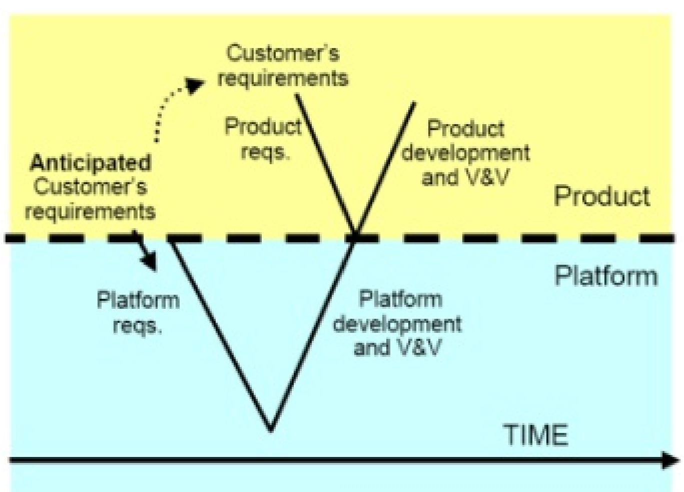

Figure 5. A modified V-model for platform-based product development.

normal way of developing products, customer interface is managed during the production programmes, instead of platform development period.

As shown above, the major challenge of V&V for platform-based development is a difficulty in defining the requirements for technologies, modules, and components. It is often either not possible to create the exact requirements, or they continuously change over time. Because of this, we have started to change the focus of verification from error detection with a pass/fail indication or point-based verification activity, toward defining opportunities, that is, a set-based verification (SBV) process developed by Perttula (2007). In SBV, all relevant information about a design is collected as early as possible using normal measurement and analysis methods. This data can be referred to whenever needed, as a way to check whether a design still meets the changing requirements. This eliminates the need to continuously repeat physical measuring and testing. Using this approach, we have found that remarkable time and cost savings can be created.

The left-hand side of Figure 6 displays the traditional, point-based way of carrying out pass/fail verification. The design in question meets the requirement with values of 5 and 5.2, but fails when the requirement is 5.9 or 6. Without repeating the verification, it is not known whether the design is working between 5.2 and 5.9. In set-based design (on the right-hand side in Figure 6), we did not verify the design against a current fixed requirement, but rather employed a 'test-to-fail' approach in order to understand what range the design could tolerate. If the initial requirement changed, we would know instantly without new verification whether the design could meet the new requirement. By utilizing a set-based approach to verification, it became possible to remarkably improve product development speed in certain circumstances, with frequently changing requirements.

4. Verification & Validation (V&V) in Agile Projects

Constant changes in product requirements might cause several issues in PD projects, while proper reactions by those in development can lead to better products. Because Agile methods (for example, Scrum) are created specifically to take note of changes, they fit very well into development projects that involve a high degree of uncertainty. The Agile manifesto (Beck et al., 2001) pointed out that Agile projects should value rapid responses to changes instead of following a pre-set plan. Furthermore, the following is included along with the 12 principles of Agile software: "Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage" (Beck et al., 2001).

The Agile manifesto is written from the viewpoint of software development. Nevertheless, it includes principles that can be implemented for any kind of development process. It is good to understand and take note of the differences between software development and, for example, physical PD. Software development is immaterial or informational, data-based, while developing physical products involves materials, manufacturing, and logistics.

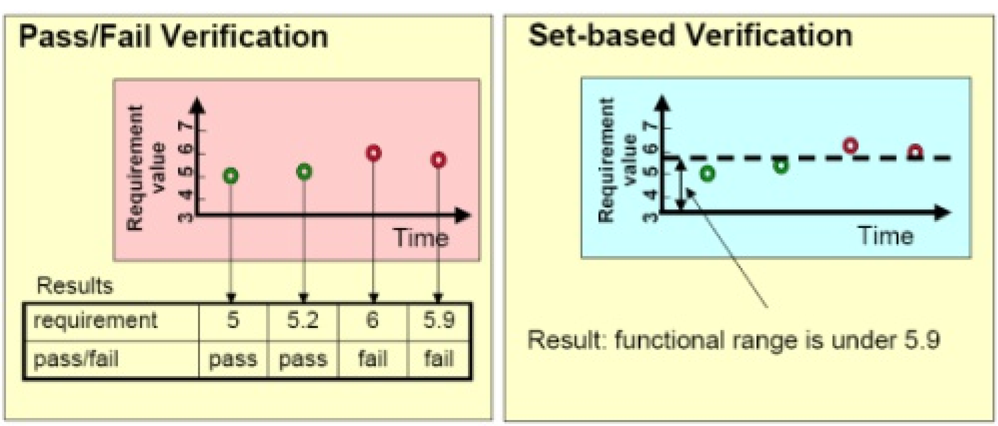

Figure 6. The Y-axis is a functional value, while the horizontal, dashed line is the maximum of this functional value that meets the requirement. Set-Based verification estimates design possibilities. (Camarda et al., 2019).

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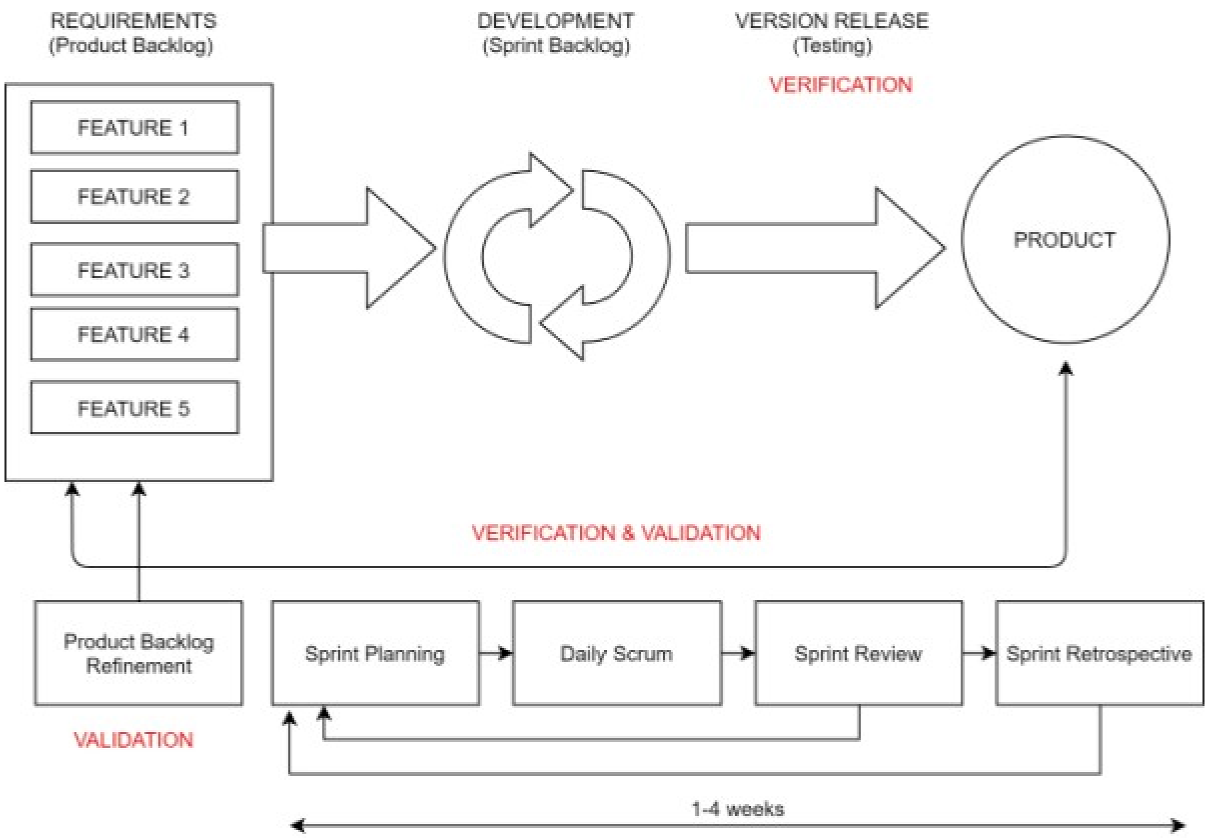

Figure 7. Verification and validation processes implemented in each iteration of Agile development.

Agile methods are usually artefact-based and iterative processes. Everything starts with features, which are usually described as "user stories". These describe who the users are, what they need and how they use a product, thus giving a strong user-centric way to developing products. According to Schön et al. (2017), when a company has compiled a comprehensive set user stories, created together with users, then a validation process can be applied to these stories.

Agile methods are iterative. Schwaber and Sutherland (2017) stated that in Scrum, one iteration is called a "sprint". In one sprint, multiskilled teams take these features to be developed in a short, 1–4-week period. The aim is to produce deliverables that are fully ready to be implemented in a product, including user testing. At the beginning of a sprint, the team splits the features into small tasks that need to be done to achieve the goals of the sprint, in order to meet the feature requirements. This way, verification can be implemented in testing processes and done iteratively.

In an Agile project, the development team focuses only on the ongoing activities and features, so that changes can be done more easily at later stages while they are still open for changes. V&V processes can be implemented for each iteration, instead of at the end of a project, as illustrated in Figure 7.

Agile methods used for PD are based on short user stories or features, which are then developed and integrated into the product during 1-4 week long sprints. Each sprint or iteration includes planning, design, coding, unit testing (verification) and acceptance testing (validation).

5. Changing the Focus of Verification in Product Development

Sometimes, we may need to change the focus of a verification process between point-based and set-based, according to the phase of PD. It is important to ask what should be done to avoid repeating the verification process when the requirements are changing. The

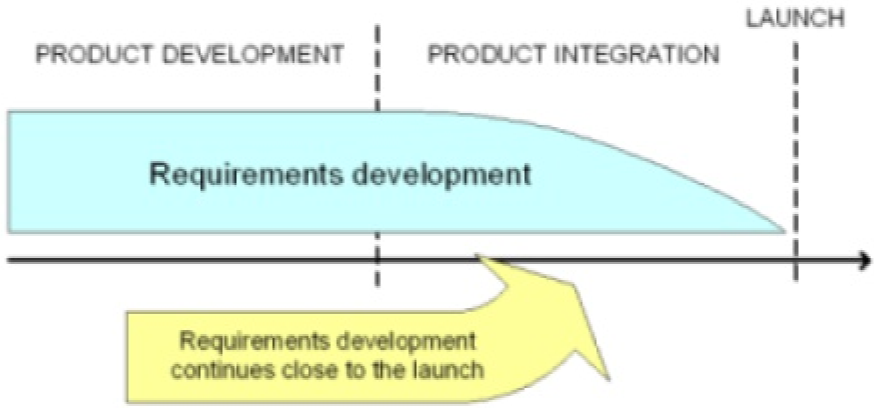

Figure 8. Requirements development continues close to the launch of the final product.

classical definitions of V&V do not give direct answers to this challenge. If we collect more information from the product than just enough to make a pass/fail justification, we may then be able to utilise it when a requirement has changed. On the other hand, when requirements are stable, the point-based verification is often enough, and is more economical to conduct than a set-based approach.

Some of the necessary components and modules for the product are usually acquired from external suppliers. These components and modules are the end products of their manufacturers. For example, a smartphone is a subsystem of a larger communication network. If we can divide the PD (end-product, module, or component) into technology development and product integration, then changing the focus of the verification process can be advantageous. In such situations, we can utilise both types of verification. At the beginning of the process, the requirements may not necessarily be well known or can even be erroneous. Thus, they will need to be clarified and changed as time passes. Figure 8 describes how the development of requirements continues almost to the end of the PD. In some development models, such as XP, the defined requirements actually continue almost with the same intensity to the end of PD.

Figure 9 shows how the focus of verification should change during different phases of PD. The requirements development occurs often at the early design phases. For this, the SBV approach is almost the only method suitable, whereas pass/fail verification plays a significant role in the later design phases.

At the later development phases, closer to product launch, the requirements are typically stable, and defined by customers or based on legislation. These requirements are often related to type approvals or customer acceptance. Product verification against these requirements is often of the pass/fail type, while the most important goal is fast execution. However, because of possible variations in both production and components, during the production phase it is usually beneficial to carry out an additional set-based type of verification to see how close to the limit a design is, as shown in the right-hand side of Figure 10.

On the left-hand side, pass/fail verification only shows that in weeks 31 and 37 some samples did not meet the acceptance criteria, while SBV gives much more information. For example, we can see how stable the production process was and how far away samples were from the acceptance criteria limit.

6. Conclusion

This paper’s goal was to study how improved definitions of V&V requirements can enable rapid PD, and in particular, to research what is required to distribute V&V actions over the whole PD process. The most important findings of this research are as follows. First, carrying out V&V at each phase of PD, instead of just close to product completion, can be very beneficial because error correction risks can be better managed this way.

Second, V&V activities can be carried out only when relevant requirements exist; hence, the need to create requirements for components and modules in addition to a complete product. However, the definition of these requirements is more complex than the definition of

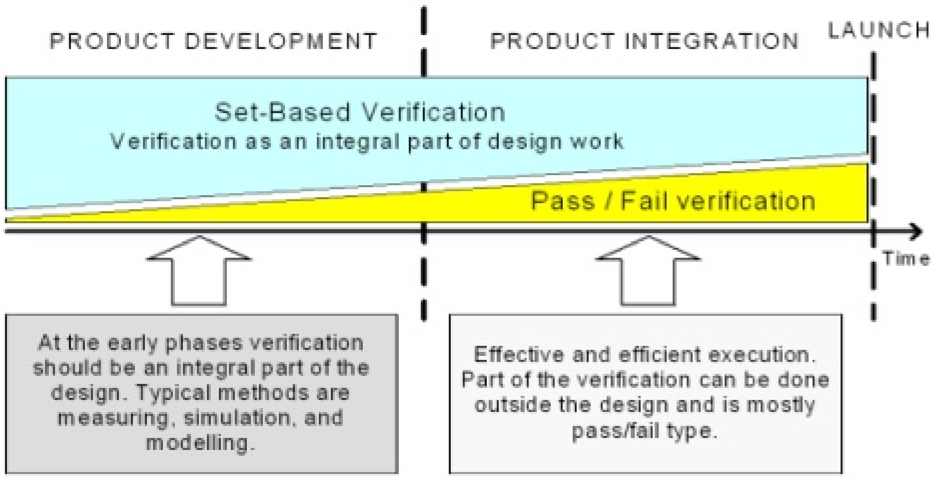

Figure 9. Changing the focus of the verification and validation in product development where technology development occurs separately before the product integration.

product requirements because customers often do not have visibility. Nevertheless, in some cases technology (including component and module) requirements can be developed from product and the customer requirements, or can be simply anticipated. The linkage between these requirements is usually not straightforward, and thus the designer's role is key. Depending on the designer's competences, existing technological possibilities, design rules, and guidelines, technology requirements may vary. Neglecting the designer's possibilities can cause delays in introducing the latest new technology into products. Using product-level requirements as technology requirements, it is also very likely that a technology supplier may not be capable of making a new technology meet these requirements on time, or in terms of affordable costs. In other words, the new technology may be so "fragile" that it just cannot meet the product requirements in the beginning, but instead requires further development that takes more time.

Third, PD requirements are often not fully set at the beginning because they are constantly changing, such as in Agile development projects. Thus, it is beneficial to apply SBV. When requirements are stable, the normal point-based verification that enables fast execution is the best and most economical approach. However, even in mass production, SBV can be useful. If we understand

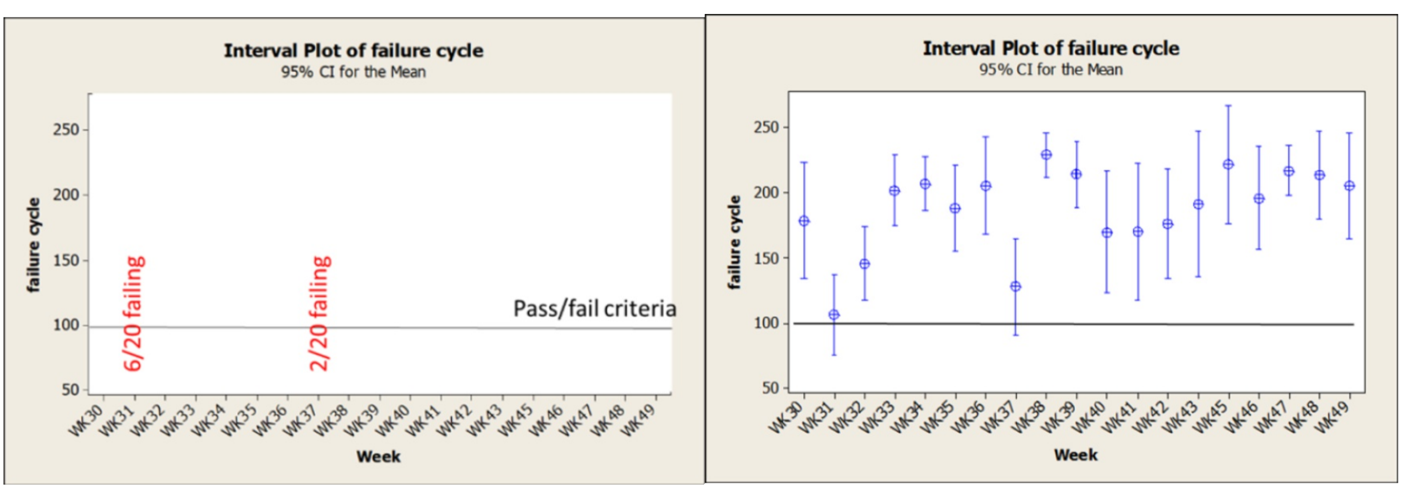

Figure 10. Information received from point-based (left-hand side) and set-based verification in mass production.

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the stability of the production process, we can predict in advance whether samples are going to fail or pass in future acceptance testing. At the initial stage, carrying out SBV requires more time and effort than point-based because information about the functional areas of a design must be collected, not just pass/fail justification as a certain criterion. Nevertheless, we believe that SBV has advantages that make it preferable in certain circumstances, as highlighted in this paper.

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Organizing the Development of Digital Product-Service Platforms

Johan Simonsson, Mats Magnusson, Anders Johanson

> *We have seen that the function of entrepreneurs is to reform or revolutionize the pattern of production by exploiting an invention or, more generally, an untried technological possibility for producing a new commodity or producing an old one in a new way, by opening up a new source of supply of materials or a new outlet for products, by reorganizing an industry and so on.*
>
> Joseph Schumpeter

Servitization is today a common theme among manufacturing companies, with the goal of better addressing the needs of their customers. Digitalization is one key enabler of servitization. One aspect of this concept can be provided through digital product-service platforms, which may facilitate the enrichment of a market offer, as well as keeping costs under control. Platforms are in general a well-established concept for manufacturing companies, as enablers of rich product offerings based on a few components. Less is known, however, about how the ambition to create digital product-service platforms interplays with the business model innovation needed as a result of the servitization efforts, along with processes and organization. This paper identifies a number of challenges that manufacturing companies may face when undertaking platform development for services, based on an empirical study made in the Swedish company Husqvarna Group.

Introduction

Today many traditional manufacturing companies desire to complement their product offerings with various services, a transition commonly referred to as servitization (Vandermerwe & Rada, 1988).

Extant literature notes many reasons why a bundle of products and services are of interest. It may, for example, facilitate a climb in the value chain (Noke & Hughes, 2010; Tongur & Engwall, 2014), be an opportunity for differentiation, or a response to increased global competition (Parida, Sjödin, Wincent, & Kohtamäki, 2014). It can also be a fruitful means to build long-term relationships with customers (Reinartz & Ulaga, 2008; Baines et al., 2013).

Digitalization can be a key enabler for servitization, as digital technologies facilitate the connection of products, services, process, and systems (Hsu, 2007). Information technology is already becoming an integral part of many products, as sensors, actuators, and connectivity are being added to them. Generated data can then be used to improve product functionality itself, or to advance productivity elsewhere in the value chain (Porter & Heppelmann, 2015). To prepare an organization for digital disruption however, can be a major challenge, as its implementation and use can demand complex changes and affect almost the entire organization (Bughin & Zeebroeck, 2017), as well as the business models applied (Kindström, 2010).

Traditional manufacturing companies will often face at least two critical issues when aiming to pursue a path towards digitalization. One is related to the use of platforms, which may either enable the servitization approach or be sold as new offerings. The other challenge is related to business models, and how these develop in line with platforms and servitization. This paper addresses two research questions. The first research question is as follows: *how does business model innovation relate to digital product-service platform development in traditional manufacturing firms aiming for servitization?* The other asks: *how is the inter-relationship between business model innovation and digital platform development managed?*

An empirical study investigating these questions was carried out at Husqvarna Group, a large Swedish manufacturing company with a strong product legacy, in which various digitalization and service offer initiatives have also grown in importance over the past years. Four different digital platform projects that have been developed in different contexts were studied. The

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empirical observations lead to several findings, one of which is that when digital platform development processes are not extensively developed, understanding of digitalization and the drive of individual persons and managers stand out as fundamental. The study also points to the importance of early business model innovation in platform development projects, in order to allow for focus on modules with the highest customer importance and values.

The paper is structured as follows. First, relevant theories are explored, which lead to the formulation of the above two research questions. Subsequently, the research setting and methods used are described. Thereafter, empirical results and an analysis of them are presented. Finally, the results are discussed, including implications for managers and suggestions for future research.

Exposition of Theory

This paper explores the intersection between servitization, platforms, and business models. The current section covers relevant theories concerning these phenomena. “Servitization” is a concept in which companies include an increasing share of services in their customer offerings. Digitalization has been pointed out as a key enabler for servitization (Rymaszewska et al., 2017), while a platform business approach stands out as an important feature of developing new services (Cenamor et al., 2017). With an increased focus on services follows also a need to review current business models (Kindström, 2010). The following section will explore how servitization, platforms, and business models are interrelated.

Servitization

The phenomenon under which manufacturing companies shift from a product-only approach to include a larger share of services is commonly referred to as “servitization” (Vandermerwe & Rada, 1988). A growing stream of research focusing on the development of new product-service combinations has proposed a number of concepts and definitions. Some commonly used are Integrated Product Service Offerings (IPSO) and Product Service Systems (PSS) (Park et al., 2012). One driver for a servitization approach is that it enables a stronger relationship with customers, which in turn can increase also sales of products over a longer period of time (Reinartz & Ulaga, 2008). Another motive for servitization is that bundles of products and services provide customers with more total value, and thereby offer an opportunity for suppliers to climb the value chain (Noke & Hughes, 2010; Tongur & Engwall, 2014). Integrated product service offerings may further be a way to keep their profit margins, as many companies are seeing increased competition for products (Oliva & Kallenberg, 2003; Parida et al., 2014; Gaiardelli et al., 2015). Services can also be a more stable source of profits, as they tend not to be as exposed to fluctuating business cycles as products (Raddats et al., 2016).

The services that companies desire to offer to the market may range from fairly simple ones, such as training or basic services for existing products, to very advanced ones, for example, when customers no longer buy the actual product, but pay for the result that this product creates. In order to create and deliver various services, companies need a set of capabilities that matches a new value proposition (Christensen et al., 2016). One factor identified that is reported as a key facilitator for servitization is digitalization (Coreynen et al., 2017; Rymaszewska et al., 2017), as this may also facilitate more advanced services based on products that become “intelligent” and “connected”, and through which access to data can enrich both the offerings and relationships to customers (Porter & Heppelmann, 2015). An increasing literature stream has also identified that a platform approach in servitization may be a way to leverage “the value of digital technologies based on modularity and IT enabled interaction” (Cenamor et al., 2017).

Platforms

The use of platforms have frequently been proposed in various contexts in the academic literature (Thomas et al., 2014). These are used in general to accomplish strategic goals and strengthen competitive advantage. Gawer and Cusumano (2014) state that there are two major variants of platforms: internal and external. The first category is specific for a company as a way to create many derivative products from a common structure. The use of product platforms have also long been a well-established concept among manufacturing companies (Sköld & Karlsson, 2013). Earlier research has illuminated product platforms from several perspectives, for example, that component re-use can increase with a platform strategy (Pasche et al., 2011), and that organizations should consider the combined use of product platforms and modularization in order to reap economies of scale and scope, and economies of substitution, respectively (Magnusson & Pasche, 2014).

Several authors have identified platforms as an interesting approach to enable and support various services (Eloranta & Turunen, 2016; Cenamor et al.,

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2017). Service enabling platforms have the potential to facilitate new service businesses that provide high quality services, and at the same time keep costs under control. This offers interesting opportunities to avoid getting caught in a "service paradox", where revenues from services do not match investments made into these new offerings (Gebauer et al., 2005; Rabetino et al., 2017). At the same time, several authors point to the fact that related theory is lagging behind (Pekkarinen & Ulkuniemi, 2008; Thomas et al., 2014; Cenamor et al., 2017; Raddats et al., 2019). A lack in understanding also persists regarding how platforms are created (Thomas et al., 2014), not only when it comes to what constitutes a service enabling platform, but also the actual process for how platforms are created.

A related challenge is transforming the business model, thus redefining the conceptual logic for how a business is built. Companies with ambitions to add an increasing share of services into their market offer portfolio, may need to redesign their current business model or add new business models to existing ones (Kindström, 2010; Björkdahl & Holmén, 2013)

Business models

All established business enterprises use some kind of business model, which is the representation of how value is created, delivered to the customer, and captured (Teece, 2010). With a servitization approach follows a need to alter traditional business models in order to match a new reality (Kindström & Kowalkowski, 2014). However, designing and implementing a new business model appears to be a substantial challenge for firms. It has even been underscored that business model innovation is far from an easy task (Beckett & Dalrymple, 2019), and that many who attempt to update their business model fail to do so (Christensen et al., 2016).

Manufacturing companies pursuing a servitization strategy need to handle both service innovation and technology innovation. This shift poses a business model dilemma (Tongur & Engwall, 2014). As highlighted by Björkdahl and Magnusson (2012), a certain amount of design autonomy is needed in order to allow for the necessary changes to current business models in use. On the other hand, there is a risk that a lack of integration in existing businesses may lead to difficulties of implementing a new business model, and potentially, also to overly divergent business model portfolios (Aversa et al., 2017), with a subsequent risk of increased costs and lack of synergies. This points to a critical dilemma in organizing a new business model design in established companies, which so far has not been thoroughly investigated empirically.

Research Questions

Servitization, as described above, continues to grow in importance for many manufacturing companies. As a consequence, digital platforms may therefore also grow in importance to enable ambitious companies to develop new service offerings. Platforms are in general a well-known concept among manufacturing companies, frequently used in product strategies. Yet how to develop digital platforms to support different services initiatives is not yet equally familiar to most companies. One complication of developing new service offerings is that these arguably often affect the currently applied business models. Companies thus need to understand how business model innovation should be managed in relation to digital platform development. Based on this, two research questions have been formulated:

RQ1: *How does business model innovation relate to digital product-service platform development in traditional manufacturing firms aiming for servitization?*

RQ2: *How is the inter-relationship between business model innovation and digital platform development managed?*

Research Setting and Methods Used

The case study company - Husqvarna Group

Husqvarna was founded in southern Sweden in 1689. Today it is a "group" organized into different divisions. The Husqvarna Group has throughout its history been able to successfully bring new and innovative products to the market, and currently holds a leading global market position for products like robotic lawn mowers, chainsaws, power cutters, and watering products. The Husqvarna Group has throughout its history been able to adapt early to new industry trends and market demands. One strong industry trend where Husqvarna is well positioned among its competitors is digitalization. The group has recently launched several initiatives with an explicit ambition to use new digital technologies to innovate their market offers to customers.

Methods used

The complex nature of the phenomenon researched in this study made an exploratory case study approach relevant (Yin, 1999). Case studies allow researchers to gain substantial depth in their research (Flyvbjerg, 2006), and thus offer opportunities for unveiling new insights in emerging areas of investigation where extant knowledge is limited.

Four projects from the company with several approaches to managing platforms and business model development were selected. This offers a possibility to compare the different approaches, while at the same time keeping a number of contextual factors constant. The decision to select four cases from a single company was also made out of convenience, as two of the three authors are employed by the company in question, and thus hold extensive knowledge about the way the investigated phenomena are dealt with inside the organization. Moreover, this enabled the researchers to have access to internal company documentation, as well as facilitated possibilities to interview key respondents in the firm.

The data presented in this study come from several sources. Interviews were made with senior managers holding key roles in four different projects, here referred to as Alfa, Beta, Gamma, and Delta. A total of 14 interviews were made with 11 different people, in which some of the respondents provided insights into several of the projects, rather than just a single project. The interviews were made at two different periods of time, approximately 12 months apart, in order to understand also how the projects developed over time.

Interview guides were developed prior to the interviews to make sure relevant questions were captured. The questions covered vital areas for this study, such as project scope and organization, platform issues, and business model aspects. A semi-structured interview approach was used during the interviews, thus allowing for minor modifications of questions, as well as the addition of follow-up questions when needed (Robson, 2002).

In addition to this, the researchers had access to an extensive post-project report from the Gamma project, as well as a substantial amount of project documentation from the Beta project. Two of the authors of this study are, in addition to their work in academia, also employed by Husqvarna Group. One of the authors was closely involved in the Beta project, and another was deeply involved in the Beta and Gamma projects.

Case Study Descriptions
Four digital platform projects were investigated: Alfa, Beta, Gamma and Delta. All these projects represent a type of project development that the company performed for the first time, and is relatively unaccustomed to.

Project Alfa
Project Alfa was developed within one Husqvarna Group company division, based on an idea from a small group of individuals who are directly responsible for various aftermarket and service offer initiatives. These individuals had identified the need for a solution that could support operational excellence in several aftermarket and service offer deliveries, based on some kind of platform to which various digital sources could be connected as different modules in a structured way. The user of the platform can then, for example, sign on to one platform instead of many to acquire information. A second rational for the need was to build a platform for registering and on-boarding multiple service offers, that is, for the platform to become an internal tool for service offer maintenance, control, and follow-up. Service offers in most cases differ from product sales in that they emerge in the aftermarket from contacts with customers. At this point, digital platforms may be needed to support service creation, in the delivery to customers as well as in the follow-up.

The project was anchored with management and then developed by a few internal resources, along with the help of an external partner. Project Alfa was not part of the product development fora within the division, and did not follow the product creation process or any similar structured process.

Project Beta
Project Beta passed through two phases during the timeframe of the research for this study. The first phase was, like in project Alfa, initiated within one Husqvarna Group company division by a small group of dedicated people who saw a need for some kind of platform to support a new service offering. The first version was developed by external suppliers and did not follow any internal company development guidelines. In the second phase, the initial idea and concept was taken as input for a new solution co-developed by two in-house company divisions, that targeted different customer groups from the divisions. Customers accessed the platform by installing a smart and connected module to their products. They were then able to monitor their product fleet on a number of business-critical elements. The platform in project Beta is able to support customer operations in a number of ways by offering its own business logic, but can also provide data to other business platforms through data export.

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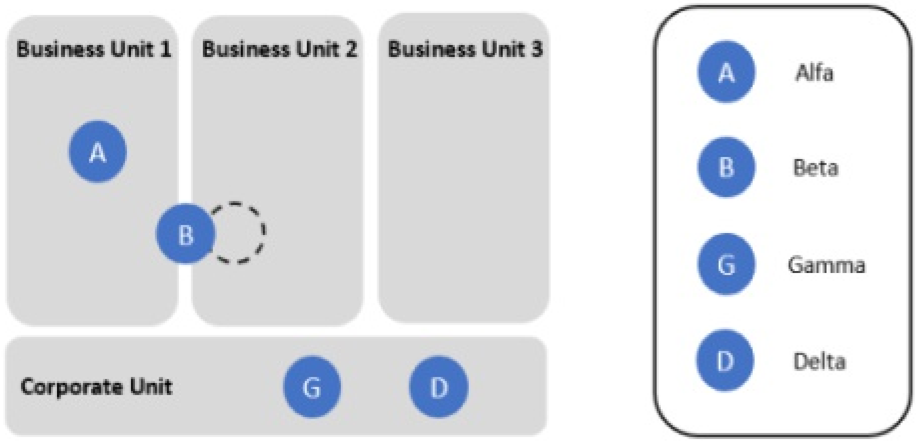

Purpose	Organization
Platform to accelerate operational excellence by connecting different digital sources into one.	Developed within one business unit
Platform which supports various fleet management issues	Initiated within one business unit, but later co-developed by two units
Platform primarily developed to address the sharing economy by being a rental platform.	Developed by corporate innovation team
Platform upon which different independent solutions could be developed	Developed by corporate unit

Figure 1. Project organization, project purpose and organization

When the research for this study was concluded, project Beta was in the second phase initiated by the executive management team, based on an understanding that both digitalization and service offerings will be important for the company going forward. The scope of project Beta included both upgrading the technology used, as well as reviewing service functionality and design in order to accommodate requirements from two company divisions. A formal project structure was put in place, including a governance structure that included senior managers from both divisions, as well as a formal agreement between the divisions regarding how to divide the project's cost.

Project Gamma

Project Gamma was developed as a platform that could be used to address the sharing economy. The intention was to facilitate easy access to Husqvarna products, based on a logistic flow where products would be stored in locations where potential customers passed by for other reasons, and could then rent products through a smart-phone based product service flow.

Project Gamma was developed outside the divisional structure of the company by an innovation lab at the corporate level. Project Gamma was also initiated by a small number of insightful individuals who early on had a vision and understood the potential of this platform. A project was formed with a few internal resources and external suppliers, and it did not follow any internal company project development flow

Project Delta

Project Delta is a platform that was initiated approximately at the same time as Alfa, Beta and Gamma as a platform to enable different service solutions, that is, to be a platform upon which several different offerings could be developed. The guiding idea was an understanding that some kind of common architecture will be needed, also for various kinds of service offerings, and that common governance for this architecture will be important not to end up with a scattered service offering platform landscape. With project Delta, the aim was that it should be possible to connect different data sources, reuse information, share components, and facilitate the combination of information into new solutions.

As seen from the above, the four investigated projects display substantial variation in how they were organized, and in particular how they were integrated with other parts of the company. A summary of the project objectives and organizational set-ups is presented in Figure 1.

Results and Analysis

Project Alfa

Project Alfa was initiated by a small group of individuals within one business unit. This team was directly responsible for improving aftermarket processes and developing new service offerings. They realized that a digital platform would enable that task. The team assessed the business value of a platform before the project started, and had the necessary seniority to anchor the project. There were also given access to internal company funds that could be re-prioritized for development of Alfa. The team was not given any particular corporate development guidelines to follow, or shared services to use, and also used an external solution provider for the platform's development.

Project Alfa became a lean project carried out with high speed. All major decisions were taken in a small group and were not restricted by guidelines and standard processes. It was early on decided to develop a minimum viable product (MVP) that could verify the value creation assumption parts of the business model, as well as prepare for further extensions to the platform in the future. There was also a common understanding within the team from the beginning that the platform would likely not be perfect from the outset.

The results of the interviews also identified several challenges in Project Alfa. One key challenge identified was a lack of development guidelines and shared technical components within the company that could be built upon. Another challenge identified was the difficulty of estimating total investment needs, as well as individual modules needed in the platform. One respondent expressed their approach, saying *"you need to narrow the scope in order to invest the money where it is needed the most".* (Director) Also, the lack of an existing formal and structured process of support and governance within the company, as compared to ones commonly used for product-based projects, was pointed out as a challenge from time to time.

Project Beta

Project Beta was, like project Alfa, initiated by a few insightful members of the aftersales department of a business unit, based on their understanding that there was an opportunity for a new service offering, for which the company needed a platform. Beta was also first developed by an external partner, thus it lacked Husqvarna Group corporate guidelines and support processes. The potential of Beta was identified by group management in the company and the project was assigned a budget and governance structure, this time with more seniority than product projects of similar size would have. Project Beta had a structure and anchoring that made it able to also handle scope changes in the middle of the project in a controlled way.

One major challenge in the project was to have consistent project participation throughout, from both partnering business units, as well as when the involved divisions needed to simultaneously handle other important business priorities. Several interview respondents commented that both divisions were not able to keep the same level of focus throughout the project, and that this dependied on the fact that some key resources needed to be assigned to other projects. Another challenge was that business modelling and Go-to-Market strategy were not part of the project. It was decided that both company divisions should be able to apply separate business model for the platform, and hence Go-to-Market and business model innovation were not included in the project at the start. Several respondents concluded that the project would have benefitted from an alternative approach, such that business model innovation would have taken place before the project started. One respondent expressed this saying, *"I believe we should have used the opposite approach, first understand what we want to offer to our customers and how we should charge them".* (Director)

One reason mentioned was that early business modelling would have given important input to the platform design, and to the prioritization among

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modules and functions.

Project Gamma

Project Gamma was developed by a central team focusing on digitalization and innovation, which has worked on different digital transformation projects for the Husqvarna Group. This team supports all business units with various digital transformation initiatives, but is not directly responsible for any business activities.

The project was initiated based on the insight that some customer groups may prefer to rent well maintained high-quality products when needed, instead of purchasing, owning and storing them for occasional use. The assumption was also that easy, self-service access to the tools had a high value. In order to prototype this concept and validate related business models, the Gamma platform was needed.

The team behind project Gamma was able to develop a new innovative digital platform with high speed and an entrepreneurial mindset. Gamma developed a successful proof-of-concept (POC) platform, but the project lacked the funding to run a full-scale verification of the platform. Running a verification project with several installations would have been expensive, but necessary in order to understand all business model aspects of the platform more thoroughly. One respondent expressed this need in the following way: *"it is first when you build the solution that you fully understand your idea"*. (Director).

Project Delta

Project Delta was initiated to be a platform upon which a large variety of different service offerings could be developed. Again, the idea came from a few insightful individuals in the company who realized the potential for a platform upon which a large variety of service offerings could be developed, thus removing the need for every service offer initiative (like for example in projects Alfa, Beta, and Gamma) to start from scratch with enabling platforms. Delta offers a well-structured and well-governed platform upon which a large variety of digital offerings can be developed. While none of the other projects Alfa, Beta, nor Gamma used components from Delta in the beginning, over time they transformed their development to use more Delta modules. Currently more than 50% of the Delta project's components are shared with the other projects. The benefits of building a single common base platform were deemed to be multiple. There are obviously costs which could then be shared, but it would also facilitate speed both in developing and scaling the market offer. Also, one common platform would create internal power within the company to facilitate transformation of internal structures and thus make it possible to create one seamless customer experience.

Some of the main challenges with Delta were that with an ambition for a common, cross-company platform comes a need for making shared priorities. This way the speed of individual offerings in the service projects may be affected, and these projects may then need to decide, in the interest of timely project execution, to develop something unique and tailored instead. This was expressed by one interviewee, who remarked that, *"doing things together also means a lot of planning and prioritization and availability of resources … so it might impact speed and freedom in innovation to some extent"*. (Vice President)

The team behind Delta identified Gamma as having many similarities with a product platform, yet without being a traditional IoT platform. It could instead be defined as a digital product-service platform. This was defined by one interview respondent as follows: *"This is more about a business platform to handle everything around the products; the user, the business models, traceability, documentation, content of different types, and of course other things like service management"*. (Vice President)

The following section relates the findings to the research questions and reviews key findings from the study.

RQ1: *How does business model innovation relate to digital product-service platform development in traditional manufacturing firms aiming for servitization?*

Product platforms have long been a well-established concept within the studied company. This study identifies an increased awareness of the growing need for digital product-service platforms, which can support various servitization ambitions. Earlier research has also identified that a platform approach can facilitate the enrichment of market offers, as well as keep costs under control (Cenamor et al., 2017). This research in this study sheds further light on how industrial companies should approach digital product-service platforms in terms of both scope definition and process. The importance of bringing business model aspects into projects early on, for example, when a company is employing new technology, has been pointed out earlier by scholars (Tongur & Engwall, 2014). Less is

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known, however, about the interplay between technological innovation, service innovation, and business innovation.

The case studies shown in this paper suggest that early business model assessment of a new platform is important in order to decide upon the right scope, and put focus on functionality that actually provides value for customers. In line with early business model assessment comes the finding of a need to start with a minimum viable platform that puts focus only on the most critical parts of the platform at first. This finding is consistent with previous literature suggesting that companies risk being caught in a servitization paradox if revenues from new offerings are not greater than the investments made to develop them (Gebauer et al., 2005). These case studies have also identified a possible dilemma in the digital product-service platform development process related to component re-use and platform incubation versus speed in development, as well as integration into business, respectively. The cases reveal that component re-use creates an opportunity to save costs in platform development, but possibly at the expense of uniquely tailored solutions and slower time to market. Also, a longer incubation time for new digital-product service platforms in a separate business development unit could benefit from verification of any assumptions made in platform design and scope. This may also, however, add to the costs and could delay integration with currently existing business units.

The observations in this research highlight that there was no process established for business model innovation in the observed cases and that ownership of development activities was also not fully defined. Instead, the entrepreneurial initiatives of a few individuals at an operational level became important in all of the studied projects, similar to the way corporate entrepreneurship has been argued to take place (Burgelman, 1983). This is somewhat surprising, as the systemic nature of platforms suggest that their introduction would actually benefit from a top-down approach to design and implementation.

RQ 2: *How is the inter-relationship between business model innovation and digital platform development managed?*

Several project steering models were used for the platform projects observed in this study. None of the projects in this study followed an earlier established process for digital platform development as gated and controlled, the way of those the company commonly uses for new (physical) product development. Observations made in this analysis suggest that in the absence of a structured process and governance structure, individuals become very important as advocates for the platform's needs, and as corporate entrepreneurs in its development. Earlier research shows that some degree of design autonomy may be beneficial when the designing process changes from existing business models, and may also imply a challenge when the innovation is to be later integrated with the business (Björkdahl & Magnusson, 2012). In a similar way, the digital platform projects Alfa and Gamma used their autonomy to develop innovative platforms, while Gamma later came to struggle with integrating itself into the business later.

The empirical observations of this study suggest it is more difficult to implement business model innovation the further away from the existing business that the new platform development is made. This is hardly surprising, as long-standing theory suggests that it is more difficult for substantially new business models to emerge in organizations that focus largely on existing market offers (Dougherty & Heller, 1994; Dougherty & Hardy, 1996). This points to a paradoxical situation that calls for new integration mechanisms that offer both enough autonomy for generating new business models, as well as a way to secure their "safe landing" in a suitable part of the established organization. Potential solutions for this could for instance be the use of formal processes and roles in the established organization that have the explicit purpose of finding a suitable organizational home for the innovations developed. Another possible integration mechanism could be the use of performance measurement and management systems that explicitly address the pace, novelty, and amplitude of innovation in existing businesses, thereby inducing more demand for embracing innovations from other parts of the organization.

Discussion

This research has identified a digital product-service platform as being similar to a business platform, which handles various aspects around products and supports new services and business models. Earlier research has identified that a platform approach may be valuable to support servitization efforts (Cenamor et al., 2017). This study adds to that knowledge by analyzing how a digital product-service platform type is developed in industrial firms, based on a study of four cases in different settings in one company. One key finding is that definition project scope, through early business model value assessment of its most important functions, is critical, and that building a minimum viable platform at the outset stands out as a preferable approach. A possible dilemma for innovative companies could be that even though a platform approach provides a cost-saving opportunity, it may at the same time constrain speed and freedom in innovation. Another dilemma involves whether or not to incubate new business opportunities supported by digital product-service platforms using a separate business development function, or rather to aim for earlier integration of the platform into existing business units.

Another finding in this study is the importance of a few key individuals, the main innovators, for identifying the need for new types of platforms. Such a need, at least in the initial phase, was not sparked simply by an internal process or higher management decision in the company. This may be a surprising finding for manufacturing companies where product platforms have long been used as a way of achieving strategic goals (Sköld & Karlsson, 2007), and where a systemic, top-down approach appears highly rational and thus preferred. The finding that an “entrepreneurial spirit” on the level of individuals was a key driver behind the studied digital product-service platforms, suggests the need to find an organization form where the legacy strategy approach can co-exist with a more autonomous entrepreneurial spirit. Burgelman (1983) discussed the notion that companies need both “diversity and order in their strategic activities to maintain their viability”, and suggested a model for corporate entrepreneurship under which autonomous strategic behavior is allowed to co-exist with more traditionally induced strategic behavior. How revolutionary a new digital product-service platform might become could perhaps be discussed. Yet it is well known that even established organizations need to generate innovation and possess flexibility, which is believed to be more associated with entrepreneurship than corporate management (Stevenson & Jarillo, 2007). Takeaways from this study also show that individuals provided not only the idea spark for new platforms, but also managed to exploit the idea in the early versions of these platforms, and eventually proved their value.

Taken together, the findings in this study points to a paradoxical situation that calls for new integration mechanisms, offering both enough autonomy for the genesis of new business models, as well as to secure their “safe landing“ in the established parts of an organization. Potential solutions for this could, for instance, be the use of formal processes and roles in an established organization, with the explicit purpose of finding a suitable organizational home for the innovations developed. Another possible integration mechanism could be the use of performance measurement and management systems that explicitly address the pace, novelty, and amplitude of innovation in existing business processes, thereby inducing more demand for embracing innovations from other parts of the organization. A third viable alternative could be to allow new types of offerings to be brought to market by new or separate business units, instead of always trying to integrate all new business opportunities within already existing business units, the latter which may hold product-related priorities or lack service competence. This implies that potential synergies between the old and the new in a company would not be realized, but instead increases the need to create appropriate conditions for new product-service offers.

Corporate entrepreneurship is commonly described as how established companies are able to exploit new ideas that differ from their existing offerings, while leveraging existing assets and resources (Wolcott & Lippitz, 2007). This is much in line with how new service offers related to existing product offerings in the studied company. It also reveals an understanding of the need for agility when creating these new offers based on the studied projects. This was put in an especially pointed way by one respondent: *“There are no alternatives in the digital world; you have to run faster than the competition”.* (Director)

This study also points to the importance of aligning business model innovation with platform development. It helps to put focus on the most important modules of a platform, and ensures that these are developed to suit existing and future business needs.

Implications for Theory

Previous research offers a wealth of knowledge on the value of platforms in general (Gawer & Cusumano, 2014), and there is already an emerging understanding of the benefits that a platform approach may also provide in servitization efforts (Cenamor et al., 2017). This study enhances the existing literature by adding new insights both regarding the definition of digital product-service platforms, and also how these platforms may actually be developed in manufacturing firms. Earlier studies have reported that early business modelling is important for discontinuous technology development (Tongur & Engwall, 2014). This paper similarly suggests that this is important also in digital

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product-service platform development, as business model innovation may guide development efforts to the most important modules. The findings further identify a couple of dilemmas related to component reuse versus uniquely tailored solutions and time to market, as well as in using an incubation approach.

The apparent key role of individuals to understand and grasp opportunities with digital product-service platforms has not been pointed out in earlier research, and will undoubtedly continue to be a challenge to align digital product-service platform development with corporate entrepreneurship.

Implications for Practice

The findings point in a direction where companies should potentially facilitate new opportunities for corporate entrepreneurs to drive the innovation of digital product-service platforms, as these are not yet as mature as product platforms.

Manufacturing companies aiming to develop digital platforms to support their servitization efforts can most likely benefit from attending to business model innovation before, or during platform development. To develop platforms that can support a wide range of core needs, in addition to more peripheral ones, clearly appears to be a questionable strategy, as this will add unnecessary costs and is likely to delay the platform's launch. Hence, companies should strive to develop minimum viable platforms, and then extend these platforms with necessary modules over time.

Conclusions

Digital product-service platforms may be quickly becoming an important facilitator for a variety of service offerings. These platforms aim to handle several aspects around the product and have more focus on supporting new business models than IoT. The context of a platform becomes important and hence makes it difficult to buy a turnkey solution on the market. This suggests that manufacturing companies should develop their own digital product-service platform or platforms, like in the studied company, but should also make sure to align their business model innovation with platform development, including how to integrate their platform or platforms with current business operations.

The entrepreneurial attitude of individuals who understand the complex drivers for a digital product-service platform, linking product data with services and business models, seem to be a most important asset, which companies should nurture and utilize for identifying a platform's potential scope. Corporate entrepreneurship is an earlier concept that has been suggested to allow more autonomous strategic behavior to exist alongside of classical processes (Burgelman, 1983; Wolcott & Lippitz, 2007), and which seem to be an approach which could be successful also in platform development.

Limitations and Future Research

This study was performed by focusing on four digital platform projects within one company. Future research should expand into several areas. First of all, it is clear that future research needs to include more manufacturing companies in order to understand if the findings made in the paper are more generally valid across the sector. Secondly, future research should look into how manufacturing companies may develop processes for digital platform development that cut across traditional product development logic. A third area that is definitely worth further research is how to include business model innovation early on in the development process of a new digital platform.

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Rapid Product Development in University-Industry Collaboration: Case Study of a Smart Design Project

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“ He will win who, prepared himself, waits to take the enemy unprepared.”

Sun Tzu
Chinese Philosopher

University-industry collaboration aims at mutually beneficial knowledge and technology exchange between higher education and business. Prototyping new products is one sweet spot where industry can gain new valuable knowledge and understanding of technology, while higher education institutions develop the skills and competences of students by encouraging them to work on authentic real-life problems. From the “design thinking” perspective, rapid product development can be defined as the creation of new products, in the shortest timescales possible, that meet the criteria of desirability, feasibility, and viability. This article addresses rapid product development by presenting a case study of developing prototypes in university-industry collaboration. As a result, the study highlights key design principles, such as the importance of involving teachers, business representatives, and students in collaborative project design, of focusing on the customers or service users who will benefit from the design, and of guiding students participating in co-creation activities. Presenting conclusions for both academics and the industry, the article contributes to design thinking and rapid product development in university-industry collaboration.

Introduction

Companies’ ability to innovate is more important than ever for improving their profitability and maintaining competitive advantage (Artz et al., 2010). Yet research has shown that only one out of four newly-developed products are a success (Evanschitzky et al., 2012), and approximately 40-50% of resources invested in product development are wasted on cancelled products or projects that yield poor results (Menold et al., 2016).

One reason for failure is a lack of flexibility in traditional research and development approaches that are typically based on waterfall development processes (Royce, 1987; Camarda et al., 2019). In contrast to traditional R&D approaches, where each functional department (for example, mechanical, electrical, software, manufacturing, service etc.) contributes sequentially to product development, more flexible approaches have been proposed, such as set-based design, originating from Toyota’s product design and development system (Sobek et al., 1999; Camarda et al., 2019). In set-based design, several alternative technological functional solutions are developed in a parallel process, thus enabling a shift between alternative solutions to take place at the very end of the product development cycle, with little or no need to return to earlier stages in the design process (Camarda et al., 2019).

Design re-use is one alternative solution for speeding up product development.

In the case available, pre-existing designed hardware and/or software modules, with well-defined interfaces, can be repeatedly reused in subsequent designs, which can lead to reduced cycle times and result in shorter time to market (Hölttä-Otto & de Weck, 2007). Shorter time to market and the increased fulfillment of customer needs were also the motivations behind a new stream that originated from the Silicon Valley startup scene, which is promising to radically transform product development practices. Customer development methodology began to question the narrow emphasis on product development and argued that companies should focus on learning about customers and their problems as early as possible in the product development process (Blank, 2007). What followed was the emergence of process models and canvases intended to guide the development of minimum viable products (Ries, 2011; Blank, 2013) or minimum desirable products (Sarvas et al., 2017; Pulkkinen et al., 2019) with the aim of delivering products both that customers desire and that are viable for the business.

"Design thinking" originated in the 1950s (Arnold, 2016), yet has recently gained popularity in business world (for example, IDEO, 1978), and gathered traction as an idea positing that any kind of business or organization can benefit from insights arising from a designer's way of thinking and working (Tschimmel, 2012). In design thinking, the lack of a design's desirability from the human point of view, the lack of technical and organizational feasibility of a design, along with the lack of financial and economic viability of a design from the organization's point of view (Plattner et al., 2010; Faljic, 2019), are considered central challenges. Following the logic of design thinking, rapid product development can be defined as the development of new products in the shortest timescales possible, whilst ensuring that the criteria of desirability, feasibility, and viability are met. Rapid product development in university-industry collaboration therefore needs to address these design specifications, and aim to deliver new products to organizations in the shortest possible time, while simultaneously developing student competencies and achieving targeted learning outcomes (Biggs & Tang, 2007; Kunnari et al., 2019).

Our main research question for the study is as follows:

> *What kind of design principles enable successful rapid prototyping in university-industry collaboration?*

In the pursuit of our research aim, the article is structured as follows. In the introduction, we first define our concepts, namely, rapid product development and pedagogical goals in university-industry collaboration. In the following two sections, the literature on co-creation in university-industry collaboration and on co-creation pedagogy is discussed to frame rapid product development in university-industry collaboration. The case study and method description involve the presentation of a multiple embedded case study of smart design projects carried out in 2019. In the findings section, we describe what we learned, outline design principles that were found to be conducive to successful rapid prototyping in university-industry collaboration, and explore how teachers can play a supportive role in facilitating the process. In the conclusion, we contemplate the results of the case study and consider their significance to design thinking and rapid product development in university-industry collaboration.

Co-creation in University-Industry Collaboration

Innovation is seldom a straightforward activity. It can be characterized as uncertain, co-constructive, experimental and interactive (Edvardsson et al., 2011; Jussila et al., 2019). Vargo and Lusch (2014) argue that the customer is always a co-creator of value, which is also the case in university-industry collaboration. University-industry collaboration aims at mutually beneficial knowledge and technology exchange between higher education and industry. Despite the growing interaction between higher education and industry, partners in university-industry collaboration often have challenges in utilizing the results of their joint efforts (Pennacchio, 2016; Kunttu, 2019). One root cause for the challenges is that the primary goal of universities is to create open and public knowledge, and provide education (Lee, 2011), whereas industrial partners have a strong focus on capturing valuable knowledge that can create competitive advantage, which is often directly associated with new product development and innovative company functioning (Bruneel et al., 2010; Lee, 2011). Thus, seemingly contradictory objectives, organizational goals, and culture have been found to limit the positive effects that can be achieved through university-industry collaboration (Gomes et al., 2005; Kunttu & Neuvo, 2019). Prototyping new products is one sweet spot where industry, as a customer for universities, can gain new knowledge and understanding of technology, and where higher education organizations can develop their students' skills while working to solve authentic real-life problems.

Several models have been introduced to enhance co-creation in university-industry collaboration. One of the most well-known models is the Triple Helix (Etzkowitz, 2003) principle that is based on the institutional triangle of government, business, and academia. The entrepreneurial university, following the Triple Helix principle, encompasses a 'third-mission' of economic development for universities, in addition to their research and teaching remit (Etzkowitz et al., 2000). Economic development can, for instance, take the form of delivering products and services (Kunnari et al., 2019) for business as part of education. Governments can support such activities by, for example, funding research and development projects that involve both business and academia. Carayannis and Campbell (2010) have further extended the Triple Helix model by introducing additional element of citizens and users to the institutional triangle of government, business, and academia, thus forming what has been termed the Quadruple Helix.

Co-creation Pedagogy

Co-creation pedagogy relies on the presence of common characteristics of competence-based education, as presented by Koenen, Dochy and Berghmans (2015). It includes the allocation of realistic tasks, the conduct of study in authentic settings, students' willingness to assume responsibility for their learning, reflection on the learning process, the performance of a facilitating role by teachers, and the use of competence-based assessment methods. When providing competencies to meet the demands of a rapidly changing and disruptive business world, flexible and innovative approaches to learning are crucial. Learning is not just for students, but also for teachers and business professionals (Kunnari et al., 2019).

Similar to the triangle in the Triple Helix model, co-creation pedagogy is based on the collaboration of students, teachers, and business representatives as important co-contributors (Kunnari et al., 2019). In order to correspond to a real working environment, the challenges and problems to be solved in co-creation pedagogy are designed together with the business world (Figure 1). Students are key actors in creating solutions for business, while the teachers' role is to guide the process. Inclusiveness is supported both by the teamwork of teachers and the collective learning of students. A very important principle is the freedom to ask questions, which means that students can always consult with teachers during the project work, in order to discuss and obtain advice on their problems. Guidance can also involve the development of specific skills, for example, how-to 3D print or laser cut shapes using various materials. Co-creation pedagogy thus emphasizes learning-by-doing by providing an authentic

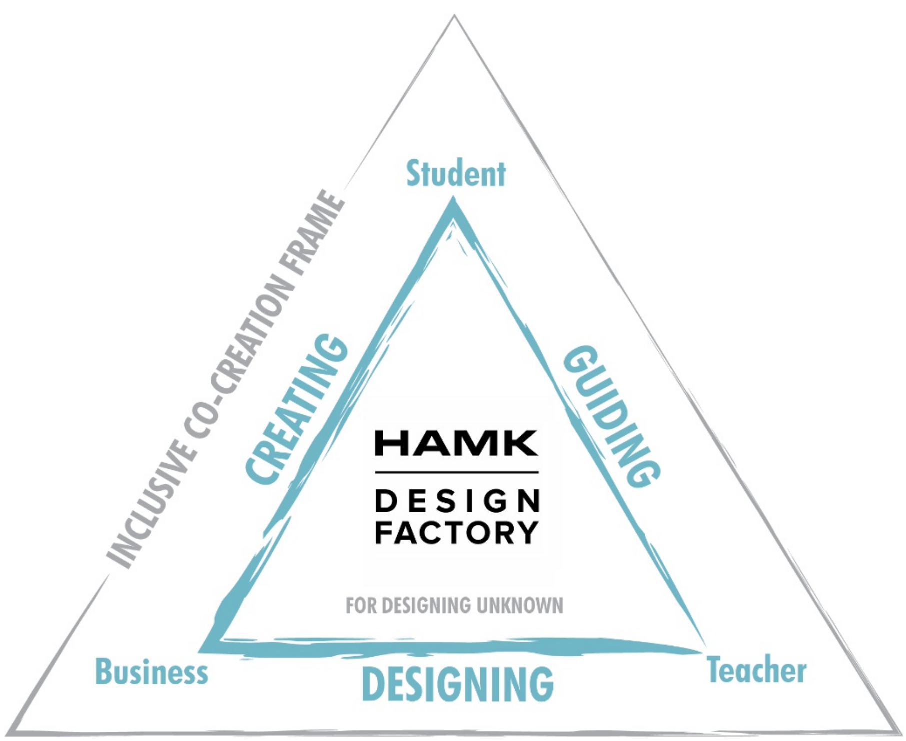

Figure 1. Co-creation Pedagogy

context where developing student competencies and targeted learning outcomes are tied to real and meaningful problems in the business world (Lombardi, 2007; Herrington et al., 2014).

Business challenges are often ambiguous, unpredictable and messy, involving many unknown factors (Faljic, 2019), and there is very seldom one single solution for any challenge. That is why the co-creation pedagogy, design tools and mindset provide a good model for building interdisciplinary student teams to solve ambiguous challenges. Businesses are often learners themselves in the process. In co-creation pedagogy, the shared journey itself is valuable, rather than only the end result. Co-creation pedagogy allows the formulation of a response to the original project challenge and, when found desirable, feasible and viable, also allows for course correction, that is, pivoting (Ries, 2011). Several iterations of any solution may also be devised, based on the active learning that occurs throughout the project's duration.

Design Thinking

The concept of "design thinking" is a simplified approach where problems are approached and solved through collaboration and systematically creative methods. It is a non-linear approach that enables challenges to be resolved through iteration. The key characteristics of design thinking methodology are that it offers person-centered and cross-disciplinary ways of identifying creative solutions to problems. Design thinking methodology aims to develop a holistic view of the subject, meaning that it focuses on the needs, values, and experiences of all stakeholders in order to obtain the best possible solution to a given problem through collaborative work (Luchs et al., 2015). Design thinking supports the mindset of co-creation pedagogy as both their key characteristics and methods arise from equal, multidisciplinary co-creation and person-centered approaches.

Several process models have been proposed and defended as the most appropriate for applying design thinking in business and innovation (Tschimmel, 2012). Some of the most well-known models include the 3 I model (Brown, 2009) and the HCD model (http://www.ideo.com/work/human-centered-design-toolkit), both developed by IDEO, the double diamond model from the British Design Council (http://www.designcouncil.org.uk), the service design model (Stickdorn et al., 2011) and the design thinking model of the Hasso Plattner Institute (http://www.hpi.uni-potsdam.de/d_school/designthinking) (Tschimmel, 2012). A variant of the design thinking model (Figure 2) of the Hasso Plattner Institute was selected as the process model in this study, as it has been previously applied in courses by the authors conducting the case study. The design thinking process has five aligned stages, but acts as a non-linear process where different modes contribute to the whole. The five stages of the process are: Empathize, Define, Ideate, Protype, and Test. The goal of the process is to gain understanding of the users, confront their assumptions, define the frameworks in which problems exist, create new and tangible solutions for prototyping, and test the prototypes in real environments where meaningful data can be generated (Interaction Design Foundation, 2019).

The first stage of the design thinking process is to empathize and understand the problems the team strives to solve. Empathizing provides the platform that enables the information gathering necessary to locate enough information about the users, their needs, the user context, and any existing problems in the status quo. The second stage, Define, guides the team to gather data from multiple sources, and transform it into information. The real problem should then be identified, and user-centered problem statement clarified, in the Ideate stage. Ideating is literally the stage for creating new ideas from conducted research, for seeking alternative ways to solve the acknowledged problems, and for using ideation tools to create a vast array of new ideas. From ideation, the process proceeds to the Prototype stage, where the created ideas are sorted, and the most viable ideas investigated and subsequently improved or rejected. Prototyping will show the restrictions regarding the problems and products and provide a clear vision of how the final product will operate (Interaction Design Foundation, 2019).

Throughout the design thinking process, different questions arise during each phase. In the Empathize phase, the major questions, for example, are: Who is the user? What is the user's job to be completed? Where is the user doing this job? What is the purpose of the job to be undertaken? What is currently preventing the user from tackling this job? What are benefits of the job to be done? In the Define phase, typical questions may be: What is the problem worth solving? What is causing the problem? What are elements of the problem? What is nature of the problem? Which part(s) of the problem should be solved? Why has the problem occurred? In the

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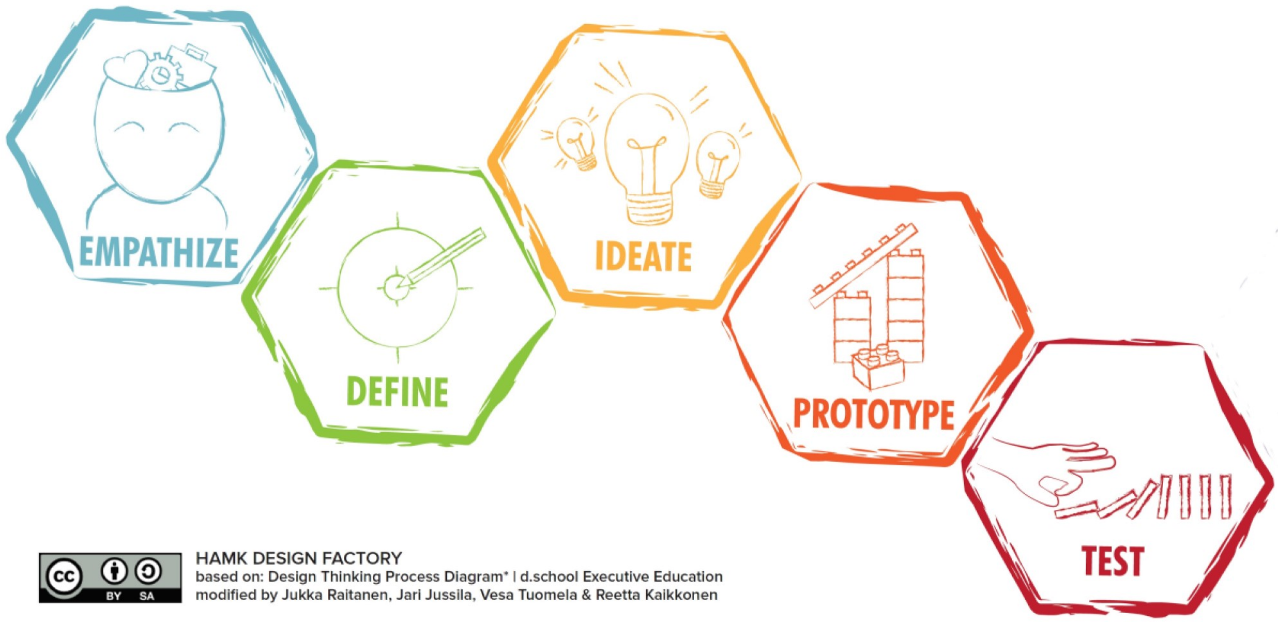

Figure 2. Design Thinking Process

Ideate phase, typical questions formulated, for example, may be: How might we solve this? (Berger, 2012) How might we design a solution? In the Prototype phase, a typical question is: How can we construct a model that would change the user experience? (Berger, 2012). In the Test phase, key questions include: What is the riskiest assumption we should test? What is unknown and important to test and know? Thus, learning through inquiry, during every phase of the design thinking process, is essential.

Case study: A Smart Design Project

We chose a case study approach (Siggelkow, 2007) to explore rapid product development in university-industry collaboration. In our case study, the theories of co-creation, design thinking, and rapid product development were identified via the existing literature. Next, an embedded multiple-case study was carried out in 2019 using action design research methodology in a university-industry collaboration involving two external organizations: a glass factory and a startup company. The context of the case study is an interdisciplinary Smart Design Project organized at HAMK Design Factory.

HAMK Design Factory is the twenty-fifth design factory to join the Design Factory Global Network (Björklund et al., 2019). Located in Hämeenlinna, Finland, it provides an interdisciplinary product, service design, and learning platform that unites students, teachers, researchers, and industry professionals (Jussila et al., 2019). The Smart Design Project organized in HAMK Design Factory lasted from June 10th to July 3rd 2019, and involved a course for students from mechanical engineering and production technology, electrical and automation engineering, business information technology, and construction engineering.

The idea of the course was to instigate intrinsically-driven development action that would result in the co-creation of a new smart design prototype to meet the specifications of the project challenge design. Originally, there were five project challenges, and students selected four of them to work on. The teaching staff belonged to Design Factory and School of Business and Entrepreneurship at Häme University of Applied Sciences, and were business, technology, and design lecturers. The project challenges were co-designed with representatives from the case organizations, and these challenges were then presented to the participating students.

The targeted learning outcome of the course were that each student team would create a rapid prototype of the project challenge in four weeks, while simultaneously developing new competences, such as design thinking, service design, 3D-modeling and printing, and working with programming microcontrollers. A design thinking process (Figure 2) was used as the process model for the

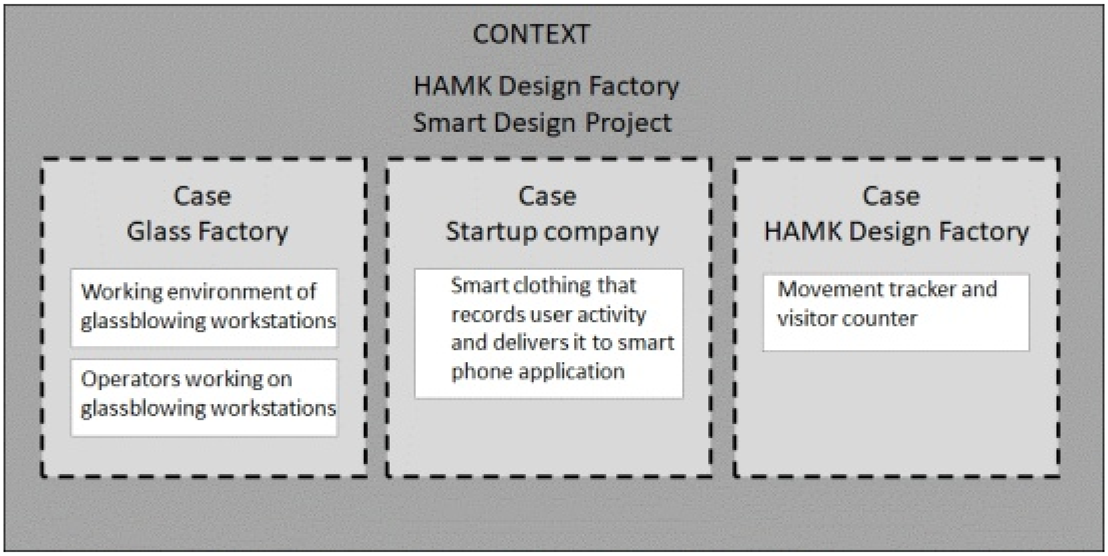

Figure 3. Case Study Description

case projects.

The glass factory was a business owner in two of the project cases. The glass factory cases were both related to developing employee wellbeing at glassblowing workstations in the glass factory. The challenge was to gain new knowledge and understanding of the working environment and conditions that surrounded the glassblowing workstations, as well as to increase the wellbeing of the operators who perform glassblowing. The startup company was owned by a business working on the development of smart mobile phone applications that would collect data on users' activities, and use this data to engage and reward users based on their behaviors. HAMK Design Factory, in addition to providing the context, was also the owner of a case study focused on developing movement counters and visitor tracking for factory spaces.

Findings

The students were first introduced to design thinking and service design. However, the application of the design thinking process was not uniform in the case projects. The degree to which each student team followed a design thinking process is illustrated in Table 1. Each team ideated one or more prototypes to be built during the four-week period. Only one student team was successful in testing their prototype during the four-week duration.

Due to the time limitation of the project, the students aimed to rapidly devise solutions and, for the most part, swiftly advanced through the Empathize and Define stages. A crucial advantage, during the first phases, was that the glass factory provided an opportunity to visit and explore the glassblowing workstations, and for the students to interact with employees that were participating in the development project. Progressing promptly into the Ideate and Prototype stages meant that neither the problem, nor the users' needs, were profoundly investigated in all the cases. Thus, the solutions created ran the risk of being irrelevant to customer goals. The glass factory played an active role also in guiding the teams from early stages of the process toward focussing on the meaningful aspects of glassblowing operations. An active approach from the customer helped both the students and teachers guide their activities towards a desirable outcome for all stakeholders.

A key finding from the glass factory case was that having an active partner to assist with the guiding process, and to provide valuable knowledge, was crucial for the student teams' success. This is due to the fact that with limited knowledge, both the Empathize and Define phases are prone to failure. Only the student teams that worked on the glass factory cases were able to develop a prototype during the four-week period. The student team working on a device for measuring workstations temperatures and environmental variables was able to develop and built a prototype that was sold and put to active use in the glass factory after the project. The students working on a smart vest for operators were able

Table 1. Design Thinking process steps applied in Smart Design Project cases

	Empathize	*Define*	*Ideate*	*Prototype*	*Test*
Device for measuring workstations	x	x	x	x	x
Smart vest for operators	x	x	x	o	-
Steps and calories counter	x	x	x	-	-
Visitor counter	x	x	x	-	-

to develop and document a concept for their prototype, although time ran out before they could build and test the prototype. The smart vest case can, however, be considered a success from the industry perspective since the learned experiences contributed to a bachelor's thesis that developed and completed the prototype after the project had ended.

An important finding from the startup company case was that the business owner defining the problem must be active throughout the project in order for the design thinking process to have a higher probability of achieving desired results. The business challenge can be made more tangible through discussions and meetings with different stakeholders. If the activities are lacking during the Empathize and Define phases of the process, the results will incur a greater risk of being vague, and of failing to deliver the desired value, both for the students and the business owner.

The HAMK Design Factory case yielded a similar finding: students may be competent at ideating autonomously, but, in order to improve the likelihood of attaining desired results, active interaction between the parties is required. In the three cases that did not achieve their desired goals, enhanced guidance from the teachers could have improved the results.

In summary, giving the students the freedom to operate relatively autonomously opens up unique study paths and solutions, and empowers the team members to act independently, thus transforming the role of the teacher into that of a coach. Having an active business partner to help with the advisory process and to provide valuable knowledge is crucial for ensuring the student teams' success. When this guidance is lacking, teachers should adopt a more active role in facilitating interactions.

Conclusion

Co-creating rapid prototypes in university-industry collaboration was found to be an exciting and meaningful learning experience. Success and failure, when evaluated in terms of desirability, feasibility, and viability, is mostly influenced by the co-design of the challenge by business professionals, teachers, and students. This combines with opportunities and activities designed to generate empathy with the user, defining the problem based on understanding the user and the customer journey, in addition to efforts taken to build and test the prototype. The challenge needs to be future-oriented, open, and ambiguous enough to facilitate and foster student autonomy in the project (Björklund et al., 2017), but not so future-oriented, open, and ambiguous that the students are unable to decide upon any definitive course of action.

Defining the problem without conducting the Empathize phase is a good recipe for creating unsatisfactory results from the user's point of view. This supports previous findings of the necessity of relational learning, which includes sharing knowledge, joint sense making, and integrating new knowledge into the relational memory of active partners (Kunttu, 2017; Selnes & Sallis, 2003).The teachers can indeed facilitate and support the Empathize phase, but based on this case study, the key to success is that industry professionals take an active role in the co-designing of the problem, as well as providing opportunities for students to empathize with end users. Recommended

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practices for knowledge sharing include enabling students to visit the site, making observations and experiments, and interviewing users. Joint sense making can be enhanced by organizing workshops with industry partners, where both students and teachers participate. By working closely with industry partners, students can validate their learning at university by testing their theoretical assumptions and hypotheses against success criteria that are perceived as important by industry itself. The benefit for industry of being active in co-designing and on the Empathize phase is that they do not waste time and effort waiting for solutions that provide little value for them. In this way, they also learn valuable knowledge about the users and their needs. Direct interaction between students and industry partners also helps to foster trust between partners that has been found to simulate rich social and information exchanges, and encourage more and valuable knowledge sharing (Ring & Van de Ven, 1992; Kunttu & Neuvo, 2019).

The aim of integrating knowledge into the relational memory of project partners is most supported by the Prototype and Test stages, thus producing practical results (Kunttu, 2017). Previous research has discovered that a without a prototype it can be difficult to communicate and integrate knowledge across different professional and student boundaries (Björklund et al., 2017). This also happened in the cases during our research that did not reach the Prototype stage. The prototype developed for a glass factory was found feasible, desirable, and viable by the company, and was modified for continuous use by the factory's engineers. Whereas the other glass factory student project, in contrast, ran out of time for creating a physical prototype, , it nevertheless created valuable knowledge that was continued in the form of a thesis project. This also shows that relationships between university and industry can develop during student projects that lead to deeper collaboration between the partners.

From the perspective of developing and organizing courses, we discovered that when students apply the d.School's five-step design thinking process for the first time, an additional preliminary step of Prepare must be undertaken, before the subsequent five steps, in order to fully orient the students into design thinking. In the Prepare step, introducing, defining, and absorbing the core concepts, as well as recalling a good product experience, are the proposed activities to be conduct as a way of inducting students or practitioners in design thinking. As for the definition of rapid prototyping in university-industry collaboration, we propose that it can be measured in terms of time taken to successfully complete all the design thinking process phases. In design thinking philosophy, the prototyping project is not complete until the product is tested and assessed. The prototype testing, if found to be unsatisfactory with regard to desirability, feasibility, and viability, will nevertheless yield new insights about users and help in redefining the problem. Thus, design thinking steps need to be repeated until satisfactory results are achieved, or until it is decided to abandon the prototyping project in light of increased understanding and knowledge gleaned on the topic. From the higher education perspective, the failure of a rapid product development project undertaken collaboratively with industry can, however, provide a valuable learning experience, while the students' development of personal and professional competences is not tied to the project's results. The project thus provides the business owners with useful new information, even if the expected result was not achieved. As a process, it requires commitment in terms of communications, as there are several variables, and that all stakeholders have access to the same information on where the project is being taken during each of the different phases.

In the optimal situation, all vertices of the triangle (Figure 1), that is, students, teachers, and business professionals, jointly learn while co-creating a rapid prototype in the shortest feasible time interval. The experiences of our case study indicate that rapid product development in university-industry collaboration is mutually beneficial, and from the students' perspective provides an authentic and meaningful approach for developing competences for their future working lives.

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The Role of Academics, Users, and Customers in Industrial Product Development

Leena Kunttu, Yrjö Neuvo

"Not all smart people in the world work for us. We need to work with smart people inside and outside our company."

Henry Chesbrough (2003)

Industrial research and development (R&D) is often adopted as a leading strategy for innovation in high-technology firms. It has been recognized that collaboration with external actors has become increasingly crucial for R&D practices in a world where product and service innovation are increasingly challenging for companies involved in knowledge-intensive technology areas. Thus, high-technology firms are increasingly engaging in collaborative relationships with external stakeholders to transfer valuable new knowledge for industrial purposes, or to create new knowledge through a joint learning process. These external stakeholders may include research institutes such as universities, customer firms, or end users of the firm's products or services. Academic involvement in industrial innovation projects has traditionally focussed on the early stages of a product's development process, when new ideas and innovations are being developed. On the other hand, the interaction between a firm and its customers takes place during the final stages of the R&D process, when innovations are brought to market. In this paper, we explore how users and customers can be involved in university-industry collaboration projects from the beginning of the product development process. Based on a case study comprising five long-term university-industry collaborations in Finland, this paper presents collaborative practices through which academic actors, users, and industrial customers may actively take part in the industrial innovation processes.

Introduction

Following the principles of open innovation (Chesbrough, 2003; Enkel et al., 2009; West et al., 2014), high-technology firms are continuously augmenting their research and development (R&D) capabilities with external players that are able to provide them with valuable knowledge, competences, and capabilities. This is particularly true for industrial actors operating in the knowledge-intensive technology areas, such as the information and communications technology (ICT) sector (Bellini et al., 2018). Indeed, there are a number of reasons to involve external partners in industrial R&D processes, including the existence of rapid technological changes, strong markets and competition, the complex nature of innovation processes with high levels of uncertainty, short product life-cycles, and the costs of internal product development (Bellini et al., 2018). Laursen and Salter (2004) showed that firms seeking opportunities to collaborate with external partners such as suppliers, customers, or even competitors, may gain more from collaboration with academic institutions. Thus, a trend has arisen that has strongly stimulated the growth of university-industry collaboration (Morlacchi & Martin, 2009), with technology firms increasingly absorbing and exploiting the results of academic research through collaborative university-industry relationships (UIRs) (Perkmann et al., 2013; Ankrah & Al-Tabbaa, 2015; Kunttu & Neuvo, 2018).

However, in addition to academic partners, industrial firms often involve their customers and end users of their products in product development (Gruner & Homburg, 2000). This is particularly important for firms operating in business-to-consumer markets (B2C) with rapidly changing consumer trends, user expectations, and high competition. On the other hand, firms operating in industrial areas of business-to-business markets (B2B) are increasingly involving customer firms in their R&D processes in order to better understand customer needs and expectations. However, to achieve the desired results of innovative UIR collaborations,

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firms must be able to commercialize the results of their innovative collaboration projects with external stakeholders, such as academics, users, or customers (Thursby & Thursby, 2000).

The importance of commercializing the results of collaboration with university research has been recognized in many academic studies in this field (Siegel et al., 2004; Perkmann et al., 2013; Weckowska, 2015). Nevertheless, few studies have actually explored what kinds of practices can help facilitate commercialization in terms of organizational learning (Weckowska, 2015). In this study, the focus of the research lies in the involvement of users and customers in UIR collaborations.

Several studies have explored and highlighted the facilitating role of customer involvement in improving R&D performance and innovation in high-technology firms (Gruner & Homburg, 2000; Un et al., 2010). However, previous research has not studied what kinds of roles customers and users may play in the commercialization process of university-industry collaborations. This paper aims to address this gap, seeking to answer the following research question: *What kinds of practices facilitate customer and user involvement in UIR collaboration?* By seeking answers to this question, the study examines practices related to customer and user involvement in successful UIR commercialization processes, through a multiple case study of five UIR cases in Finland. Practices related to customer involvement were examined through inductive, qualitative research based on interviews, which was useful in this context for analyzing organizational practices related to stakeholder collaboration.

Background

Acquiring and absorbing new state-of-the-art knowledge for a new product development process is a central challenge for firms operating in high-technology areas. To stay ahead of their competitors in terms of innovation performance and product development outcomes, the firms must search for knowledge outside (Asakawa et al., 2010). Thus, collaboration with a network of different external partners and stakeholders has become crucial, and firms are actively exploring opportunities for collaborative relationships with external partners (Emden et al., 2006). In research collaborations carried out in UIRs (Perkmann et al., 2013; Ankrah & AL-tabbaa, 2015), industrial actors share and jointly develop new knowledge with university partners (Kunttu, 2017; Kunttu & Neuvo, 2018). Academic involvement in UIR collaboration typically contributes to the early stages of industrial firms' product development processes (Gruner & Homburg, 2000), as presented in Figure 1. This is because academic involvement in industrial projects often generates new ideas. Nevertheless, the commercialization of UIR innovations has traditionally been executed as an internal industrial process, not usually involving research partners.

On the other hand, industrial firms often involve their customers and end users in the final stages of product development, for example, in piloting or testing newly developed products or services (Gruner & Homburg, 2000). In this manner, customer involvement in product

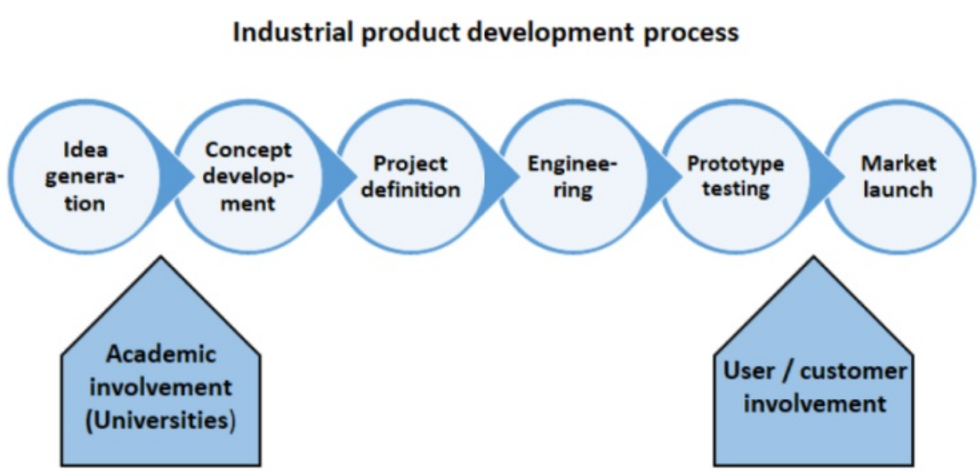

Figure 1. A traditional approach for stakeholder involvement in industrial firms' product development process.

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development usually focuses on the incremental improvement of current products, rather than on generating new ideas and possibilities for future products (Danneels, 2003 & 2004; Un et al.a, 2010). Moreover, Gruner and Homburg (2000) have suggested that a firm's collaboration with customers best contributes to new product success when customers and users are involved in the later stages of the product development process, especially product testing activities — stages that are directly related to commercialization (Figure 1). However, as indicated by Gruner and Homburg (2000), customer involvement could also potentially contribute to the earliest stages of product development in terms of generating ideas, if this kind of interaction is correctly facilitated. The purpose of this paper is to investigate how customer and user interaction with industry could be combined with academic interaction taking place in UIRs, and how these two types of interaction could jointly contribute to industrial product development and commercialization.

University collaboration with industry typically contributes to the early stages of the process whereas the main focus of customer involvement lies in the final stages. This paper analyzes the role of user and customer involvement in UIR collaboration and, in particular, their impact on the commercialization process of collaboration outcomes. Since customer relationships can be seen in two distinct ways: relationships with B2B customers and direct relationships to end-users (B2C), these customer relationship types are being analyzed separately. The first group of relationships with *customers*, includes the firms who are an industrial partner's B2B customers. Involving customers in R&D collaboration (Cohen et al., 2002) helps collaboration partners to understand customer preferences and needs, which in turn contributes to the joint innovation process between collaboration partners (Un et al., 2010). The second stakeholder group are the *end-users* of an industrial firm's products, representing the consumers that may provide collaboration partners with valuable, experience-based knowledge using products. Understanding end-user expectations, needs, and favors is essential for companies that provide products and services for consumers.

Methodology

To explore what kinds of organizational practices may facilitate the involvement of customers and users in successful university-industry collaboration, and in this manner enable commercialization of collaboration results, a comparative, qualitative case study was conducted. The main case data collection method was interviews, but additional secondary data such as corporate brochures and archives, Internet information, and partnership descriptions were also used. The case studies were selected in a purposive manner to find long-term and close collaborative UIRs that had yielded successful results in terms of commercialized results from the collaboration. In addition, in all the selected cases, the customers or users were involved with the industrial partner in the UIR collaboration.

For the interviews, we designed and used a semi-structured template. The template focused on the commercialization process by asking interviewees to tell about the process that yielded successfully commercialized innovations in their UIRs. Special focus of the interviews involved industrial firms' customers in the UIR. The interviewed industrial managers named their key collaborators on the university side, who were usually leaders of research groups. This way, the most appropriate people for the selected case study were involved, such that all the respondents were key persons in cases representing the selected UIRs. Interviews were recorded and transcribed. To maintain confidentiality of interview data, the analysis presented in this paper identifies interviewees only by position.

This paper has five cases, as summarized in Table 1. Cases A, B, and C represent situations in which industrial firms collaborated with universities. This collaboration had a clear and significant involvement of the firms' users (B2C). In cases D, E, and F, the UIR collaboration involved firms' customers (B2B). In addition, case C also involved the firm's customers.

Case descriptions

In case A, a technology firm developing software for mobile devices had close collaboration with its university partner in the area of algorithm development. User experience is a very important aspect in the firm's final products, so it decided to include a user experience analysis on the scope of the joint development project. In practice, this meant that the university partner made user experience testing for new technologies that they were jointly developing. According to the firm's representatives, this kind of joint activity brought clear additional value to the project results, and also lowered the threshold to commercialize the results of the joint development activities.

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Table 1. A summary of case descriptions for the studied UIRs involving users or customers

	Case A	*Case B*	*Case C*	*Case D*	*Case E*	*Case F*
Industrial area	Mobile devices	Telecommuni cations	Heating systems	IT systems for logistics	Machinery for construction and mining	Electrical equipment and systems
Relationship age	Five years	Three years	Six years	Four years	Six years	Four years
Area of the joint R&D projects	Software and algorithms	Service products	Service products	Smart services for logistics	Service products	Service products
Stakeholder group involved in collaboration	Users	Users	Users and customers	Customers	Customers	Customers
Participants of case interview (industry)	Research Manager	Development director	R&D Director	Global program manager (R&D)	R&D Director	Head of R&D unit

In case B, a technology firm operating in the area of telecommunications collaborated with its university partner to develop new services to its users. In this kind of service product development, the role of user experience is essential, and for this reason, the collection and analysis of user experience data of the new services was an important part of collaboration.

Case C also presented a UIR collaboration case in which the partners jointly developed new service products for the firm's end users. For this, the collection and analysis of end user expectations and needs were examined at the beginning of the project, and also at a later stage when the developed services were introduced to the users. In this case, the collaboration also involved an analysis of the development of the firm's B2B partners, including retailers and service partners.

In case D, the company involved some of its key customers in pilot R&D projects, which relied on long-term research collaboration with a university partner. In this collaboration, pilot customers tested, and the results of the research were verified under real market circumstances.

In a similar manner, case E presents a UIR in which an industrial firm's key customer was involved to test and give development feedback on the innovative solutions developed in the UIR.

In case F, the firm's key customers were involved in a practical research project carried out with the university in terms of a commercial pilot.

Results

Analysis of the case interviews and secondary data revealed a number of practices for commercializing UIR collaboration results. This section discusses the most prevalent practices for commercialization categorizes based on three central facilitators of collaboration: industrial partners' customer relationships, academic knowledge, and university student work.

Utilizing an industrial partner's relationships to its customers and users in UIRs

Involving customers and users in new product development has been shown to have a clear positive impact on new product success, especially in the final stages of the product development process (Gruner & Homburg, 2000). For this reason, it may be beneficial for industrial firms to involve their customers and users in the collaborative research process with their university partners (Un et al., 2010), who typically contribute to the early stages of product development (Markman et al., 2008). The role of user involvement in UIR collaboration was analysed in cases A, B, and C, whereas cases C, D, E, and F represent customer involvement in UIR research. In all cases, the collaboration between the firm and university were developed around a specific product or service development task. The involvement of users or customers was selected for a key research area in a joint project. The interviewees in cases considering end-user involvement (A-C) described this in the following manner:

> *Our research collaboration started some years ago as a joint research project that contributes to our consumer product development. However, quite soon we understood that it is important for the research project to collect field data from end-users to understand how the users really use our products (IND, A).*

> *In our business area, the role of consumer experience is very important. Therefore, it was really good that we could use the consumer data analysis as an input in our university collaboration project that was related to service development (IND, B).*

Thus, the interview data reveals that firms making research collaboration with universities in the area of consumer products see it as important to use end-user information as input in joint development work. The university researchers also had a very positive attitude towards this kind of collaboration, but pointed out that the consumer information could be utilized even more in UIR collaboration, since analysing user data also provides researchers with topics for developing scientific outcomes from the collaboration:

> *I feel that consumer and customer involvement fits very well to the scope of our joint development projects with industry. Our industrial partner has been very satisfied with the results of this kind of collaboration, and we as a research institute have been able to utilize the data collected from users (UNIV, C).*

> *Publishing research results is often difficult in industrial research projects. However, user experience aspects in these projects are usually not so sensitive to industrial partners, who often allow us to publish the results related to consumer behavior (UNIV, B).*

According to the interviews, the cases related to user involvement in research collaboration projects (A-C) focused on both ends of the product development projects:

> *In our collaboration, we were able to obtain valuable end-user information regarding the usage of our current products, as well as ideas for new features to be developed for future products (IND, A).*

> *Consumer data collected in the project contributed both to the creation and conception of new services as well as improving our current services (IND, B).*

In the surveys executed in our university collaboration projects, we collected user data concerning both feedback on our current products, and also obtained ideas for new services to be developed (IND, C)

Thus, the interview data indicates that when users are involved in UIR collaboration, a project may focus on both early stages (idea generation and concepting) and late stages (consumer testing and market launch) of the product development process. The interviewees in cases A-C had quite coherent opinions that this is a clear benefit compared to traditional UIR research projects that typically involve only early stages in the process:

> *When the users are involved in university collaboration, we definitely obtain more concrete research results, which contribute directly to our consumer products (IND, A).*

> *Consumer data was crucial input for our joint development work with university (IND, A).*

In cases representing customer involvement (C, D, E, and F), the industrial partners involved some of their key customers in research collaboration. The main motivation for industrial partners in this kind of collaboration was to enable smooth commercialization of technologies they were developing with universities:

> *Co-creation with our pilot customers is quite active in our own R&D. We have also a long tradition of making research collaboration with universities. In some projects, we have been able to combine these two things, which really helps us to implement the results of research collaboration and test them with*

pilot customers (IND, D).

We have developed a new technological solution in our joint research project with our university partner. Now, one of our large customers has been involved in this project, and it will test the prototype in its real working environment. Our university partner also collects information on this testing and uses it for further development work (IND, E)

Making a commercial pilot with one of our key customers clearly helps us to reach valuable results in the current collaboration project with the university (IND, F)

The interviews in cases D, E, and F reveal that industrial firms may facilitate the commercialization of university collaboration research results by adopting their customers to the final phases of the development process (Gruner & Homburg, 2000). When these "lead customers" test the prototypes together with the firm's R&D and university researchers in real circumstances, researchers and industrial developers may collect valuable data and feedback on product usage. This, in turn, helps the collaborating partners to take steps for further development:

For us, our university partner contributed our service development work by facilitating interaction with our key customer firms, for example, by interviewing customer representatives. This steered the development work a lot (IND, C)

Thus, the interview data from our study indicates that involving customer firms in university collaboration helps facilitate the commercialization of joint development work by means of prototype testing and product validation. This finding is in line with the conclusions of Gruner and Homburg (2000), who indicated that customers' contribution focuses on the later stages of product development. However, the interview data also showed that customer involvement has in many cases also impact on the early phases of the process (idea generation):

The customer firms have ideas that are related to the improvement of the products by means of new features and properties. The customer interviews made by the university partner helped us to collect and systematically utilize these inputs (IND, C)

Sometimes our pilot customers have innovative ideas that may initiate new R&D projects. These projects are typically carried out together with this customer and our university partner (IND, E)

Combining academic knowledge with customer input

One of the researchers' key interest areas in the interviews was to understand industrial firms' motives to involve their users and customers in research collaboration with universities. The industrial interviewees agreed that the main benefits for them lies in academic competences and scientific knowledge that can be complemented with user and customer experience knowledge that most university partners also possess:

When we decided to involve the user experience aspects to our research project with the university scientists, the project team was extended with new researchers who were concentrating on consumer experience. They carried out the user studies related to our project, and we could utilize the results in the project (IND, A).

In our research project, we have utilized data collected from both users and customers. In both cases, the university researchers have been in a key role, since they have had both scientific understanding, and practical skills to make surveys and interviews of our users and customers. They have also analyzed the results and have made good suggestions how to use them in our product and service development (IND, C).

Thus, the interviews highlight the importance of multi-disciplinary capabilities of university research teams: the university partner should be able to provide the industrial collaborator with both technological knowledge, and understanding of user or customer relations. For this reason, the universities have utilized multi-disciplinary teams in their industrial projects:

In our research team, the main competence area is technology development. However, we have seen it beneficial to extend our teams with people having backgrounds from marketing, consumer interaction, or psychology. This way, we can provide our industrial partner an optimal combination of competences for both technological and user experience understanding (UNIV, B).

I have seen in many previous industrial projects that

Category:	*User Involvement* (*Cases A, B, C*)	*Customer involvement* (*Cases C, D, E, F*)
1) Utilizing the industrial partner's user/customer relationships in UIRs	- Collecting and utilizing data on the end-user experience within UIR collaboration projects - Analyzing consumer behavior aspects in terms of surveys or interviews	- Collecting and utilizing data on the customer experience within UIR collaboration projects - Collecting and analysing the data from joint development work carried out between a firm and its pilot customers
2) Combining academic knowledge with customer/user inputs	-Involving a UIR project with user experience experts having backgrounds in marketing, psychology, or management	-Involving multi-disciplinary research teams - Utilizing inputs from the sales department
3) Employing students and university research staff in customer interface	-Employing university students in field data collection -Utilizing a student's understanding of consumer behavior	-Employing university students in the collection of customer inputs via interviews

Table 2. A summary of collaborative practices identified in this paper

> *pure technological understanding is not enough. For this reason, we have gained competences, for example, for marketing and management in our research team (UNIV, C).*

While utilizing multi-disciplinary university research teams in collaboration is important, it is also crucial that industrial partners involve cross-organizational teams in UIR collaboration:

> *We found it important to involve also our marketing people and people responsible for customer relationships in this collaboration. They know the customers best, and they can help the researchers to make contacts with customers. It is also very beneficial to analyze the results of customer studies with them (IND, C).*

> *Involving pilot customers in joint research projects means that we involve also our sales department in the project. This way, the university researchers get inputs from both customer, sales, and R&D. I think that this is really beneficial (IND, D).*

Employing students and university research staff in the customer interface

Experiences involving university students in research collaboration between industry and academia in terms of innovation and idea generation have been promising (Kunttu, 2017). In all the cases analyzed in this paper, students have been somehow involved in the joint research project between university, industrial firm, and its customers or end-users. The interviewed industrial managers underlined the role of students in the project, particularly in collecting field data from product users

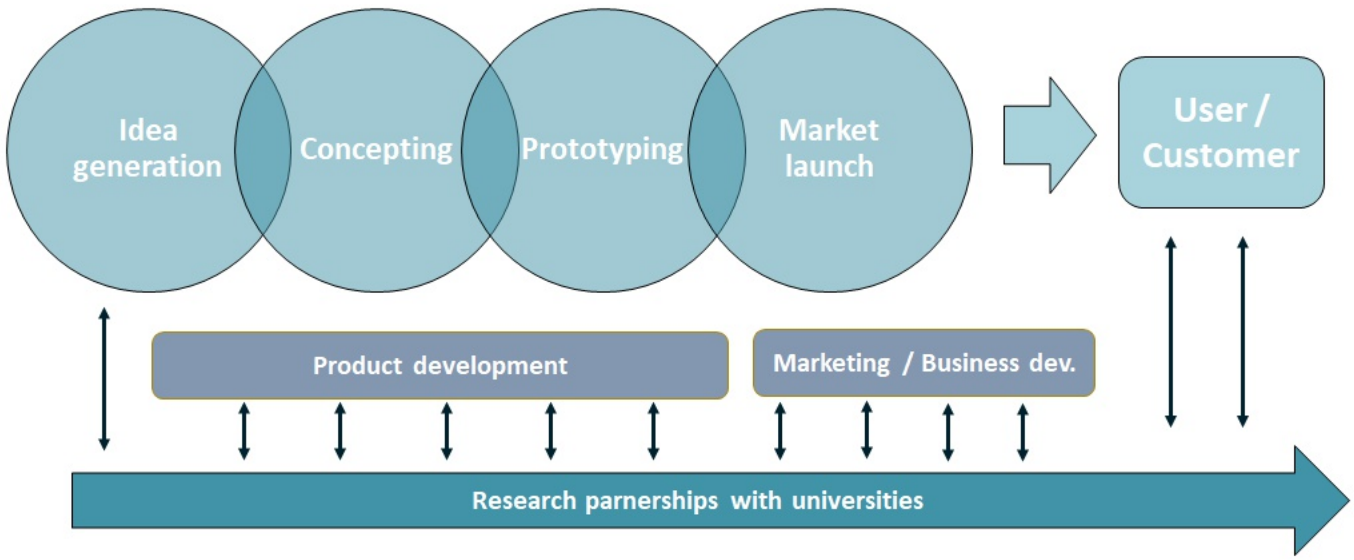

Figure 2. A model of the academic involvement in university-industry collaboration.

(Cases A-C):

> *In our joint project with a university partner, the university students made an excellent job when they collected field data from our product users. This way, we were able to get very valuable information on the users' opinions related to the real usage of our products, and in particular to the new features that we were developing (IND, A).*

> *The university partner provided us an opportunity to use student groups to make user studies as a part of our larger collaboration project. The groups collected information from our current users and also potential new users, and we really learned a lot about user experience and expectations related to our services. I feel that these findings were one of the key results of the whole collaboration (IND, B).*

> *The user studies carried out in different phases of our research project with university really steered the project targets and scope in the right direction. At the end of the project, the user feedback collected by the students really helped us to understand the potential of the service products that we had developed (IND, C).*

Again, the interviewees in cases A-C felt it valuable that when working in user interface the students collected data at both early and late stages of the product development process, which confirms our earlier indication about contributing both to the product development cycle. The students were involved in customer involvement in case C, whereas in cases D and E, the students and university research staff were mostly involved in customer interaction:

> *The students made valuable work in interviewing the customers along with university researchers (IND, C).*

The university partners also appreciated the students' contribution in the research collaboration:

> *I have employed student groups in several industrial research projects. In my experience, one of the most fruitful ways of working for students is to operate in the end-user interface. This is probably due to the fact that the students can easily take the position of a consumer, and they can also collect consumer information easily from their networks (UNIV, B).*

> *Students are eager to contribute to the industrial projects and they are pretty good in making consumer interviews, surveys, and other data collection from the field (UNIV, A).*

Academics should be involved in the whole productization chain beginning from idea generation to customer and user involvement. This requires academic skills and competences to collaborate with a variety of different stakeholders.

Conclusion

The goal of this paper was to investigate user and customer involvement practices in UIR collaboration, and in particular, to understand the collaborative practices by which users and customers may be involved in UIR collaboration. The key practices recognized in this paper are summarized in Table 2.

The main findings of the paper are as follows. First, an analysis of six UIR cases showed that involving users and customers in joint research efforts between universities and their industrial partners clearly helps the partners to commercialize the results of their research collaboration. Involving users and customers in UIR collaboration helps companies and universities to extend the focus of joint research also to later stages, which are directly related to commercialization, as summarized in Figure 2. For this reason, university research staff should nowadays acquire skills and competences to collaborate with a variety of stakeholders. These stakeholders are not only users and customers, but also industrial partners' marketing and business development organizations, who are mainly responsible for commercializing new products and services. Second, user and customer feedback, opinions, and experiences represent very important inputs to product development and new product success. In this sense, they are also valuable inputs for practical-oriented UIR research projects.

The interview data showed that involving user and customer inputs with academic research capabilities brings clear benefits to UIR projects, thanks to the multi-disciplinary capabilities of university research teams, which can combine scientific knowledge with understanding of user behaviours and customer relations. Third, user and customer involvement fit well with university-industry collaboration. This is because universities have good capabilities to interact and communicate with users and customer firms, collect consumer data, and make different kinds of user or consumer studies as a part of their research. The interviewed industrial managers appreciated this, and agreed that this kind of interaction clearly adds value for UIR research collaboration between the firms and universities. The interviews also emphasized the value of university students in collecting and analysing consumer and customer data.

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Agile Product Development Practices for Coping with a Learning Paradox in R&D Offshore Units

Janne Kuivalainen, Iivari Kunttu, Marko Kohtamäki

> *[The product development] person has to feel that a customer is looking over their shoulder, one who is really looking for some added value that we can deliver by leveraging our systems. That's one of the key principles of how we develop ourselves, how it drives our innovation.*
>
> Interviewed Head of R&D offshore unit

R&D offshoring involves the relocation of in-house R&D activities to subsidiary units located in other countries, often associated with low-cost engineering work, to meet global operational requirements. The main motivation behind R&D offshoring by global technology companies is usually to utilize local resources, knowledge, and competencies provided by geographically dispersed subsidiaries in the most effective manner, which in most cases involves high expectations for project performance. However, offshore units often have their own local interests, such as developing their activities to compete with the company's other global R&D units, by not only building their project performance, but also demonstrating learning and innovativeness. This causes a learning paradox in which the R&D unit is expected to possess capabilities for innovation and learning, while at the same time demonstrating a high product development performance. This paper presents a qualitative case study that analyzes how R&D managers in the offshore units of a global technology company can cope with conflicting tensions between learning and performance. The results present a variety of coping practices that are based on developing local innovation strategies, constant learning, and supporting local innovation culture. The results also underline the meaning of agile working models in facilitating local innovation activities.

Introduction

As an important part of globalization, the world has witnessed a movement of industrial manufacturing work from developed countries to countries associated with low-cost operations. However, over the last few decades, knowledge-intensive product development work has increasingly shifted from high-cost developed countries to countries with lower costs of engineering work, and the internationalization of research and development (R&D) activities has emerged as an important practice for global technology companies. The internationalization of high value-added product development activities has been referred to as "the next generation of offshoring" (Einola et al., 2017). R&D offshoring provides companies with opportunities to gain competitive advantage by utilizing skilled and cost-effective labor in emerging markets (Parida et al., 2013). In this manner, R&D offshoring can be seen as a process whereby a globally operating company relocates its in-house product development activities to other countries, often associated with low-cost engineering work. Integrating the capabilities owned by these offshore units is a special advantage of global technology companies (Yamin & Andersson, 2011), and utilizing the competencies and capabilities developed in these units may help the parent unit to improve the company's competitiveness (Birkinshaw & Hood, 1998). Previous studies have shown, however, that the coordination of R&D activities across geographically dispersed units is a challenge for the parent units, which in turn may have a negative impact on R&D performance (Parida et al., 2013).

On the other hand, because subsidiaries are typically embedded in various local networks in their own geographic regions, they may develop and maintain unique and idiosyncratic patterns of network linkages. This, in turn, helps the subsidiaries to be exposed to new knowledge, ideas, and opportunities provided by their local networks (McEvily & Zaheer, 1999). This differential exposure has been regarded as one of the basic competitive advantages of multinational firms, because it increases the breadth and variety of network resources (Ambos et al., 2010; Andersson et al., 2002). As the main motivation of the parent unit (or headquarters) is to utilize the local resources, knowledge, and competencies provided by the geographically dispersed subsidiaries in the most effective manner, the offshore subsidiaries often have their own local interests to develop their activities. This is because the subsidiaries frequently have to compete with each other in the company's global R&D unit network in order to maintain or increase their status in the view of headquarters. In this context, the R&D offshore units located in countries with a relatively low cost of engineering work have to maintain and develop their project performance, as well as demonstrate learning and innovativeness to the parent unit(s) (Kunttu et al., 2019). In this manner, offshore units attempt to maintain and improve their position among other R&D units with whom they are competing globally, not only by offering a lower cost of work, but also by their resources and capabilities (Lewin at al., 2009; Bäck & Kohtamäki, 2016; Kunttu & Kohtamäki, 2018). This means that offshore units have to demonstrate innovation performance by engaging in strategic goals and targets set by the current competitive environment, and the views of headquarters (Ambos et al., 2010). This, in turn, means that the managers of the R&D offshore units are increasingly facing a dilemma of how to encourage their product development staff to engage in exploratory innovation, and to simultaneously ensure that the R&D function meets its performance targets in terms of project timings and costs (Lewis et al., 2002). This general dilemma is shared by R&D managers in countries with both a high and low cost of engineering work, and it can be seen as a learning paradox, in which the R&D organization is expected to have high innovation performance and learning capabilities, yet at the same time must simultaneously demonstrate high project performance (Kunttu & Kohtamäki, 2018; Kunttu et al., 2019). The previous literature on organizational paradoxes shows that these kinds of situations can seldom be solved, but rather that organizational members may develop practices to navigate them by "both-and" thinking (Smith & Lewis, 2011; Jay, 2013; Kohtamäki et al., 2020).

In this paper we focus on improving the understanding of how R&D offshore units located in countries with a low cost of engineering work may develop their dynamic capabilities to compete with other R&D units in the same company, not only in terms of labor costs, but also based on their product development skills and capabilities. This is an obvious learning challenge for newly-established offshoring units, provided that they may occur at significant geographical distances from their parent or partner units, and often have a limited knowledge base, with different cultural backgrounds (Einola et al., 2017). For this reason, local R&D management has to make efforts to develop and learn the new capabilities of these units.

Thus, this study aims to answer the following research question: *How can managers of R&D offshore subsidiaries develop learning capabilities and at the same time maintain project performance?* This study addresses the research question by analyzing the coping mechanisms related to the learning-performance paradox, and by both identifying the managerial practices that facilitate simultaneous engagement in project performance targets and, at the same time, maintaining learning and innovation performance. The qualitative case study is based on interviews conducted in offshore units of a global technology company located in Poland. In this manner, this study contributes to the research work on R&D offshoring by presenting practices of learning and competency development in R&D offshore units. The findings of this paper can have important managerial implications, given that global technology companies are increasingly offshoring their knowledge-intensive R&D work to countries with lower costs of engineering work.

Developing dynamic capabilities in R&D offshore units

R&D units of technology firms often operate in dynamic environments characterized by strong competition, rapid changes, accelerating product life cycles, changing customer expectations, and product discontinuities (Marsh & Stock, 2003). In addition to these general challenges, geographically dispersed R&D subsidiaries have to cope with tensions caused by project performance expectations set by their parent units, and on the other hand, demonstrate learning and innovation capabilities (Kunttu & Kohtamäki, 2018; Kunttu et al., 2019). To successfully develop and sustain their competitiveness under these environmental circumstances, the technology units need to develop dynamic capabilities that enable them to draw on, extend, and redirect their technological capabilities and R&D resources (Marsh & Stock, 2003). Dynamic capabilities have been defined as: "The firms' processes that use resources – specifically resources to integrate, reconfigure, gain, and release resources – to match and even create market change. Dynamic capabilities thus

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are the organizational and strategic routines by which firms achieve new resource configurations as markets emerge, collide, split, evolve, and die." (Teece et al., 1997). Accordingly, dynamic capabilities represent organizational processes by which an organization's actors employ their resources to develop new value creation. Creating and maintaining valuable resources, skills, and capabilities can be an important dynamic capability for geographically dispersed R&D units when they contribute to a company's common R&D targets.

Previous research in the area of business relations has acknowledged that subsidiaries often contribute a parent company's competitiveness through innovation, knowledge sharing, and transfer, as well as by identifying new business opportunities (Reilly et al., 2012; Reilly & Sharkey Scott, 2014). Literature on the role of R&D subsidiaries emphasizes the processes of initiative-taking and utilizing local opportunities in the competition between subsidiaries (Ambos et al., 2010; Figueiredo, 2011). Both of these activities can serve as a means for coping with the competing demands of learning and performance in the subsidiaries. Enterprising subsidiaries may utilize their specific and sometimes unique local knowledge, as well as their specific skills and competencies to generate initiatives (Figueiredo, 2011). This kind of initiative generation may mean that the subsidiary unit develops internal innovation by taking advantage of its own capabilities or local opportunities (Kunttu et al., 2019). However, as offshore units typically have only minimal power to make decisions concerning their own projects and tasks, they have to find ways to allocate their resources for their own innovation development work. For this reason, internal development work typically takes place in isolation, and often without explicit approval from the parent company (Reilly et al., 2012). In this paper, we concentrate on managerial practices that may facilitate this kind of internal innovation development in R&D offshore units.

Methodology

This paper is based on a qualitative case study approach and examines three R&D offshoring units in a global high-technology firm. The R&D units in question are all located in Poland, and represent product development capabilities of large high-technology firms operating in various areas of information technology. Table 1 summarizes the information gathered on the three R&D units. The empirical data collected for the study involved interviews based on discussions with managers of the R&D and innovation functions in each unit. The selected interviewees were key decision makers concerning R&D and innovation in their organizations, as listed in Table 1. All the interviews were recorded and transcribed. The interview data were analyzed by the authors after the interviews were completed.

Results

In this section, we analyze the data acquired from three company case studies. The analysis is divided into three subsections. In the first subsection, we aim to find answers to the research question from the viewpoint of strategy-based management, by identifying local-level innovation practices that help managers to cope with tensions between learning and performance. In the

Table 1. Description of case studies

	Case Study A	Case Study B	Case Study C
Location	Poland	Poland	Poland
Number of employees in R&D unit	330	200	18
Main products/ services	Software development and electromechanical engineering	Software development	Software development
Position of the interviewee	Head of the R&D unit	R&D site leader	R&D team leader

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second subsection, we analyze learning practices in local R&D teams. The third subsection focuses on practices supporting innovative culture at local level. Table 2 summarizes the identified managerial practices.

Local innovation strategies
In one of their case studies, Kunttu et al. (2019) found that the tension between exploitative project performance and explorative innovation spurs competition between the globally dispersed R&D units.

> *"Competition [between offshore units] means looking at quality, response time, need time, and customer satisfaction that drives a little bit more innovation and operational excellence on our side." – Case Study B*

In practice, R&D performance is measured by quality, response time, on-time deliveries, or customer satisfaction. In addition to achieving short-term performance targets, R&D units have to simultaneously stretch their capacity to innovate and learn. In many cases, innovation and learning capabilities have been regarded as a competitive advantage for geographically dispersed R&D units (Bäck & Kohtamäki, 2016; Kunttu & Kohtamäki, 2018). Local R&D management should therefore accept the expectation of constant explorative learning in product development, while simultaneously maintaining competitive levels in project performance. At the local organization level, this can be regarded as a learning paradox. As has been indicated by the literature, these kinds of contradictory tensions can seldom be solved, yet organizational members may develop practices to navigate the paradoxes by "both-and" thinking (Smith & Lewis, 2011; Jay, 2013; Kohtamäki et al., 2020). Exploratory learning in R&D subsidiaries can be facilitated by developing local innovation strategies that are often informal and salient (Kunttu et al., 2019). When asking R&D managers about the factors that drive local innovation, direct customer engagement was emphasized:

> *"When we sit with external clients around the table and we are discussing what kind of futures our systems need, how they may cover the requirements and expectations … [the product development] person has to feel that a customer is looking over their shoulder, one who is really looking for some added value that we can deliver by leveraging our systems. That's one of the key principles of how we develop ourselves; how it drives our innovation." – Case Study A*

Local R&D management sees direct customer contact as key for local innovation and value creation. This can be regarded as initiative-taking at a local level (Ambos et al., 2010; Figueiredo, 2011), in which the R&D unit develops and maintains its own relationships with customers, which in turn helps the subsidiaries get exposed to new knowledge, ideas, and opportunities that are provided by their local networks (McEvily & Zaheer, 1999). As discussed in Kunttu and Kohtamäki (2018), local-level initiative-taking plays a key role when local R&D managers have to cope with the contradictory demands of learning and performance. These initiatives include local-level practices regarding innovation development work, which is typically implemented in an unofficial and salient manner. Thus, as R&D resources are mainly allocated based on project performance targets, local R&D management has to arrange "flexible time" for innovation, and the development of new ideas. The interview data revealed local-level practices for this:

> *"One of the ideas that we are trying to implement right now is that we have some fixed time inside the product slot of part of our capacity fully allocated to innovation … we are trying to put some systemic space, or build the space, for this innovation to work with our processes, that they somehow ensure that we have time for that." – Case Study B*

Interestingly enough, local R&D managers explained that by creating efficient and automated routines related to, for example, testing and administration, the R&D unit may save time that can then be used for learning and innovation work:

> *"Continuous testing and continuous delivery of SW in every sprint enforces the quality and allows us to work with new ideas and technological innovations when they can be integrated into standard product development cycles. High quality enables innovation activities." – Case Study B*

In the same manner, the costs related to time spent on innovation and administration are added as overheads to the product development hourly rate:

> *"We included in our real life a couple of hours or an amount of time people can devote to developing their idea. … This development can be also idea or innovation generation events, yes, so it means that I already calculated this as a part of our hourly rate." – Case Study A*

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Supporting learning

In all three cases, the meaning of constant learning was underlined as a necessary condition for innovativeness in each organization. The development of core competencies was seen as a strategic asset in the competition with other R&D units:

> *"I believe what we need to learn is how to collaborate with partners, external partners. It means two things actually. The first one is to really fully and deeply understand what has to be on our side, what has to be our core competency, what has to be our very well integrated and embedded capability on our side. The second thing is partnership means dealing with our partners and making sure that we can develop this partnership very well in certain areas."– Case Study A*

Again, initiative-taking in collaboration with external partners and customers was emphasized as a strategic learning challenge. Along with stating the importance of recruiting new and promising talents for R&D work, the interviewed managers suggested a number of practices related to constant learning in their daily R&D work.

> *"We encourage people to actually try new technology, try new stuff, to go to some interesting conferences from which they actually can gain knowledge." – Case Study C*

> *"Going to different conferences and training regarding the technology and keeping people up to date with what's happening in the world and what are the efficient ways of coding, what are the efficient ways of ensuring quality and constantly learning, that's definitely one of the key elements of R&D." – Case Study B*

In addition to formal learning events such as training, courses, and conferences, the interviewees emphasized the importance of locally-invented learning practices, such as hackathons or learning workshops, in which the R&D staff came together to watch live streams of conferences or engage in pair programming:

> *"We organize the hackathon after working hours so we start after 5pm. The goal is actually to use some technologies that we are not working on every hour on a daily basis." – Case Study C*

> *"To have the opportunity to do live streaming or to watch live streams online of different events like the Microsoft Build or Google IO. Sitting in the in the afternoon watching and commenting and exchanging online what they are seeing, etc., commenting on those things." – Case Study A*

> *"[In shared learning events] they do the pair programming during that, and the pair that is programming is on the projector, on the big screen, and other people in the room can see how they code, what tools they use, what shortcuts they're using, things like that." – Case Study B*

According to the interview responses, managers appreciated informal learning events as opportunities for their staff to get involved with new technologies. This in turn has led to initiative-taking on an individual level:

> *"People somehow, even maybe they don't realize, but being active after hours in different conferences, different communities, different meetups, they're processing what they see, what they learn at these events and immediately believe they associate the technology, the discussions they have around software technologies. … Usually, after such meetings, they are back to the office, they are approaching us as leaders, and they are saying, 'I have seen something good which we could potentially implement in our centre." – Case Study A*

In all three cases, the product development organizations had adopted and deployed agile and lean development methods driven by iterative improvements. All three R&D managers underlined the effectiveness of the use of agile principles, especially in terms of project performance. To support agile working models, R&D organizations have full-time agile coaches for their teams. The role of these coaches is related more to mental models, rather than tools or processes:

> *"[T]he quality of our R&D or quality of our work is definitely a full commitment to lean development and agile development. With each iteration, you can see what brings value, [and] what does not bring value. That's why we have a couple of agile coaches among our teams. They go through all teams and they check this mental model." – Case Study A*

Again, the meaning of quality was emphasized. The interview data also present an interesting link between agile working procedures and innovation work:

> *"What we try to implement in our team is to so-called*

Table 2. Summary of the identified practices

Topic	Practice category	Identified practices
Local innovation strategy	Fostering local innovation	Arranging flexible time for innovation work. Workshops with external customers to verify needs, requirements and expectations. Drive for productivity and the utilization of automated tools in, for example, testing and administration, increases time for learning and innovation. Opportunities for formal and informal learning.
	Initiative-taking	Developing and maintaining relationships with local partners. Direct relationships with external customers. Local innovative projects and initiatives that have an impact on customer value.
	New ways of organizing R&D work	Arranging flexible time for innovation by automating processes related to, for example, administration and testing routines. Including innovation time with daily project work. Agile and lean development methods driven by iterative improvements. Facilitation by full time agile coaches and focusing on mental models instead of tools or processes.
LEARNING: Supporting learning	Identifying new technologies	Participating in learning events, conferences, and other events. Hiring new talents who know new tools and technologies and who can drive their introduction into old products.
	Supporting competency development	Pair programming workshops. Hackathons. Live streams from tutorials and learning events.
CULTURE: Innovative culture and structures	Innovation mindset	Organizing guided hackathons where idea generation is framed by challenges with the current product or service by product management. Measuring how many innovation ideas from hackathons and other idea-generation workshops are delivered with products. Encouraging "fail quickly" mindset.
	Encouraging entrepreneurial mindset	Organizing large units into smaller product-oriented teams and ensuring connections between them. Product teams gain business knowledge to become capable of managing clients and products to create value and quality.

> *'fail quickly'. It means that I'm trying to convince people they shouldn't be afraid to try something, just to check if it's going to work or not." – Case Study A*

Innovative culture and structures

In the spirit of agile development, local R&D management may also decide to make organizational changes that enable more efficient and entrepreneurial mindsets and working models. In practice, this may mean that larger units get organized into smaller product-oriented teams that have strong connections and interactions between each other:

> *"It means the team can get knowledge, experience the capability of dealing with such products, with such clients. Really going through all details from software level to customer. Even what the customer looks like when they sleep, when they get up, why, etc., so that's the first thing. How to make sure that everything, how to build up this idea or bring this idea to the next level." – Case Study A*

As a part of the agile innovation mindset, the R&D organizations also measure how many innovative ideas from hackathons and other idea-generation workshops are delivered within the products:

> *"[W]e run innovation tournaments, [and] innovational idea-generation, hackathons. [At] these kinds of events we measure how many ideas out of those events have been implemented within our product. It means that we can show that we took some effort to generate ideas and we already took some effort to make sure that those ideas are running things on customer sites. We measure this and we report this on a monthly basis." – Case Study A*

Conclusion

This study set out to understand how local R&D management in R&D offshore units develop capabilities for learning and innovation while simultaneously maintaining project performance. In the previous literature, this tension has been regarded as a learning paradox (Smith & Lewis, 2011; Jay, 2013). Following the results obtained in Kunttu and Kohtamäki (2018), and in Kunttu et al. (2019), the analysis of our work on three cases demonstrates the paradoxical tension between performance targets and demands related to innovativeness in daily R&D operations. At a general level, tension exists in knowledge-intensive R&D work where performance targets related to time schedules and project cost represent "tough targets" that must be met by R&D organizations. In addition to these formal requirements, the local offshore unit must be able to provide added value for the parent unit by demonstrating innovativeness and capabilities for learning. In this manner, the offshore unit must be initiative-taking and innovative (Ambos et al., 2010), despite the fact that it has only minimal opportunities to affect decisions regarding their projects and resources.

The main contribution of this paper has been to present several managerial practices that managers of local R&D offshore units may use to balance between contradictory demands and project performance. The identified practices were divided into three main categories: strategy, learning, and culture. In local-level strategies, the key coping practices include initiative-taking and maintaining direct relationships with customers. In this manner, offshore units may use direct customer views and initiatives as direct inputs for their local-level innovation development. The offshore unit managers seem to use initiative-taking in arranging "flexible time" for R&D teams to develop their own innovation projects. This flexible time can be arranged by, for example, organizing R&D work in a more agile manner, applying automated processes in administration and testing, or including some extra time in project work. Despite the fact that these kinds of arrangements are typically made without explicit approval from the parent unit, they provide the offshore unit with the only way to develop internal innovation, which in turn increases customer value and provides the unit with a competitive advantage compared to other offshore units.

Concerning the learning practices, the interviews revealed a number of local-level practices that facilitate learning and competency development. In parallel with formal learning opportunities such as training, the interviews highlighted informal learning opportunities such as hackathons, programming events, and various kinds of conferences and meetings, in which the R&D staff may gain insights into new technologies and methods. In the third category of innovative culture and structures, our research revealed that local offshore unit managers may encourage an innovation mindset in their units by arranging guided hackathons and other activities around selected innovation themes. In this context, an entrepreneurial mindset in companies has been facilitated to go along with organizational change, and by introducing performance metrics for innovation-

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oriented activities.

As a managerial contribution, the paper presents a number of practices that will potentially help local management in globally dispersed subsidiaries and offshore units to cope with tensions between project performance and fostering local learning and innovation. These practices relate to creating local strategies for initiative-taking in innovation development, learning, and competency development, as well as facilitating innovation management in R&D teams.

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Company Offers to Meet the Needs of Business-to-Business Customers: Strategies and Orientation

Mikko Mäntyneva

"Culture eats strategy for breakfast."

Peter Drucker
Father of management

Companies develop and refine their market offer by creating new products for current and potential customers. Customer-focused research and development (R&D) is expected to shorten the time to market, improve cash flow, and reduce risks. It considers both customer strategy as well as customer orientation. In practice, this means that customer strategy directs current and potential customers to a company's offering, while customer orientation allocates R&D activities to meet customers' needs. This paper contributes to customer-driven R&D research by investigating whether a company's offer meets customer needs that can be supported by customer strategy and orientation. Specific focus is given to companies operating in business-to-business (B2B) markets. The paper is based on an analysis of quantitative survey data from 292 respondents representing key account management and sales management professionals in Finnish firms across several industries. The findings indicate that offer meeting customers' needs are supported by customer strategy and orientation. The paper provides guidelines on how companies can align their research and development activities to address both existing customers as well as current and potential needs and requirements.

Introduction

The question of whether a company's market offer meets the needs and requirements of its current and potential customers is crucial from the perspective of its competitiveness. In case there is not a good match between market needs and what a company intends to sell, the investments in new products related to research and development (R&D) activities will be difficult to justify.

R&D can be interpreted as one of the most critical areas of a company's competence related to business success or failure (Calabrese et al., 2005). While implementing R&D activities, successful companies understand that they should be proactive in their customer relationships, and involve customers in ongoing dialogue and relationship building (Alam & Perry, 2002; Yakhlef, 2005). Modern agile and iterative product and service development methods are often efficient, but in case the target market's needs and requirements for newly developed products are not served, the outcome will be unsatisfactory. On the other hand, it can be assumed that in case a company has a customer-focused culture, and its customer strategy emphasizes meeting and satisfying the needs and requirements of its existing customers, it will help to increase the company's overall competitiveness.

This article assumes that a company's competitiveness in markets depends on its value proposition, that is, that what is being offered to customers meets the customers' needs and requirements. The value proposition consists of products, services, and solutions. The role of R&D is important for a company's competitiveness in selected markets and individual major business-to-business (B2B) customer relationships. In case a company's offering does not meet their customers' needs, it is assumed that customers will find other suppliers. This explains why a company's offering can be extended and improved by its R&D activities (Svendsen et al., 2011; Chuang et al., 2015).

While previous marketing and R&D literature has

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covered customer needs as a basis for product development (Krasnikov & Jayachandran, 2008), the customer strategy perspective presented in this article contributes by providing additional information on the topic. Also, from the perspective of managing an overall R&D portfolio, time to market and cash flow perspectives are both important. It should be therefore be emphasized that R&D should not be implemented in isolation, but rather from the perspective of a company's current customer base, which especially in B2B markets provides better opportunities to shorten the time to market, as well as improve the cash flow of product related R&D investments.

In B2B markets, in which a few individual customers may generate the majority of a company's revenues, the company must focus on its current customers, and how the value proposition meets their needs. Another perspective is whether the market offer could be further developed to increase customer satisfaction, customer loyalty and commitment, share of customer, customer profitability, and other relevant aspects that support a company's growth and prosperity. Increased competition for relatively few available B2B customers in a market serves to emphasize the importance of a company's market offer. Matching its offer with the needs of a company's current and potential customers makes it more immune to competitive pressures.

This article focuses on studying whether a company's market offer meets the needs of customers and is supported by their customer strategy and orientation. This raises the research question: *can a company's market offer meet B2B customers' needs in a way that is supported by customer strategy and orientation?* The objectives of this paper are to (1) study the market offer, customer strategy, and customer orientation further as theoretical constructs, especially in the context of B2B markets, (2) empirically explore customer strategy and orientation as determinants of a company's market offer to meet customer needs, and (3) test the related hypotheses. In doing so, this paper contributes to the literature on customer-focused R&D in a B2B setting.

The rest of the paper is organized as follows. The second section presents a brief literature review and introduces the research hypotheses. A brief description of the data and the applied research methodology is covered in Section 3. Subsequently, the research results based on hypothesis testing are discussed, then the last section introduces managerial implications, as well as concluding remarks.

Conceptual Model and Hypotheses

In this section, theoretical concepts of a company's market offer to meet customer needs supported by customer strategy and customer orientation in B2B markets is developed.

Market offer to meet customer needs

Companies aim to modify and extend their offer to utilize potential growth opportunities in markets. Normann (2001) implies that a company proactively intends to generate new offerings in which customer value is created in a way that adds value for the provider as well. Part of this activity focuses on creating completely new products. While creating new products, input from a company's customers should be linked to the R&D process as a way to avoid expensive decisions and mistakes based on erroneous assumptions (Koufteros et al., 2005). One example of a common erroneous assumption is a market need exists for a developed product, even if it really does not. Another example of a faulty assumption is overestimating the market need.

In B2B markets, customers have requirements that are closely linked to their needs. However, these requirements may not necessarily be negotiable, and therefore the supplier simply has to meet them. Therefore, a company has to consider customer requirements while designing new products (Narver et al., 2004).

While considering customers' needs and requirements, organizations should possess effective means to capture relevant information from their customers and markets. Thus, the integration of sales, marketing, and R&D activities is important for meeting an organization's overall goals (Day & Van den Bulte, 2002). One of the reasons for product failures in the market is due to the supplier's inability to take customer requirements as an input for product development (Narver et al., 2004).

A dialogue should be opened for two-way communication between the supplier and its customers. Through dialogue, a company is able to customize its offering to better meet customers' needs and potential requirements. In B2B markets, a natural way to promote this dialogue is to involve the company's sales force. Besides selling, they have a good chance to collect feedback and may sense the potential of unfilled needs, as well as noticing important customer requirements. It is also possible that some products are tailored primarily to meet the needs of certain individual customers, or a

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small group of customers. Therefore, it is important that creating or refining new products is based on well identified customer needs and potential requirements.

A company's market offer often does not consist of physical products. Since in most economies the companies are more and more involved with some kind of service offering, it is also important to make a potential service offering meet customers' needs. Both modern agile and more traditional product and service development methodologies are available. Both of these have their own strengths and weaknesses. On many occasions, the perspective of co-creation is also relevant, meaning that products and services are not just created within the selling organization, but ongoing dialogue is also necessary to make the collaborative efforts a reality.

Customer Strategy

Customer strategy can be seen from two main perspectives: how to retain and develop existing valuable customer relationships, and how to attract and gain new customers (Grönroos, 1994). While linking customer strategy to a company's market offer, the question remains to whom we want to allocate a company's limited R&D resources. At the same time, it is not only about R&D, but it is also about managing risk and cash flow. It is considered less risky to serve already existing customers, rather than trying to develop and commercialize new products and services for completely new markets or potential customers (Ansoff, 1957).

Customer strategy depends on a company's business strategy. In order to generate future revenue growth, an important perspective on business strategy is to identify in which markets a company identifies opportunities in the future and, as an outcome of that, what customers can be found in those markets. This means deriving the objectives of how to manage a company's customer relationships and support its growth opportunities within existing and potential customers. This means that business strategy and customer strategy are being formulated in practice at the same time that strategy is being developed, (Payne & Frow, 2006).

If a company can divide its customer base into different groups with different needs and expectations, then they can be better served (Day, 2003). A well-prepared customer-segmentation analysis, for example, improves the odds of managing customer relationships effectively in a way that fulfills customer needs (Rigby et al., 2002). A standard approach to implementing this segmentation is to apply similar customer needs as segmentation criteria (Blocker & Flint, 2007). Segmentation is a normal approach for allocating activities in B2B markets, but it has received less attention than segmenting consumer markets (Goller et al., 2002). One reason for this could be that consumer markets have been taken care of traditionally by mass marketing activities, while in B2B markets, more tailored personal sales activity is required.

While considering allocation of R&D activities to meet individual customer needs, some customers may be prioritized based on perspectives like strategic and business value, future potential, and operational risks (Storbacka et al., 2011). These criteria can then be applied to consider whether tailored R&D activities for specific customers are justified.

Customer strategy is thus closely linked to customer prioritization. Customer prioritization can be defined as the degree to which certain customers are treated in a different way than others, according to a customer's importance to the company (Homburg et al., 2008). Prioritizing customers is a rather typical practice for companies operating in B2B markets (Reinartz et al., 2004). This has its reflections also on creating new products. The resources allocated to meeting customer needs should be based on priorities that are linked to customer strategy and related objectives (Zeithaml et al., 2001).

Thus, customer strategy is about supporting a company's offer to meet customer needs in B2B markets. The following hypothesis is tested:

H1: *Customer strategy has a positive direct effect on offers to meet customer needs.*

Customer Orientation

R&D activities should not be implemented in isolation. Involving the sales force in R&D can help companies capture useful customer data and insights (Judson et al., 2006). According to Nwango (1995), customers are often unsure of their needs, and sometimes irrational in the expression of those needs. Relevant caution should therefore be taken. Wrongful assumptions about customer needs and requirements can lead to product development delays or market failure. Both of these outcomes may prove very costly for a company. However, for most companies, their customers have

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heterogeneous needs. This means that companies need to consider the potentially different needs of their various customers.

Customer orientation reflects the culture of a company as it tries to determine the perceptions, needs, and wants of its target markets, and to satisfy them through the design, communication, pricing, and delivery of appropriate and competitively viable offerings (Deshpandé et al., 1993). Although this definition applies more to business-to-customer (B2C) markets, it can also be adapted for B2B markets. However, business customers are usually interested in more or less tailored value creation from their suppliers. This is in line with Jolson (1997) who argues that value creation is related to a company's ability to provide products and services that meet customers' needs.

The importance of a market-oriented culture is important for all levels and functions of a modern organization (Narver & Slater, 1990). Deshpande et al. (1993) propose a more divergent view of market orientation, suggesting it is synonymous with customer orientation. According to Berry and Yadav (1996), a customer-oriented approach aims at developing long-term relationships with customers, understanding their needs and requirements, and then moving to match them. Fournier et al. (1998) emphasize the importance of an ongoing dialogue with customers. Customer needs and preferences can be actively collected via customer feedback. In practice, this can be done both via formal and informal means. With B2B customers, one way to collect customer feedback can be based on the sales force's or account manager's communication with customers. This feedback and related insights gathered in dialogue with customers can be used to develop and further improve a company's market offer.

In B2B markets, companies are dependent on relatively few customers. Therefore, it is important from a perspective of customer loyalty, customer satisfaction, and customer profitability that they are able to fulfill the needs of their customers. In this paper, the existing and potential customers form the market for a companys products and services. Market orientation is a similar concept to customer orientation. Uncles (2000) defines "market orientation" broadly in operational terms as the processes and activities associated with creating and satisfying customers by continually assessing their needs and wants, and doing so in a way that there is a demonstrable and measurable impact on business performance. Kohli and Jaworski (1990) define "market orientation" as the organization-wide generation of market intelligence in order to identify existing and forthcoming customer needs, dissemination of intelligence both horizontally and vertically within the organization, and organization-wide action, or responsiveness to market intelligence. Slater and Narver (1995) define "market orientation" as consisting of three major components: 1) customer orientation, 2) competitor focus, and 3) cross-functional coordination. Each of these components should be appropriately linked with a company's industrial context.

Narver and Slater (1990) define "customer orientation" as having adequate understanding of one's target buyers in order to be able to continuously create outstanding value for them. Customer orientation at the organizational-level emphasizes culture and processes that promote the importance of customers' needs, as well as being able to fulfill these needs. Saarijärvi, Kuusela, Neilimo, and Närvänen (2014) emphasize the customer value dimension through a mechanism of customer value. The value dimensions are considered important, but it is evident that value attributes to customers are at least partly implicit, and thus difficult to interpret and communicate. However, customer orientation is about gaining insights about customer needs and converting that information to be applied in a company's R&D activities. In this paper, "customer orientation" is defined as a seller's orientation to understand implicit and explicit customer needs, so as to modify the existing product and service offering, as well as operational procedures, to better meet these needs. This customer orientation can be demonstrated by involving customers to participate in suppliers' R&D activities, along with collecting in-depth feedback on customer needs.

Consequently, the second research hypothesis is:

> H2: *Customer orientation has a positive direct effect on market offers that meet customer needs.*

Empirical Research

In this section, methodological issues are discussed, covering data collection, research variables, and data analysis-related procedures.

Data Collection

This research targeted large and medium-sized Finnish organizations. Data was collected through an Internet survey. The survey questions were answered by

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participants in a two-day training program that concentrated on key account management. The data collection was done before implementing the training program on multiple occasions during 2010–2019. The respondents represented key account management and sales management professionals. Even though there was no sampling method used while collecting the data, it is expected that due to the relatively large number of respondents the data accurately represent the research population. The total number of respondents was 292. Respondents were guaranteed anonymity, thus, industry and other background data was not collected.

Because the data collection was tailored to meet the needs of participants in a key account management training program, the research instrument was based on that. The survey instrument consisted of various areas related to customer relationship management within organizations. The following standard procedures (Churchill, 1979) were followed for developing new scales. First, a literature review on customer relationship management was conducted (Rackham & DeVincentis, 1998). Second, field interviews with key account management and sales management professionals were conducted to better understand the research domain. Third, based on the literature review and qualitative insights, an item pool for potential research variables was developed. All questionnaire items were measured using a five-point Likert-type scale (1 = strongly disagree to 5 = strongly agree).

Two independent sum variables were constructed for measuring customer strategy and customer orientation. All of the constructs were based on marketing literature (Homburg et al., 2008; Bhatnagar et al., 2008; Sin et al., 2005; Lin et al., 2010; Frow & Payne, 2009; Coviello & Joseph, 2012; Perks et al., 2009; Wang & Feng, 2012). Customer strategy as an independent sum variable was constructed from four variables (Clear customer strategy, Customer strategy communicated, Clear objectives and metrics, and Customer strategy directs action). Exploratory factor analysis showed factor loadings between 0.62 and 0.88, and therefore all individual variables were included in the sum variable customer strategy. The internal consistency of this sum variable was measured using Cronbach's alpha coefficient (0.88). Customer orientation as an independent sum variable was constructed from four variables (Customer needs, Customer feedback collected, Customer orientation improved, Customers participation in R&D). Exploratory factor analysis showed factor loadings between 0.46 and 0.74, and therefore all individual variables were included in the sum variable customer orientation. Cronbach's alpha for the sum variable of customer orientation was 0.72. For both of these independent sum variables Cronbach's alpha values were good, that is, at least 0.70 (Nunnally, 1994). The dependent variable measured whether the company's offering was meeting the needs of its customers.

Testing hypotheses

A regression analysis test was applied to the data in order to check the relationship percentage between variables. Linear regression was used to estimate the linear equation coefficients, involving one or more independent variables that best predict the value of the dependent variable. The value of R Square indicated that there was a 22.5% relationship between customer needs, improved customer orientation , competitive new products, and offer that meets customer needs. The regression model as a whole significantly predicts the response (offer that meets customer needs) ($F_{2,289}$=41.840, p<.001).

The results indicate that customer strategy has a statistically significant association with market offers that meet customer needs; hence, this study's proposed hypothesis H1 is supported.

Furthermore, the results indicate that customer orientation has a statistically significant association with offers that meet customer needs; hence, this study's proposed hypothesis H2 is supported.

Table 1. Model Summary

R	R Square	Adjusted R Square	Root Mean Square Error
.474	.225	.219	.813

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Table 2. Coefficients

	Standardized coefficients		Standardized coefficients / Beta	t	P
	B	Standard Error			
(Constant)	1.748	0.174		10.031	<0.001***
Customer strategy	0.044	0.017	0.175	2.641	0.009 **
Customer orientation	0.100	0.019	0.345	5.216	<0.001***

Notes: *p<0.05, **p<0.01, ***p<0.001

Theoretical and Managerial Implications

Two hypotheses concerning a company's market offer that meets customer needs were set and tested. The findings of the hypothesis test supported Hypothesis 1 and Hypothesis 2. They showed that customer strategy, as well as customer orientation, both positively affect a company's offer that meets customer needs in B2B markets.

The examination of standardized coefficients revealed that customer orientation (0.345) has almost twice the effect of customer strategy (0.175) on offers that meet customer needs. Based on these findings, it can be concluded that customer orientation has a more important effect on offers that meet customer needs in B2B markets. This appears logical while customer orientation as a sum variable was constructed from such variables as Customer needs, Customer feedback collected, improved Customer orientation, and Customer participation in R&D; all of them describing the importance of meeting customer needs.

Several theoretical implications can be derived from the findings. The first contribution stems from covering market offers with customer strategy and customer orientation in the same study. Prior research focused more on customer orientation while implementing a company's R&D activities, but rarely both (Narver et al., 2004; Svendsen et al., 2011). However, theoretical development of the conceptual model and empirical findings in this study suggest a connection between a company's market offer and its customer strategy and orientation.

The findings also contribute to the existing customer relationship literature in marketing by further documenting customer strategy within a B2B context. This study extends other research on customer strategy by considering it from the perspective of offers that meet customer needs (Nijssen, et al., 2012). This perspective contributes to a deeper understanding of the interaction between a company's market offer, and both customer strategy and orientation.

When it comes to managerial implications of the findings, companies operating in B2B markets should take systematic and consistent measures to clarify their customer strategy and improve their customer orientation. This is expected to improve the effectiveness of their R&D activities while they are better allocated to meet the needs and requirements of a company's current and potential customers. This is expected to improve the time to market and cash flow perspectives of companies' R&D activities, and therefore reduce the financial risks involved. In organizations that lack a clear customer strategy and customer oriented culture, the competitiveness of a company's offering is not self-

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evident (Chuang et al., 2015). This means that further efforts should be made to clarify whose customers' needs and requirements a company intends to meet, and how a company's market offer should be developed further to meet those identified needs.

Conclusion

Companies have and develop their offerings further including the products and services. On a cultural and strategic level, developing a market offer should be based on fulfilling the needs of a company's current markets. The prioritization of customers and the broadening of target markets is closely linked to managing a company's R&D portfolio, along with projects related to it. In case it seems that customer or market demand does not justify creating a new product and service, then that particular project should not be continued further. In B2B markets, winning major new customers may take time. Therefore it is less risky to focus on fulfilling the needs of a company's current customers. Customer relationship management literature (see Frow & Payne, 2009; Wang & Feng, 2012) encourages the maintenance and development of existing customer relationships. Developing a company's market offer and commercializing it through cross-selling to customers that the company already has, provides a less risky avenue to generating revenue from the new components of a company's offering, that is, its product and service portfolio.

While allocating a company's R&D efforts, their innovation portfolio is relevant (Klingebiel & Rammer, 2014). Focusing on meeting the needs of a company's current customers is less risky than targeting new potential customers and their potentially different needs and requirements. Especially in case a company intends to expand its market offer by utilizing new technologies, it increases the risk not only from the viability of a technology perspective, but also from a cash flow perspective. In B2B markets, a company is able to commercialize and sell a new offer's components, that is, products and services to its existing customers rather than its competitors customers. Therefore, customer strategy and orientation is considered to be an important aspect guiding a company's R&D activities on a strategic level. Whether actual R&D activity is implemented through agile or more traditional product development project methods is considered here to be a more tactical issue.

As with most empirical studies, this particular research also has its limitations. Limitations that result from the research data collection and analysis methods (cumulative data collection and regression analysis), may inspire further research to be conducted using alternative approaches, that would produe further empirical evidence on how customer strategy and orientation affect company offers that meet customers' needs. This paper has focused on R&D to meet the needs of B2B customers. It may be that some needs of a company's customers are rather customer-specific, and therefore affect also the allocation of a company's R&D resources. On B2C-related R&D, markets are segmented and after that prioritized. This means that product/market strategy provides a more traditional approach to meet the needs of a broader market.

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The Effect of Machine Learning on Knowledge-Intensive R&D in the Technology Industry

Daniel Viberg and Mohammad H. Eslami

> *"The ambiguity, as a consequence of knowledge integration becoming a fashion word, is in itself an explanation for why theorists sometimes end up in incomplete explanation."*
>
> Anna Jonsson
> (Translated from Swedish)

The impact of such current state-of-the-art technology as machine learning (ML) on organizational knowledge integration is indisputable. This paper synergizes investigations of knowledge integration and ML in technologically advanced and innovative companies, in order to elucidate the value of these approaches to organizational performance. The analyses are based on the premise that, to fully benefit from the latest technological advances, entity interpretation is essential to fully define what has been learned. Findings yielded by a single case study involving one technological firm indicate that tacit and explicit knowledge integration can occur simultaneously using ML, when a data analysis method is applied to transcribe spoken words. Although the main contribution of this study stems from the greater understanding of the applicability of machine learning in organizational contexts, general recommendations for use of this analytical method to facilitate integration of tacit and explicit knowledge are also provided.

Introduction

The rapid pace of innovation in the context of new technology development has attracted significant attention of technology firms, as this offers potential for using these tools for knowledge integration as a means of creating and sustaining competitive advantage (Grant & Baden-Fuller, 2004). Previous research has shown that knowledge integration has great potential to accelerate innovation, since identifying and combining distributed knowledge can enhance the competitive advantage of firms, distinguishing them from their competitors (Carlile & Rebentisch, 2003; Yang, 2005). However, while firms acknowledge the advantages and necessity of knowledge integration, they typically face different difficulties in accessing distributed knowledge (Enberg et al., 2006; Schmickl & Kieser, 2008). In other words, integrating distributed knowledge is challenging, especially tacit knowledge, as this is knowledge gained through personal experience, making it difficult to transfer or codify.

Despite these difficulties, many researchers are of the view that artificial intelligence (AI), and machine learning (ML) in particular, can be adopted in organizational knowledge integration (Li & Herd, 2017). Paradoxically, ML algorithms rely on experience-based knowledge (Jin et al., 2018), in the sense that large sets of data are interpreted in order for some general rules to be codified. In this context, it is important to study firms that focus on technology-based activities (Berggren et al., 2011), because their innovation efforts are under the effect of two major influences: (a) strong interrelationship activities between R&D and production, and (b) changes in the character of AI that can mandate either specialization or increase in complexity (Lin & Chen, 2006). These two trends necessitate further exploration of AI for knowledge integration activities within organizations.

Thus far, this topic has not been sufficiently investigated, as AI, and ML in particular, are relatively recent innovations. Thus, the aim of the present study is to investigate how ML could be combined with human ability and knowledge in a broad sense in order to help in the acquisition and transfer of different types of knowledge. To achieve this goal, the following research question, pertaining to the fundamentals of both domains, is addressed in the present study: *How can ML facilitate tacit and explicit knowledge integration in technological organizations?*

By answering this question, the study contributes to both individual and organizational knowledge, while expanding the current scholarship on links between AI and knowledge integration theories. The next section provides a review of extant literature, focusing on knowledge integration and ML. This is followed by a brief description of the research design adopted in this study, after which the results are presented. The paper concludes with a discussion of key findings and their implications for research and practice.

Literature Review

Knowledge integration
According to Grant (1996a), knowledge integration is "a process for coordinating the specialized knowledge of individuals", whereas other researchers define knowledge integration as a combination of various activities. For instance, Tell (2011) distinguished among studies in which knowledge integration is defined as transferring or sharing knowledge (Huang & Newell, 2003; Marsh & Stock, 2006), applying similar/related knowledge (Teece et al., 1997), and combining specialized and complementary knowledge (Kogut & Zander, 1992; Tiwana & McLean, 2005). However, according to Okhuyen and Eisenhardt (2002), the concept of knowledge integration exceeds sharing and transferring to include combining specialized knowledge in order to create new knowledge.

While there is presently no consensus on the definition of knowledge integration, most researchers make a clear distinction between explicit and tacit knowledge (Nonaka & Takeuchi, 1995; Grant, 1996b; Spender, 1996). Explicit knowledge refers to factual knowledge that can be easily recorded in, for example, manuals, written policies, and procedures (Ernst & Kim, 2002). However, engineering knowledge– such as that based on experience, intuition, and professional judgment– is tacit (Backlund, 2006). As this is the greatest source of innovation, companies must continually regenerate and capture their tacit knowledge (Grant, 1996b; Hansen et al., 1999). If a company fails to retain the tacit knowledge of its most experienced and talented employees, then its overall competence will falter. Therefore, allowing employees to learn from each other is a key requirement for companies' long-term success (Argote & Miron-Spektor, 2011). Tacit knowledge is not a static stock of knowledge, as it is continuously expanding through deliberate and experiential learning. However, it is also rapidly eroding, as it relies on the memory of those that possess it. The degree of tacitness can also vary; the less explicit and codified knowledge tends to be, the more difficult it will be for individuals and organizations to assimilate it (Howells, 1996). The knowledge a person possesses can also require application of explicit theories to practical situations or problems.

In most cases, knowledge with both explicit and tacit elements is required, especially when performing a development task. Hence, as Jonsson (2012) argued, it is important to know to what degree some knowledge is explicit and/or tacit, as this will help define appropriate methods for transferring and translating this knowledge. To aid in this process, nearly 30 years ago, Nonaka (1994) developed a model depicting four stages of individual knowledge creation, denoted as Socialization, Externalization, Internalization, and Combination. The initial process of Socialization involves exchanging exclusively tacit knowledge between individuals through activities like master-to-apprentice mentorship or informal meetups. Externalization relates to articulating the tacit knowledge to explicit notions, and can be performed using various mediums, such as metaphors and stories. Combination involves combining explicit knowledge in different ways, which can be done via IT systems or knowledge banks. Finally, during Internalization, explicit knowledge is ingrained into corporate culture and work methods. In sum, this entire sequence modifies the tacit knowledge that an individual currently holds, by introducing new explicit knowledge (Jonsson, 2012; Nonaka, 1994; Wiig, 1997).

Machine learning (ML)
ML is an analytical technique whereby an algorithm is developed based on computational statistics derived from available data. The main goal of ML is to apply rules developed through exposure of large datasets to new (but similar) scenarios (Witten et al., 2016). The process, in its simplest form, relies on classification, whereby a dog can be classified as an animal or a dog, depending on the level of specificity, or a voice input can be recognized as language and thus translated into text. The ML field experienced an initial expansion in 1983, when researchers started asking questions related to how, what and why machines should learn (Simon, 1983; Provost, 2000; Feldman, 2011).

Table 1. An estimated square function

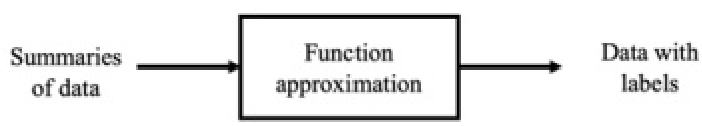
Input	1	2	3	...	n
Output	1	4	9	...	n^2

It has since advanced considerably, giving rise to various types of ML, one of which is supervised learning, which involves taking labelled datasets, learning from them, and then labelling new datasets. An example of this is function estimation based on a set of input and output numbers. If a learning algorithm is told that the first number in a set, which is 1 in the case described in Table 1, produces 1 as the output, 2 yields 4, 3 relates to 9, etc., it can deduce that the function relating input to output is x^2. It is important to note that the algorithm will always provide only an estimation, which will then become more accurate as more data becomes available (Kubat, 2015).

Supervised learning is based on induction, as the algorithm takes a set of examples and tries to extrapolate those examples to some generalized rule. For example, if the question "Did the sun rise during the last 10 days?" produces a "yes" response, then it would deduce that the sun will rise tomorrow as well. Figure 1 shows a simplification of supervised learning.

In contrast to supervised learning, unsupervised learning is comprised of large sets of data that are provided to the system from which structure is created based on the relationships among input parameters (Kubat, 2015). In other words, the algorithm is responsible for assigning meaning to input data. For example, an algorithm can be given a large set of images of different dogs and will learn to conclude that a picture of a car is not the same as those previously shown. Another example relates to crowd classification (Hoffer & Ailon, 2015). Given a large crowd, the algorithm will learn to distinguish males from females, individuals with facial hair from those without, people of different ethnicities, etc. (see Figure 2 for a simplification of the algorithm). Still, as is the case with supervised learning, larger data sets serve to make unsupervised learning algorithms more accurate (Kubat, 2015).

Figure 1. Supervised learning labels data well



Clustering and applicability of ML

Clustering is one method of summarizing collected data. It can be of hard and soft type and entails collating data points into groups based on some measure of similarly (Kearns et al., 1998). In the hard-clustering approach, classification is binary, whereby the input data points either belong or do not belong to a group, whereas soft clustering assigns probability of belonging to a group. In practice, hierarchical clustering is often applied, as it allows building hierarchal clusters of data groups with applications in recommendation engines, market segmentation, social network analysis, search results grouping, medical imaging, image segmentation, or anomaly detection (Domingos, 2012). A particularly useful feature of hierarchical clustering algorithms is their ability to handle multidimensional data, which are usually utilized in ML (Dugad & Ahuja, 1998).

Figure 2. Unsupervised learning clusters data well

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According to Hodson (2016), in order to ascertain if ML can be applied to a certain context, the problem at hand should be examined, followed by the available data, as well as feasibility and expectations of the ML process. It is also essential to understand the difference between automation and learning problems, as ML can facilitate automation, whereas not all problems require learning ability. In practice, automation without learning can be applied to scenarios when predefined sequences of steps– typically executed by humans– are consistent, and are executed in a similar manner, and therefore do not require any flexibility in a problem-solving algorithm (Hodson, 2016)

Problems that require automation paired with learning typically, (1) involve prediction rather than causal decision making (in other words, the average relatability in data is of interest), or (2) are sufficiently self-contained, or relatively insulated from outside influences, as this would allow the algorithm to make relevant inferences (even though it will not be able to learn anything beyond the data provided) (Hodson, 2016). It is also important that the data provided has certain characteristics. Hall et al. (2016) outlined a few aspects that ML data should fulfil to be valid, namely, that the data should not be biased, or contain any misleading information or missing values, as more reliable data would yield a more precise algorithm. In summary, ML is applicable when: (1) there is a problem that requires prediction rather than causal interference, (2) the problem is insulated from outside influences, (3) a large dataset is available for training, (4) the training data does not contain misleading information, and (5) the training data is not biased (Hodson, 2016).

Research Design

To address the research question guiding this investigation, a single case study at a large technological firm in Sweden was conducted. The company employs more than 15,000 employees and has R&D centres at different locations where an extensive variety of high technologies with applications in different industrial areas are developed, along with industrial products and services. The company applies several approaches toward product development projects, whereby R&D engineers collaborate with other units to identify key features of new products and services, as well as potential challenges that may arise in their design and production.

Given that the focus of the present investigation was on use of ML, three specific functions within the organization, namely design, industrialization, and production, were chosen as the research object. The design division is responsible for developing detailed models of parts comprising the final product, whereas the industrialization division ensures that those parts can be manufactured in practice, and the production division is tasked with physically creating these parts. These three divisions are in constant collaboration with each other via digital and physical interfaces that allow them to share pertinent knowledge. Our observations at the site revealed that some of the collaboration took the form of standard documents that were used by all parties. The information pipeline is of particular interest for the present study because the company leadership suspected that the manner in which both explicit and tacit knowledge was used and shared was inefficient.

Based on information that emerged during the discussions with representatives of all the aforementioned units, it was surmised that both knowledge integration and ML could address the efficiency issues. As discussions progressed, a specific research question emerged: *Can both explicit and tacit knowledge be handled by ML, with the aim of more efficient knowledge integration?*

As our aim was to provide a knowledge integration solution for a specific technology company, as well as to relate that outcome to ML theories, it was important to obtain as many opinions on the subject as possible, as this would allow us to elucidate how consistent interpretations of knowledge integration were throughout the company. Moreover, by analyzing this information, a more precise practical definition of knowledge integration could be adopted in the study.

To meet the study objectives, three sources of data were used: (1) relevant documents that contained an explicit form of knowledge integration as well as a strategy for tacit knowledge integration; (2) formal and informal interviews, focusing primarily on the tacit aspects of knowledge integration; and (3) the so called “Go to Gemba” strategy, based on learning theory and its related philosophy (Liker & Meier, 2006). The last data collection method required assessing the way systems operated, documents were generated, and meetings were conducted within the three hierarchal levels and divisions. The investigation was deliberately not limited to documents and systems only, since decisions pertaining to how and when meetings should be performed could influence tacit knowledge integration.

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Table 2. The interview strategy

Category	*Limitation*
Structure	Semi-structured interviews guided by predefined questions that allow for further discussions
Size	3 (hierarchical) ×3 (divisional) = 9 actors
Communication medium	Face-to-face
Responsibility	Management Group leader First line subordinates

Moreover, there were also some indications that official procedures and guidelines were not always followed. In other words, the explicit description of how tacit knowledge should be shared and documented likely deviated from actual methods adopted in practice. To facilitate our case analysis, a significant amount of information about the company's structure, culture, strategy, and current knowledge integration methods was obtained via informal discussions with relevant company staff who were knowledgeable on the topic of knowledge integration.

In addition, as noted earlier, formal interviews were conducted with key informants. The primary objective of individual interviews was to, (1) elicit the employee's interpretation of knowledge integration and usage for retrieving relevant information; (2) establish what the employees would like to do and have in order to develop their knowledge; and (3) identify potential areas where ML could be of use. To aid in addressing the third aim, pertinent literature on ML was examined.

Analysis

Based on findings yielded by an analysis of all pertinent information, ML might be used for increasing workplace efficiency, as the resulting automation of administrative and repetitive tasks can save managers time. Moreover, ML can benefit company staff by assisting them with finding the most relevant knowledge sources on topics of interest. Based on these assertions, a general description of how ML fits in the knowledge integration perspective is suggested using knowledge integration theories, with an aim of specifying data suitable for ML applications, as well as how it can be sourced and used.

However, it is important to note that ML is not suited for determining how to reach value-dependent goals (Domingos, 2012; Kubat, 2015). This is intuitive, as an algorithm does not "understand" what it is learning, as the value of the knowledge it entails is not considered during the learning process. Consequently, when data is biased or erroneous, a ML algorithm would produce incorrect output. Hence, to fully benefit from ML in practice, a value interpreting entity (usually a human expert) is required to provide feedback to the ML algorithm during the learning phase.

In sum, ML is a tool that will not function without the assistance of a value interpreting entity. Such algorithms can utilize both explicit and (some types of) of tacit knowledge. Explicit forms of knowledge are codifiable, objective, not connected to a specific context, simple to transfer, and are often described as "data" or "information". Typical forms of explicit knowledge that ML algorithms use involve numerical data, images, and transcriptions, that is, objective input, since correlations among subjective data are very difficult for an algorithm to "interpret". For example, if an image recognition algorithm was used to find pictures of objects and the

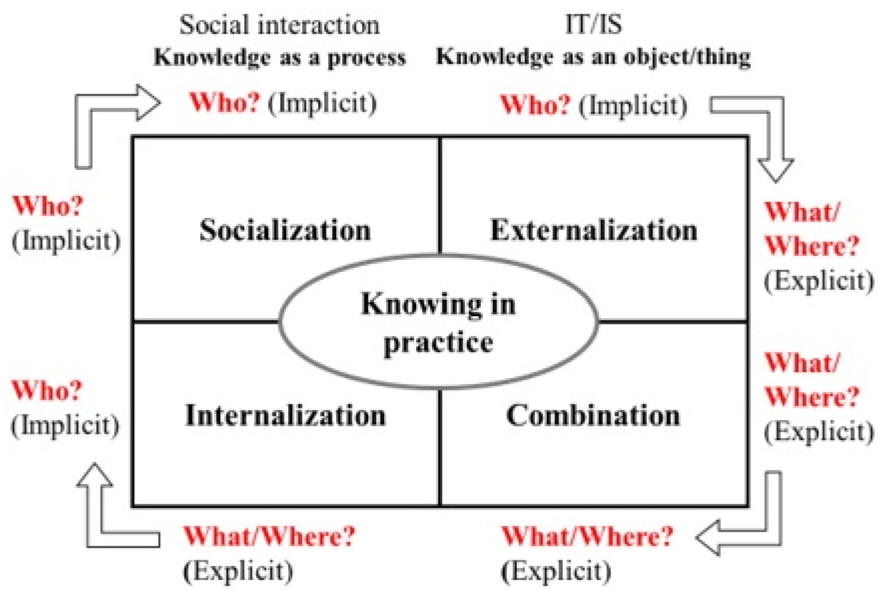

Figure 3. Knowledge sourcing issue represented in the SECI model, adapted from Jonsson (2012)

user searched for a car, it would be successful in providing an image of a car. However, if the user decided to search for an attractive-looking car, the algorithm would not be able to provide an image that would meet this requirement, since attractiveness is subjective. Nonetheless, it could correlate large amounts of data to determine what most users considered an attractive-looking car.

This last example indicates that ML algorithms can acquire a certain level of tacit knowledge, even though their inferences may not fully correspond to a particular user's interpreted preferences. Thus, based on the absence of value interpretability in ML, there is a limit to what types of tacit knowledge an algorithm can acquire. For example, in a scenario where a ML algorithm learns to identify voices and attribute them to individual speakers, the algorithm will work as intended through experience, gaining an ability that is related to the tacit form of knowledge. Still, that experience is relevant only to a specific case, because the algorithm would not be able to label unfamiliar voices or perform any other function for which it was not specifically trained. In summary, ML is expected to handle explicit knowledge well, along with a certain level of tacit knowledge.

Discussion

As mentioned earlier, the purpose of this study was to investigate how ML technology can facilitate tacit and explicit knowledge integration in technological organizations. The key issue that emerged during the investigation pertained to the difficulty of identifying either explicit information or a person with the right knowledge. Since ML involves learning by experience, it is interesting to investigate if issues related to recognising individuals' knowledge domains– one of the mechanisms lacking in "common knowledge"– and knowledge sourcing in documents, could be improved. In this section, therefore, a speculative framework of how ML could be used to solve this issue is presented based on the SECI model (Nonaka, 1994). As shown in Figure 3, during the different phases of knowledge creation, several different mediums are used. For example, during the socialization phase, employees talk to each other to obtain the required information, whereas documents

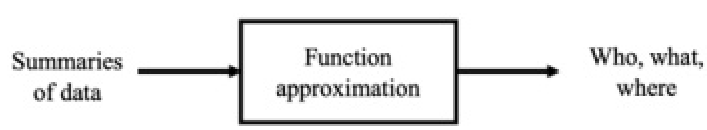

Figure 4. A supervised learning algorithm in the smart knowledge bank

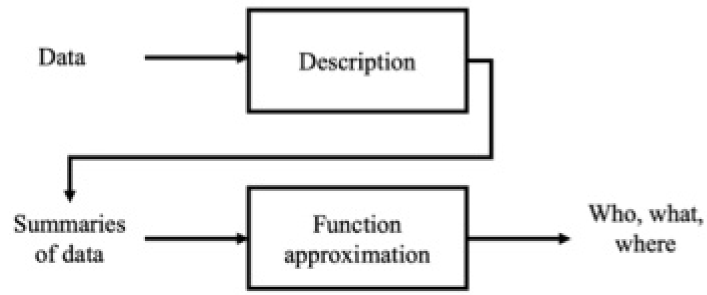

Figure 5. A smart knowledge bank algorithm using unsupervised and supervised learning

and manuals are generated in the combination phase. Thus, the aim was to ascertain who possessed what types of knowledge and where documents or manuals were stored.

As stated previously, in the company where our case study was conducted, there seemed to be a correlation between knowing where to find relevant information and the employee's duration of employment at the company, which was also related to the size of an individual's social network within the firm (Nonaka, 1994; Miller & Fern, 2007). From the perspective of ML, the question thus became how to retrieve and share the ability of experienced staff to identify the most likely individual that possesses knowledge on any given question or topic, or determine where that knowledge was stored, as well as if it was shared with any other individual. A solution could then be constructed from the initially determined output, which in this case would be a classification that results in labelled data that contains the knowledge source, such as a person, document, or system. Moreover, input required for the ML algorithm to reach a decision would be derived from the question being asked, which could be related to a broad topic, such as "thermodynamics", or a very specific subject, such as "entropy." The resulting algorithm could function as shown in Figure 4.

Summaries of data would in this case consist of data clusters that contain roles, assignments, documents, manuals, systems, topics, projects, people, divisions, etc. Clearly, clustered data with such dimensions, however,

Table 3. Data dimensions required for a smart knowledge bank algorithm

Data dimensions	*Collection method*
Role	Documented digitally
Division	Documented digitally
Assignment	Documented digitally
Project	Documented digitally
Systems used	Traced digitally
Documents used	Traced digitally
Manuals used	Traced digitally
Colleagues spoken to	Traced using ML transcription
Alleged knowledge	Traced during meetings + mail and chat conversations

would be difficult to collect and modify manually (Karypis et al., 1999). Therefore, an unsupervised learning algorithm should be employed to identify any clusters in the various data dimensions. In this case, it would involve correlating data points, that is, a particular system with a topic, or a specific person with a role. The type of algorithm that would be suitable in this case is based on a hierarchical clustering method because it does not necessitate prior knowledge of the number of clusters required, which is not the case for other methods. Additionally, hierarchical clustering is suitable because this scenario entails relatively low data quantity (Kubat, 2015). An augmented algorithm is shown in Figure 5.

Having the right data is a prerequisite for developing an algorithm as exemplified in Figure 5. Some of the data requirements are presented in Table 3, where the data dimension represents types of information collected, while the collection method describes how the information is to be collected. For example, the Role, Assignment, or Project related to a particular employee should be obtained from digital documents. On the other hand, the Systems used, or Documents used by an employee, would be traced, since it is not initially possible to know which documents someone has read. Colleagues spoken to– which also includes the discussion subject– would be gathered using an appropriate ML method.

Using this strategy, data pertaining to all employees, projects, documents, and manuals, their usage and knowledge shared, would be hierarchically clustered. Speculatively, it would be possible to gradually arrive at an algorithmic output that pertains to what, where, or who holds knowledge that is connected to a specific topic, assignment, or question. On the other hand, ML cannot be used to classify knowledge, since such an algorithm would be highly dependent on the result of the clustering and classification's interpretive reliability. A representation of the expected process' output is shown in Figure 6.

This proposition for ML data clustering was tested using the Google visualization tool known as tensor flow, as shown in Figure 6. Tensor flow takes vectors in high-dimensional space and visualizes them (plots them visually) along with their correlations with other vectors in a lower-dimensional space. Using this tool and a dataset that simulates employees' knowledge and experiences related to various tasks, documents, projects, systems, and hierarchical levels, it was possible to generate a visual cluster representing the output of a hierarchical clustering algorithm. The data utilized in this scenario consisted of 3,000 rows (each row representing a person) and 27 columns, each of which represented the time an employee spent on a certain task, system, project, or document. The graph in Figure 6 shows how all employees (denoted as dots) correlated with other, similar employees.

Figure 6. A visualization of how a smart knowledge bank could cluster experiences into various categories

In this context, "similar" means that the employees are at the same hierarchal level, embody the same experiences in a system, or have spent the same amount of time looking at a document. The branches represent groups of individuals who are connected to a specific task, document, or other relevant differentiating aspect, such as a project or role. Although ML seems promising theoretically, there are many obstacles that must be overcome in order to implement such a system in practice. Some of these are related to various limitations, namely hardware, software, or performance, as well as ethical issues and interpreting organizational culture.

Conclusion

Theoretical contribution

The aim of this investigation was to provide insight into the role of ML in tacit and explicit knowledge integration in technology firms. The findings presented here contribute to the ongoing debate on the value of knowledge sharing and integration within organizations in generating competitive advantage. The case study results suggest that ML technology cannot be viewed as a static knowledge bank, like typical IT systems. Moreover, as some forms of tacit knowledge can be interpreted by ML algorithms, it would be beneficial to revise the SECI model proposed by Jonsson (2012).

ML can also be applied to capture verbal communications and knowledge exchange during meetings, as the content can be transcribed based on supervised learning, and then stored for others to read. In addition, ML provides companies with the ability to automate the way that individual employees search for knowledge and store information that others might find useful.

Practical implications

As knowledge is becoming increasingly significant in organizational activities, managers need to consider adopting AI for integrating tacit and explicit knowledge. This is particularly important for firms that rely on innovation and R&D. The findings reported in this work could aid companies in determining what types of knowledge they wish to integrate and how best to utilize ML in this process

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These guidelines should assist in the process of translating your expertise into a focused article that adds to the knowledge resources available through the Technology Innovation Management Review. Prior to writing an article, we recommend that you contact the Editor to discuss your article topic, the author guidelines, upcoming editorial themes, and the submission process: timreview.ca/contact

Topic

Start by asking yourself:

- Does my research or experience provide any new insights or perspectives?
- Do I often find myself having to explain this topic when I meet people as they are unaware of its relevance?
- Do I believe that I could have saved myself time, money, and frustration if someone had explained to me the issues surrounding this topic?
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If your answer is "yes" to any of these questions, your topic is likely of interest to readers of the TIM Review.

When writing your article, keep the following points in mind:

- Emphasize the practical application of your insights or research.
- Thoroughly examine the topic; don't leave the reader wishing for more.
- Know your central theme and stick to it.
- Demonstrate your depth of understanding for the topic, and that you have considered its benefits, possible outcomes, and applicability.
- Write in a formal, analytical style. Third-person voice is recommended; first-person voice may also be acceptable depending on the perspective of your article.

Format

1. Use an article template: .doc .odt
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4. Begin with a thought-provoking quotation that matches the spirit of the article. Research the source of your quotation in order to provide proper attribution.
5. Include an abstract that provides the key messages you will be presenting in the article.
6. Provide a 2-3 paragraph conclusion that summarizes the article's main points and leaves the reader with the most important messages.
7. Include a 75-150 word biography.
8. List the references at the end of the article.
9. If there are any texts that would be of particular interest to readers, include their full title and URL in a "Recommended Reading" section.
10. Include 5 keywords for the article's metadata to assist search engines in finding your article.
11. Include any figures at the appropriate locations in the article, but also send separate graphic files at maximum resolution available for each figure.

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We are currently engaged in a project focusing on identifying research and knowledge gaps related to how to scale companies. We are inviting international scholars to join the team and work on shaping Calls for Papers in the TIM Review addressing research and knowledge gaps that highly relevant to both academics and practitioners. Please contact the Editor-in-Chief, Dr. Stoyan Tanev (stoyan.tanev@carleton.ca) if you want to become part of this international open source knowledge development project.