Creation processes for radical manufacturing technology innovations

Pooja Chaoji and Miia Martinsuo
Department of Industrial Engineering and Management, Tampere University, Tampere, Finland

Received 6 August 2018
Revised 11 January 2019
13 March 2019
Accepted 13 March 2019

Abstract

Purpose – This paper empirically investigates the processes by which manufacturing firms create radical innovations in their core production process, referred to as radical manufacturing technology innovations (RMTI). The purpose of this paper is to improve the understanding of the processes and practices manufacturing firms use to create RMTI.
Design/methodology/approach – Creation processes for 23 RMTI projects from diverse industry and technology contexts are explored. Data were collected via semi-structured interviews, and an inductive analysis was carried out to identify similarities and differences in RMTI types and creation processes.
Findings – Three types of RMTI and three alternative RMTI creation processes are revealed and characterized. An integrated view is developed of the activities of the equipment supplier and the manufacturing firm, highlighting their different roles and interaction across the three RMTI creation process types.
Research limitations/implications – The exploratory design limits the depth of the analysis per RMTI project, and the focus is on manufacturing technology innovations in one country. The results extend previous case and context-specific findings on RMTI creation processes and provide novel frameworks for cross-case comparisons.
Practical implications – The manufacturing firms' proactive role in RMTI creation is defined. A framework is proposed for using different RMTI creation processes for different types of RMTI.
Originality/value – This study addresses recent calls for empirical research on understanding the ways in which process innovations unfold in manufacturing firms. The findings emphasize the role of manufacturing firms as creators of RMTI in addition to their role as innovation adopters and implementers and reveal the suitability of different RMTI creation processes for different RMTI types.

Keywords Technological innovation, Radical process innovation, Manufacturing technology, Creation processes in firms

Paper type Research paper

1. Introduction

The development of production operations can occur through incremental, continuous improvements, or through radical shifts in the method of production. This study focuses on the latter, i.e., the development of production through a radical shift in the core production technology and process, here labeled as radical manufacturing technology innovations (RMTIs). In practice, this implies the introduction of new industrial equipment (Reichstein and Salter, 2006; Milewski *et al.*, 2015) that embodies a new method of production, and may involve the invention, development and piloting of new technological and process know-how in the core production operations of the firm.

Previous studies on new industrial equipment dominantly cover the implementation of RMTIs as new technology development and technology transfer from the perspective of the industrial equipment supplier firms (e.g. Stock and Tatikonda, 2008; More, 1986;

Journal of Manufacturing Technology Management
Vol. 30 No. 7, 2019
pp. 1005-1033
Emerald Publishing Limited
1741-038X
DOI 10.1108/JMTM-08-2018-0233

Von Hippel, 1978). Various RMTIs have been covered in different contexts, including: new technology innovations in footwear manufacture such as flow molding, numerically controlled stitchers and computer pattern generating systems (Dewar and Dutton, 1986); new packaging technologies for cooked and sterilized food (Ettlie *et al.*, 1984); and various forms of automated manufacturing technologies such as numerically controlled machines and robotics (Gomez and Vargas, 2012; Khazanchi *et al.*, 2007). With the supplier-centric focus, some studies have indicated that it is crucial for the equipment suppliers to understand the perspective of the customers, lead users in particular, for them to be able to implement the innovations successfully on the market (Baldwin *et al.*, 2006; Von Hippel, 1978).

Indeed, particularly in the implementation of RMTI, it is necessary to understand the technology-adopting manufacturing firm's perspective. Even if the novel process and technology were well-established in the manufacturing firm's industry, they may be new for the adopting manufacturing firm. Previous research shows that the implementation of RMTIs presents many unknowns and challenges, dealing with the modification and adaptation of a component technology, the equipment and the entire process to fit the needs of the specific manufacturing firm (e.g. Milewski *et al.*, 2015; Tyre and Orlikowski, 1994; Leonard-Barton, 1988; Von Hippel and Tyre, 1995).

Compared to RMTI implementation and adoption, few studies have investigated the ideation and development (or creation) of RMTI, and there is a dearth of empirical research on this topic (Lager and Frishammar, 2010; Kurkkio *et al.*, 2011). The few studies that do exist are mainly single or multiple case studies limited to specific industries, most of them concentrating on process-based industries (e.g. Lim *et al.*, 2006; Linton and Walsh, 2008; Lager *et al.*, 2010; Frishammar *et al.*, 2013). This creates a need for further evidence on RMTI processes from diverse contexts, to address the different requirements in different industries (Linton and Walsh, 2008; Lager and Frishammar, 2010; Kurkkio *et al.*, 2011; Rönnberg-Sjödin, 2013), and in technologies at different maturity levels (Lim *et al.*, 2006).

The purpose of this research is to improve the understanding of the processes and practices manufacturing firms use to create radical innovations in their core production processes. The research seeks answers to two main questions:

RQ1. What types of processes do manufacturing firms use to develop RMTIs?

RQ2. How do these processes vary across different RMTI projects?

The focus is on the perspective of the manufacturing firm radically innovating its production process, but the perspective of equipment supplier firms is considered as well, since novel production technology and equipment are created in and between the manufacturing firm and the equipment supplier firm (Frishammar *et al.*, 2013; Baldwin *et al.*, 2006; More, 1986).

The focus is on the core production process of the manufacturing firms, and we do not cover innovations in enabling processes (as included in Milewski *et al.*, 2015) or incremental process innovations (as included in Kurkkio *et al.*, 2011). We explore the creation processes of 23 RMTI projects from different contexts (industries, technologies and firm sizes), to determine their similarities and differences. The research offers evidence regarding alternative types of RMTI and different RMTI creation processes. The findings reveal manufacturing firms' use of certain RMTI process types for specific types of innovation novelty, and the activities of equipment suppliers and manufacturing firms during the RMTI processes. In doing so, RMTI are characterized through a wide variety of recent industrial examples, answering to a challenge described in previous studies (e.g. Reichstein and Salter, 2006) on how to define and sort radical innovations from other process innovations.

The following Section 2 reviews previous research on RMTI creation processes. Section 3 describes the research design, data collection and analysis method. Section 4 presents the findings on RMTI types, processes and activities in the 23 RMTI projects, and Section 5 further discusses the findings. Section 6 concludes the contributions, limitations and implications for practice and further research.

2. Literature review

Section 2.1 introduces the terminologies and conceptualizations of radical technology and process innovations based on previous research, and positions the concept of RMTI among other types of innovations. Section 2.2 discusses the meaning of "radical," differentiating it depending on the novelty of the innovation. It also builds a foundation for understanding differences between RMTI projects. Section 2.3 summarizes the present understanding on RMTI creation processes, manufacturing firm's and equipment supplier firms' activities in them, and the need to investigate RMTI creation processes across different projects.

2.1 Radical manufacturing technology innovations: definition and positioning

Radical technological innovations involve the introduction of a technology that is radically novel and different from the previous technology it may be displacing. For example, fuel cell technology that is expected to replace traditional engines in automotive industry can be considered a radical technological innovation (Harborne *et al.*, 2007). While such product-related technological innovations may offer direct benefits to end-users, manufacturing companies seek technological innovations also in their own processes, to achieve higher performance in terms of value, efficiency and quality. In the present study, we take the perspective of manufacturing firms radically innovating their core production process, as there is a call for further research regarding process innovations (Lager and Frishammar, 2010; Kurkkio *et al.*, 2011).

In this study, we focus on RMTIs that transform the manufacturing firm's core production processes used to directly shape and make the products. RMTIs do not deal with peripheral or enabling processes in manufacturing plants such as those used for production quality control and monitoring (Bessant, 1982), innovations in other than manufacturing operations such as material purchase processes (Parikh and Joshi, 2005), or other types of process innovations such as those concerning commercial issues. Where process innovations in general can cover any types of processes (core, non-core production processes, material, financial and information flows, commercial processes, administrative processes, etc.) and any types of innovations (radical, incremental, material and immaterial, technological and non-technological, organizational, administrative and managerial, etc.) (Milewski *et al.*, 2015; Reichstein and Salter, 2006), this study is focused on RMTI only. Figure 1 shows the distinction between RMTI and other technological process innovations in manufacturing.

Previous research in the field of technology management has covered some issues related to RMTI such as new technology adoption (Raymond and St-Pierre, 2005; Sinha and Noble, 2008; Gomez and Vargas, 2012; Akgun *et al.*, 2014), implementation of new technologies in production (Khazanchi *et al.*, 2007; Swink and Nair, 2007; Stock and Tatikonda, 2008; Karlsson *et al.*, 2010; Da Rosa Cardoso *et al.*, 2012), technology and knowledge transfer (Frishammar *et al.*, 2015; Datta and Jessup, 2013; Lee *et al.*, 2010) and technology diffusion (Antonelli, 2006). In these studies, the manufacturing firm is dominantly perceived as an adopter, buyer and user of a technology developed elsewhere, whereas the development of the technology is not in focus. As our interest is both in the creation of RMTI and its implementation, it is not sufficient to cover the technology adoption perspective only.

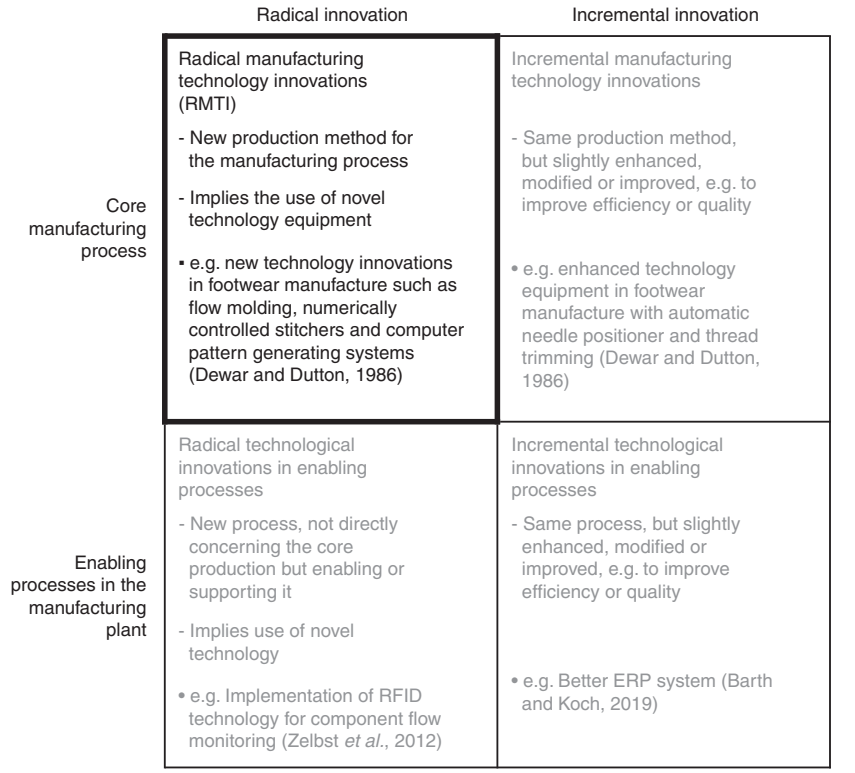

Figure 1.
Technology innovations in manufacturing, and the positioning of RMTI

Research on the development of new industrial equipment covers the ideation and development processes of RMTI, from the perspective of a technology supplier. Some of such studies acknowledge the involvement of the customers, e.g., in terms of open innovation (Sjodin *et al.*, 2011; West and Bogers, 2014), co-development (Appleyard, 2003), joint R&D (Frishammar *et al.*, 2015) and other ways of collaboration (Terwiesch *et al.*, 2005; Hausman and Stock, 2003; Dulluri and Raghavan, 2008; Von Hippel, 1978; More, 1986). However, these studies dominantly concern the empirical contexts of equipment supplier firms, and their focus is on how the equipment suppliers can develop and sell their technologies successfully and facilitate their use in technology-adopting manufacturing firms (Frambach and Schillewaert, 2002; Ng *et al.*, 2013; Baptista, 2013). Such studies are limited as they do not inform the perspective of manufacturing firms in creating the radical technological innovation within their core process.

While manufacturing firms' technology adoption and equipment supplier firms' equipment development processes are relevant and informative for this study, they appear as disconnected and do not offer a comprehensive view on RMTI creation processes from the perspective of manufacturing firms. Since "adoption and innovation are two complementary aspects of a broader process involving the introduction of localized technological changes that build upon the creative adoption and recombination of internal and external technological knowledge" (Antonelli, 2006), there is a need to consider the creation of RMTI more comprehensively for the manufacturing firms. As the manufacturing firm and its suppliers face the novel manufacturing technologies from their unique circumstances, there is a need to delve deeper into what is "novel" and "radical" in their specific context.

2.2 Radical manufacturing technology innovations: degrees and types of novelty

The term "radical" is used to refer to innovations that involve distinct new knowledge or (re-)combination of existing knowledge, thus distinguishing them from incremental innovations which take minor steps and involve little novelty (Oke *et al.*, 2007; Reichstein and Salter, 2006; Keupp and Gassmann, 2013; Maine *et al.*, 2014). However, radicalness may mean different things, depending on whether the level of newness is defined at the level the world and industry (Oke *et al.*, 2007; Reichstein and Salter, 2006), or at the level of an adopting firm or adopting individuals (Damanpour and Wischnevsky, 2006; Frambach and Schillewaert, 2002). Scholars taking a broad look at the multiple levels of novelty face the challenge of sorting the broad "gray area" of innovations which lies between new-to-world level and new-to-manufacturing (adopting) firm, as the adopting firm does not necessarily know what is readily available in other firms (Reichstein and Salter, 2006).

Creation of new-to-industry or new-to-world production technologies or equipment has not been covered widely in empirical studies (Lim *et al.*, 2006), although they appear in conceptual discussions of RMTI (Lager and Frishammar, 2010). More often, empirical studies related to RMTI have focused on within-adopter organization newness and analyzed technological and organizational adaptation issues in this context (Milewski *et al.*, 2015). Such differences in levels of novelty make it difficult to compare radical innovations across contexts, e.g., with different levels of theoretical process knowledge (Linton and Walsh, 2008). Previous research does not operationalize the separation of process innovations with less and more novelty (Reichstein and Salter, 2006; Kurkkio *et al.*, 2011), but has highlighted the need for a good categorization system for avoiding the confusion caused in both practice and academia when different types of radical innovations are compared (Lager, 2002; Sergeeva, 2016; Reichstein and Salter, 2006).

The radicalness of the innovation can mean novelty also for the technology supplier, and such supplier innovations may be intended for a specific customer or generally for the market (Winter and Lasch, 2016). Creation of technology innovations has previously been portrayed as an activity between equipment suppliers and technology-adopting (manufacturing) firms (e.g. Appleyard, 2003; Hausman and Stock, 2003; Terwiesch *et al.*, 2005; Dulluri and Raghavan, 2008; Baptista, 2013). The role and activities of suppliers and other external stakeholders may vary over the innovation process (Van Lancker *et al.*, 2016; West and Bogers, 2014), the absorptive capacity of the manufacturing firm may influence how external innovation sources are leveraged (West and Bogers, 2014; Robertson *et al.*, 2012), and these naturally may have an effect on the manufacturing firms' own innovation activities as well. Van Lancker *et al.* (2016) emphasize the systemic nature of radical innovations, requiring multi-dimensional and multi-partner changes in the socio-technical system.

In conclusion, in this study we acknowledge the continuum of incremental to radical innovations (e.g. Kurkkio *et al.*, 2011), and the alternative definitions of radicalness implying novelty to the industry or world (Reichstein and Salter, 2006; Oke *et al.*, 2007), or to the adopting manufacturing firm (Milewski *et al.*, 2015; Keupp and Gassmann, 2013), with a need to develop a better categorization system (Lager, 2002). At the same time, we focus on the manufacturing firm's perspective to RMTI creation in particular, while acknowledging the active involvement of equipment supplier firms in creating the RMTI. This idea of manufacturing firm's and equipment supplier firm's mutual engagement in RMTI will require a more fine-grained operationalization of radicalness and novelty in the RMTI, as well as deeper understanding of the manufacturing firms' RMTI creation processes.

2.3 Processes used for creating RMTI in manufacturing firms

Empirical studies on RMTI creation processes are rare, particularly covering the full lifecycle of RMTI creation from their conception to implementation spanning across the

manufacturing and equipment supplier firms. Table I reports the findings from previous empirical studies on processes in firms for the creation of new production processes and industrial equipment. None of the studies has focused on RMTI directly, but RMTIs are included in their data, and hence their findings are of interest in this study.

As is seen in Table I, existing studies have concentrated on the study of RMTI creation process phases within either the equipment supplier firm or the manufacturing firm. Both firms are, thereby, shown to play a central role in the creation process. The overall phases in the innovation creation process across both firms appear as similar, while details of the activities in either firm within the phases differ. The manufacturing firm leads the new production process concept ideation and requirement planning in the pre-study phase (Rönnberg-Sjödin, 2013; Kurkkio *et al.*, 2011), followed by negotiation, decision making and ordering within and between the two firms (Adrodegari *et al.*, 2015; Rönnberg-Sjödin, 2013), equipment engineering and construction phases in the equipment supplier firm (Adrodegari *et al.*, 2015; Rönnberg-Sjödin, 2013), finally leading to the installation and start-up of production in the manufacturing firm.

Some of the studies covered in Table I draw attention to the importance of the early phases in the RMTI creation process. For example, Adrodegari *et al.*'s (2015) study of 21 engineer-to-order equipment supplier firms from various industries emphasizes the engineering-intensive nature of the activities in the early phases of the RMTI creation process (p. 923). Kurkkio *et al.*'s (2011) investigation of the early activities in the creation process within a large metal and mineral processing firm reveals uncertainty about the process technology and equipment design leading to an iterative and experimental nature of the overall creation process. Rönnberg-Sjödin's (2013) model of typical experiences of new equipment purchase within a metal and mineral processing equipment supplier firm differs from the other studies in the more delivery-centric orientation in the process phases.

Within such an overall framework of phases in the RMTI creation process, the nature of the actual process and its activities are shown to vary for different project types. Using evidence from two cases of RMTI and five cases of innovations in non-core technologies in enabling or peripheral operations, Milewski *et al.* (2015) have argued that innovation processes differ between core vs enabling production processes. Their results from assembled-product industries show that core production process innovations have a stronger technology adaptation focus, and enabling processes have a stronger organizational adaptation focus (Milewski *et al.*, 2015). The comparison of the other studies (Adrodegari *et al.*, 2015; Kurkkio *et al.*, 2011; Rönnberg-Sjödin, 2013) draws attention to whether the process is primarily used for new equipment purchase (Rönnberg-Sjödin, 2013) or more broadly for RMTI creation (Adrodegari *et al.*, 2015; Kurkkio *et al.*, 2011). Particularly, Kurkkio *et al.* (2011) draw attention to the degree of novelty: "higher novelty resulted not only in more activities, but also in longer time-frames for individual activities, e.g. to verify ideas and problems" (p. 497). Kurkkio *et al.* (2011), however, did not explore this issue further and suggested further research to elaborate on how the processes vary in process innovation projects with different degrees of novelty.

The presently understood models for RMTI creation suggested in Table I are thus "ideal" and do not reflect how the process varies with different project types. The earlier studies describe the nature of activities within phases either from the perspective of the equipment supplier firm or the manufacturing firm, but not jointly. Some conceptual studies suggest an integrated view toward RMTI creation processes in equipment supplier and manufacturing firms (More, 1986; Lager and Frishammar, 2010). More's (1986) framework includes three sub-processes: the development sub-process within the equipment supplier firm, the adoption sub-process within the manufacturing firm and the interfacing sub-process between the two firms in which both firms work collaboratively, sharing information and resources. The conceptual framework by Lager and Frishammar (2010, p. 701) illustrates the

Table I. Summary of previous empirical research on the processes for RMTI

Authors	Perspective and empirical context	RMTI focus	RMTI creation process model	Comments, gaps
Kurkkio *et al.* (2011)	Innovation processes within manufacturing firms Qualitative data on firm-level process development practices in the early innovation stages in 4 metal and mineral processing firms	Process innovation	Informal start-up – formal idea-study – formal pre-study – formal pre-project	Partial lifecycle focus (front end only) Interaction with equipment supplier firms not covered Further research encouraged in broader samples of firms
Rönnberg-Sjödin (2013)	Collaborative opportunities in the lifecycle of machinery for process industry firms Qualitative data from 8 metal and mineral processing machinery supplier firms	New equipment development and delivery	Pre-study at the manufacturing firm – purchase negotiation for equipment and development – assembly and installation – start-up – production	Equipment supplier's perspective emphasized Focus on challenges and collaboration possibilities Further research encouraged on both sides of the dyad and entire innovation lifecycle
Milewski *et al.* (2015)	Technological process innovation and related technological and organizational adaptations in the innovation lifecycle Qualitative data on 6 examples of technological process innovations (2 involving RMTI) in 5 large assembly manufacturing firms	Technological process innovation	Ideation – adoption – preparation – installation	Emphasizes the asymmetric nature of technological vs organizational adaptations between the supplier and manufacturer RMTI cases covered as part of incremental process innovations Further research proposed to elaborate technological process innovation components
Adrodegari *et al.* (2015)	Processes within equipment supplier firms Qualitative data from 21 engineer-to-order machinery supplier firms, various industries	Engineer-to-order machinery	Quotation and order management – technical and commercial development – design – purchasing – production, assembly and testing – delivery – commissioning – after sales service. Additionally support activities	Custom-engineering effort, as part of creation activities; radicalness not evident. Does not observe ideation or prototyping activities Focus on the supplier's perspective Focus on required software support Further research suggested to develop process frameworks further for engineer-to-order industries

RMTI development phases that occur in equipment supplier firms, followed by the operational lifecycle phases in manufacturing firms. Winter and Lasch (2016) recommend evaluating supplier innovations before acquiring external resources for innovations. Such an integrative view of the RMTI creation process across the manufacturing firm and the equipment supplier firm is rare in empirical studies, and empirical research has been called for (Lager and Frishammar, 2010).

A core issue in the RMTI creation process appears to be the division of work between the technology-adopting manufacturing firm, and the equipment supplier firm. Von Hippel (1978) suggested equipment supplier firms to initiate their process for novel product development inside the manufacturing firms (with distinguished lead users, or early adopters of innovations). With the lead users, the suppliers can receive new equipment ideas and concepts from the customers rather than invest their own resources in idea generation and development (Von Hippel, 1978). Baldwin *et al.* (2006) modeled the RMTI process to be initiated at the manufacturing firm that develops the first prototype equipment in-house, uses it and even markets or sells copies to other manufacturing firms. Eventually, a market is created for the new process technology, attracting equipment supplier firms toward the technology's further refinement and development, leading to new industrial products and solutions in their business. To achieve a complete picture of the RMTI creation processes, there is a need to understand both the technology supplier's and the manufacturing firms' perspectives to the processes.

In conclusion, previous research describes the phases and activities in RMTI creation, but covers these processes only partly, dominantly from the equipment supplier's perspective. The findings indicate the presence of different types of creation processes based on project type, but differences of RMTI processes across different project types remain to be further explored. The few existing empirical studies on RMTI creation processes have investigated RMTI among other types of process innovations, including incremental innovations and innovations in non-core processes (Kurkkio *et al.*, 2011; Rönnberg-Sjödin, 2013; Milewski *et al.*, 2015). While pointing out the importance of both the technology-adopting manufacturing firms and equipment supplier firms in the RMTI creation processes, the earlier studies do not sufficiently cover the participation patterns of the two firms in different RMTI creation processes.

3. Research method

3.1 Research design

A qualitative research strategy was used for the exploratory research task, with the intent of generating new knowledge on alternative RMTI processes. A purposive sampling strategy was followed, to obtain information relevant to the research task (Bryman, 2012) concerning various RMTI projects. Emphasis was placed on gathering data from a variety of firms that had recent experiences with implementing new technology in their core production processes, with RMTI project as the unit of analysis.

Firms that had active process R&D and that had adopted novel technologies, such as nano-technology and additive manufacturing, which are considered topical manufacturing innovations (McKinsey Global Institute Report, 2012, p. 10), were included. A second search strategy was to contact production development managers and production directors in manufacturing firms regarding their RMTI experiences. Altogether, 17 suitable firms were identified and contacted as prospective contexts for RMTI projects. In the final sample, firms of different sizes (fewer than 50 employees – more than 10,000 employees) and in different industries (e.g. equipment, assembly and process manufacturing, metals, electronics, nano-technology, luxury goods and ship building) are represented to achieve variety as well as identify common patterns across the RMTI projects. The companies are well-known firms, and some of the RMTI projects resulted in patents.

Within the firms, we sought for such knowledgeable informants that were closely involved with a recently completed RMTI project, particularly from the perspective of innovation decision making and leadership. The interviewees are directors and managers who had the best first-hand knowledge of the RMTI project in the specific firm (1–2 per project). In this way, the interviewees are the best experts to discuss these projects, and often – particularly in the small and medium-sized firms – they were the only persons that could tell about the innovation and the RMTI creation process. As a contrast to the previous in-depth case studies, this exploratory study builds upon the first-hand knowledge of these informants and seeks variety and breadth of RMTI projects. The total number of interviews was 23, and 23 RMTI projects were discussed as part of them. Table II summarizes the background information of the firms and interviewees. Table AI describes the 23 RMTI projects in more detail.

3.2 Data collection

Semi-structured interviews were used for the primary data collection. They allow the investigator to probe interesting and important topics that arise based on the interviewees' experience (Bryman, 2012, p. 471). The interview outline (Appendix 2) had four main thematic sections: background of the interviewee and firm; the drivers and process of emergence of the selected RMTI project; RMTI development; and RMTI implementation, including challenges in its realization. The timing, duration and different phases of the process, the roles of individuals, and other influences were discussed for all RMTI projects. Each theme included specific questions, but the outline was largely used as a guideline for offering information and setting expectations for the scheduled interview meeting. Based on the first two interviews, the outline was slightly modified.

The interviews primarily took place in meeting rooms on company premises, and they were recorded with the permission of the interviewee and subsequently transcribed. After each interview, the first author reviewed the interview content, and compared it with earlier interviews, taking general notes on emerging themes and code categories as a preparatory step for the actual analysis and to assess the sufficiency of data. Data saturation was reached during the latter phase of the interviews, meaning that

	Equipment supplier firms	Manufacturing firms: equipment adopters/users
Nr. of firms	3	14
Range of firm sizes (in turnover MEUR)	Smallest: 7; median: 21; largest: 2,900	Smallest: 6; median: 500; largest: 31,000
Range of industries	Machine tools, nano-technology, paper and pulp	Sheet metals, assembled machines and machine components (industrial vehicles, ship engines, valves), electric motors and generators, electronics, semiconductor, luxury goods, paper and pulp, furnace
Range of technologies involved	Atomic layer deposition, paper-web heating technology	3D printing, induction heating, lignin production technology, dry etching, 3D laser cutting technology, robotics and automation, atomic layer deposition, gasification (renewable energy production) technology, etc.
Nr. of RMTI projects	6	18 (one overlapping with the supplier firm's RMTI project)
Nr. of interviewees	4	19
Job positions of interviewees (examples)	Vice president (business unit), business director, sales manager	Production director, Sr. production development manager, manufacturing manager
Average duration of interviews (minutes)	60 min. per interview (total duration: 312 min)	60 min per interview (total duration: 1,005 min)

Table II. Interview data collection

the appearance of new information on RMTI experiences was rare in later interviews (Guest *et al.*, 2006), and the number of interviews was determined as sufficient to achieve thematic exhaustion (Bryman, 2012).

3.3 Data analysis

The data were analyzed using an inductive approach, examining both the specific RMTI project and its contextual setting. The RMTI projects were numbered (1–23, see Table AI), and they are referred to using these numbers when reporting the key findings. The interview data were first reviewed to derive analysis categories or themes (Bryman, 2012). The RMTI project characteristics were analyzed in terms of innovation novelty, roles of the manufacturing and supplier firms, activities in initiating and creating the RMTI, and activities in developing and implementing the RMTI.

An in-depth systematic comparative analysis of the RMTI projects was carried out in four phases, including a search for support from or framing in previous literature. First, in order to be able to compare the RMTI projects, we mapped the types of RMTI by coding the interviewees' expressions of novelty for the manufacturing firm, for the equipment supplier and in the industry. Table III shows the approach for coding novelty in the RMTI projects. After this, the RMTI projects were categorized into low, medium and high novelty as shown in Table IV. As all projects were through the sampling criterion new to the manufacturing firm, it was not coded separately.

In the second analysis step, we identified the different activities included in the RMTI creation processes in all the RMTI projects, considered the similarities and differences across the projects, and clustered the RMTI projects with similar processes features. Similarities were evident in the investment decision and implementation phase, whereas particularly the front ends and development phases differed significantly. Consequently, we identified three types of RMTI creation processes (i.e. clusters of RMTI projects):

(1) A procurement-type process, if the equipment existed, if there was previous knowledge on its use and the suggested application, and if the RMTI process featured a front end emphasis for the manufacturer, with a deep pre-study, feasibility analysis, investigation of technology, and perhaps also process conceptualization, prior to a fairly ordinary purchasing and implementation phase.

(2) A development-type process, if the process included engineering work for a complete functioning equipment and, thereby, involved the manufacturing firm into the development activities, including various design, prototype, testing, re-working and installation activities.

(3) An invention-type process, if it required process R&D and inventions before development and validation and, consequently, engaged the manufacturing firm and the supplier(s) in a much deeper and complex cooperation already quite early than in the other types of processes. The detailed differences in the activities of these process types as well as included RMTI projects are reported in the results section in Table V.

Third, we identified the activities of the manufacturing firm and the equipment supplier firm as well as in their cooperation during the creation processes. For this third task, the basic idea in More's (1986) conceptual framework was adopted and adapted based on the previous phases of the analysis, as it was the only framework acknowledging that the idea for the RMTI may emerge in either the supplier or the manufacturing firm. The names of the activities in the framework were adapted to match the empirical findings. All 23 projects were mapped separately, and three representative examples were selected to illustrate the flow of activities between the two firms for each RMTI process type. To visualize the result

Code	Explanation	Example quotation
New to equipment supplier	The interviewee expressed that the supplier had never developed or used such a technology	"No I think this was totally new, also for them [the supplier]. Of course they have knowledge for the robots" manufacturing firm, Project 13 "We were in an area, or an unexplored area of process beyond the process window where we used to be. So that was completely new for everyone" equipment supplier firm, Project 3
Known by the equipment supplier	The interviewee expressed that the supplier knew the technology beforehand	"I think the machine itself, it is already a product. So it is not that someone had to invent it or something like that, I think they have been producing this for some other customers […]" manufacturing firm, Project 10
Established technology in the specific industry (custom engineering using known technology)	The interviewee expressed that the technology was already known in the manufacturing firm's industry	"It's not a new method. I think that we didn't do any innovation in the technology I would say. But designing the machine, how it works, and what kind of programs are used, and, all the variations […], there I think it was the need for designing […]" manufacturing firm, Project 22 "We had the needs now and investigated what was the best technology at the moment to do it [and it was available in the industry]" – manufacturing firm, Case 8
New technology in the specific industry (technology or its application invented)	The interviewee expressed that the technology was new also for others in the specific industry – no-one in the industry had developed or used it before	"We made some market studies, nothing really big but, to the knowledge we had, it showed up that there is nothing concrete around the world. Nobody you can buy something from," equipment supplier firm, Project 3 "But the problem was that there was no experience in that kind of scale as we are implementing, so there was the risk. There was no implementation in this kind of an industry earlier" manufacturing firm, Project 14

Table III.
Coding framework for assessing technology novelty in the RMTI projects

in an effective way and to enable comparison, ordinary flow-charts are reported instead of the original matrix format (Figure 3).

Finally, we mapped the use of different creation process types for different RMTI types. This result combines the results from the first two analysis steps and is reported in Figure 4 and in the text. Quotes from the interviews are used, and summary tables, process descriptions and flow-charts were developed to compress and illustrate the findings.

Actions were taken to enhance the validity of the research. Concerning confirmability, a thematic interview protocol was used for all interviewees, the interview frame was developed into its final form through the first few interviews, and the interviews were recorded and transcribed. Reliability was enhanced by selecting informants that had first-hand knowledge of the RMTI projects, using a consistent data collection protocol, and building a simple analytical frame for the analysis. To enhance the credibility of results, the novelty and process categorization frames were validated

Table IV.
Clustering of RMTI projects to identify different levels of novelty

New to mfg. firm	New to equipmt. supplier firm	Established in the specific industry: custom engineering using known technology	New to the specific industry: technology or its application invented	RMTI type	RMTI projects in the sample (see Figure 1 for the content of RMTI projects)
x		x		Low-novelty RMTI	8, 10, 16, 17, 19
x	x	x		Medium-novelty RMTI	5, 6, 11, 13, 20, 21, 22
x			x	Medium-novelty RMTI	2
x	x		x	High-novelty RMTI	1, 3, 4, 7, 9, 12, 14, 15, 18, 23

Note: "x" signifies the novelty features that characterize the RMTI type

Table V.
Three processes for creating RMTI identified in the studied RMTI projects

Process type	Process description
Procurement-type process	Pre-study → Procurement → Implementation • Process conceptualization • Technology investigation • Investment planning and decisions • Investment preparation • Order equipment • Delivery, install, trials • Ramp-up • Learn to use RMTI projects in the sample: 2, 8, 10, 16, 17, 19
Development-type process	Conceptual phase → Development phase → Implementation • Process conceptualization • Equipment concept development, including technology selection • Equipment prototype (proof-of-concept models) • Investment planning , preparation and decisions • Contract • Equipment engineering, designing • Construction, trials, possible rework • Delivery, installation • Production trials, possible rework • Ramp-up • Learn to use, possible adaptations RMTI projects in the sample: 5, 6, 11, 12, 13, 15, 18, 20, 21, 22
Invention-type process	Creation of new process know-how → Process concept validation → Investment consideration → Equipment Development → Implementation • Discovery – Basic research • Application R&D (technical, lab-scale) • Discussions exploring new process application • Create consortium for development of idea • Equipment concept development • Proof-of-concept level prototype, e.g., demo plant • Revise, improve process concept and equipment concept • Address and solve critical areas of risk and uncertainty • Investment planning • Decision, negotiation, contract • Equipment design and engineering • Construction • Trials, possible redesign, rework • Delivery, installation • Production trials, possible redesign, rework • Ramp-Up • Learn to use, possible adaptations RMTI projects in the sample: 1, 3, 4, 7, 9, 14, 23

through reporting the findings to the interviewees in a practitioner-oriented report, organizing a workshop to present the findings, and requesting for possible feedback. Changes were not requested by the interviewees at this stage. To enhance transferability and application of results, we have delimited the focus to RMTI as the innovation type,

purposely selected companies that have participated in RMTI recently, and invited also new participants to the results workshop. Remaining validity limitations are discussed in the concluding section.

4. Findings

4.1 Types of RMTI

The sample of 23 RMTI projects was heterogeneous, as it covered examples from different industries, involved different process technologies, and included differences in the levels of novelty, ranging from adopting a widely known technology to creating new inventions. As shown above, all RMTI projects were "new-to-manufacturing firm," while "new to the supplier," "known by the supplier," "new technology in industry" and "established technology in industry" emerged as the differentiating novelty themes in the interview transcripts. The clustering of firms on this basis revealed three types of RMTI based on the level of novelty (Table IV).

Low-novelty RMTI projects involve newness at the level of the manufacturing firm changing to a new-to-firm technology for their core production process. For these projects, no newness was involved at the level of the equipment supplier firm, and the technology and related equipment represents "a standard product" for the equipment supplier firm and also more generally in the industry. The equipment involved can therefore be selected from the product catalogues of the equipment supplier, and usually the best equipment suppliers are well-known in the industry. For example, in RMTI Project 10, a flexible automated stacking equipment was implemented, and as such automation existed already, the main thing was to find a suitable supplier and customize the system for the manufacturing firm's product range. The equipment supplier can provide previous customer references, arrange benchmarking visits to other installations of the same or similar equipment, and arrange systematic training for the manufacturing firms.

Medium-novelty RMTI projects involve tailor-made, special-purpose equipment engineered dominantly using known technology. These RMTI involve newness at the level of the equipment concept, and there are no ready solutions available for direct purchase, e.g., by selecting from suppliers' catalogues. In addition to newness at level of the manufacturing firm, medium-novelty RMTI projects typically involve newness at the level of the equipment supplier firm that must develop the application for the first time; however, the core technology was not invented as part of the RMTI, and the development effort involved engineering using known technology principles and the use of commercially available components. For example, in RMTI Project 20 the joining technology existed and the supplier firm had to do inventive design work and engineering, to build the solution for the customer. Such RMTI often involve equipment suppliers who have experience and expertise in the technology involved, e.g., testing equipment suppliers, small machine tool builders and automation systems builders.

RMTI Projects 2, 12, 15 and 18 did not completely match the criterion described above for medium-novelty RMTI. In line with the other medium-novelty RMTI projects, Projects 12, 15 and 18 involved engineering of unique equipment, developed for the first time by the equipment supplier firms involved in these projects. However, the technology was not invented in these projects, but technologies and process concepts were explored outside of their specific industry and implied a novel process concept in the projects' specific industries. Since piloting a novel process concept is a feature of high-novelty RMTI (as described further below), these three projects were categorized as high-novelty RMTI projects. Project 2 resembles these projects, with respect to exploring and piloting of a novel process concept within their industry. In Project 2, advanced 3D printing technology equipment was implemented, and the equipment was adapted as part of a trial for mass printing of wax castings. The traditional process in the manufacturer's industry involved

the use of die casting and pressure-injection technologies to create mass copies of wax castings based on a master prototype piece. In comparison to RMTI Projects 12, 15 and 18, the RMTI Project 2 lacks the design and development of the equipment itself, and the equipment procured was a standard solution for the equipment supplier firm. Taking into account the simultaneous presence of features of low and high-novelty RMTI in this project, it has been identified as a unique medium-novelty RMTI project.

High-novelty RMTI projects involve the invention of a new technology or an invention that enables a novel application of an existing technology that is patentable. They involve newness for the manufacturing and equipment supplier firms and newness at the level of the technology or application and thus newness at the global or industry level. Ready-made solutions do not exist, the manufacturing firm and the technology supplier do not have previous experiences with the technology, and there are no benchmarks to visit and learn from. For example, in RMTI Project 7, a new solution was designed for material extraction in pulp processing, the technology was patented, and the implementation required multiple breakthroughs before turning it into a production concept. Technology patents were involved in nearly all RMTI projects in this category, with the exception of Projects 12, 15 and 18. In addition to the development of the equipment concept, high-novelty RMTI projects involved the creation of new process know-how and piloting the use of a non-proven technology in an industrial production process. Figure 2 illustrates the 23 RMTI projects and the level of novelty for each project.

4.2 Types of RMTI creation processes

The 23 RMTI projects differed in terms of the processes in which the RMTI was created. Some projects involved a shorter creation process and some a longer process with additional

	Established technology in the industry	New technology in the industry
Known by the equipment supplier	LOW NOVELTY RMTI 8, Electronics assembly tech. 10, Flexible stacking equipment 16, Robotized transfers 17, Robotized welding and laser cutting 19, Laser cutting	MEDIUM NOVELTY RMTI 2, 3D printing of castings
New to the equipment supplier	MEDIUM NOVELTY RMTI 5, Flexible testing equipment 6, Large automated furnace 11, Large fully automated assembly 13, Complex welding using robots 20, Complex joining equipment 21, Complex winding equipment 22, Complex welding equipment	HIGH NOVELTY RMTI 12, Flexible cutting equipment 15, Renewable fuel process 18, Smart material prod. process 1, Nano-coating 3, Nano-production tech. 4, Nano-production tech. 7, Pulp-processing tech. 9, Paper web-heating tech. 14, Pulp production process 23, Electronics production Process tech.

Figure 2.
Types of RMTI and degree of novelty identified in the studied RMTI projects

activities and phases. The creation process for each project was outlined based on the interview transcripts, and the processes were compared for commonalities and differences. The analyses revealed three types of RMTI creation processes, which were labeled procurement-type (six projects), development-type (ten projects) and invention-type processes (seven projects). Table V summarizes the basic features of the RMTI creation processes and the RMTI projects that best match each process type.

The procurement-type process of RMTI creation is where both the creation of new process know-how and new equipment concepts are missing, and it primarily involves identifying the suitable technology, ordering and implementing it, and learning to use it. As the RMTI involves a shift in the core production technology used in the firms, it involves an early phase of new process conceptualization "outside of the box" of current ways to create products. The new-to-manufacturing firm process concept is followed by technology investigation, i.e., a detailed investigation of the available technology and equipment. For most projects, the technology choice was immediately clear, and the pre-study phase focused on searching for the most suitable equipment and supplier. For some projects, the pre-study phase involved interactions with equipment suppliers regarding their equipment technology and test samples (Projects 2 and 8) or visits to reference plants where similar technologies had been successfully installed by the same supplier (Project 17).

The pre-study phase leads to investment planning and decision making, including quotations from alternate suppliers, comparisons and negotiations for optimal supplier and solution selection, planning the financing of the equipment, refining the business case, and justifying the purchase, e.g., pay-back calculations, for approval by management. The timing of the decision is influenced by business strategies, business environments (e.g. recessions) and investment decision makers' involvement in the early stages. The phases following the investment decision and before the ramp-up were brief and smooth from the interviewees' perspectives. For example, the interviewee for Project 8 stated "[…] it's more like implementation. Order the device and make sure that they are as you ordered them and then assemble them and then ramp-up the production; it's more like doing then." For three projects (8, 10 and 17), engineering was required for the modular equipment, whereas in other projects (2, 16 and 19), the equipment supplier delivered the ordered standard equipment. Collaborative efforts were involved during the installation, production trials, training and ramp-up. Most interviewees discussed a period of one year following equipment installation during which the plant employees learned to use the new technology equipment with confidence, e.g., making small improvements and regulating settings on their own.

The development-type process of RMTI creation involves the creation of a new equipment concept – designing an approach to implement a certain process know-how in a specific manufacturing context – and involves engineering work and specification development. These projects began with new process conceptualization in the manufacturing firm. Compared to projects using the procurement-type process, projects with the development-type process were less clear regarding the feasibility of the equipment concept in the process conceptualization phase, and in some projects, there was no clarity regarding the technology that should be selected initially. For these projects, the equipment concept development activities were more technical and involved detailed investigations of potential solutions and methods. At the end of process conceptualization phase, proof-of-concept, e.g., prototypes (Project 5 and 12), detailed drawings (Project 6) or detailed plans for proposed RMTI implementation (Project 11) led to the initiation of investment planning work.

The remaining phases of the development-type process were similar to the procurement-type process with the addition of a design phase. The design work involved engineering for a few months at the equipment supplier firm and required interaction and

feedback from the manufacturing firm to develop detailed specifications. The subsequent testing stages were critical as errors, rework and development issues could arise, which did arise for some projects (6, 11, 15 and 22). For Projects 18 and 12, there were uncertainties related to the equipment concept until the production trials were completed.

The invention-type process of RMTI creation includes the creation of new process know-how in addition to new equipment concept development. This process has a longer front end, involving basic research followed by application-oriented research to determine whether the new process application is feasible for real industrial use. These projects began with new knowledge and discoveries about process know-how from scientific research within either the equipment supplier or manufacturing firm, or in joint research projects in industrial research networks. The initial phase involved discussions on the potential of utilizing the new process know-how and search for the right types of partners (e.g. willing to take risks, be leaders and bring in needed experience in technical areas) needed for development. Concept validation via proof-of-concept prototypes, industry-scale prototypes and detailed implementation plans (Projects 1, 3, 4, 7, 9 and 14), at times involving concept improvement iterations, was perceived as a turning point, making the new RMTI concepts appear to be more feasible. It created the rationale for the pre-study phase on commercial, economic and construction issues in the manufacturing firm. The investment planning considerations and the following stages involved activities similar to those described for the procurement-type and development-type RMTI processes. For some projects (e.g. Projects 3 and 7), chance events had a significant impact, and active leadership and communication were needed (promoting the concept and its opportunity over its risks), leading to the investment decision of the manufacturing firm.

The equipment engineering, design and construction phases involved a period of intense activities for the equipment supplier firm. Testing was described as a critical phase in which unplanned, unexpected errors emerged, causing the need for redesign (at times, new development issues occurred) and rework. Following the ramp-up phase, there was a learning period of up to one year in which the manufacturing firm employees gained experience in using the new technology and becoming confident in equipment maintenance. During this period, small adaptations in the equipment were made in Projects 1, 3, 4, 7 and 14.

4.3 Activities of manufacturing and equipment supplier firms in RMTI creation processes

The creation of RMTI in the projects involved at least two organizations: a manufacturing firm and an equipment supplier firm. For some projects, a research institute played the role of the manufacturing firm as a financer of the development work and the buyer of the equipment developed during the RMTI project. For some projects, additional technology expert organizations participated, such as firms specializing in the technology, research institutes or universities. Searching for suitable and interested partners in the development of the process technology and arriving at a contract between the firms were important turning points during the RMTI creation process.

As the manufacturing firms' and the equipment supplier firms' individual activities and collaboration appeared to be a central component of RMTI creation, we mapped the firms' activities and further analyzed the processes of the 23 RMTI projects. Figure 3 summarizes the results of the most typical RMTI project examples. The activities at the intersection of the two actors indicate collaboration. Projects 19, 13 and 7 were selected as examples to illustrate the typical process flow for the three process types.

As shown in the figure, the early period of Project 19 (example of procurement-type process) consisted of pre-study phases including process conceptualization, investigation of available technology and equipment, investment considerations and decision, which largely took place within the manufacturing firm. The equipment supplier firm was contacted to

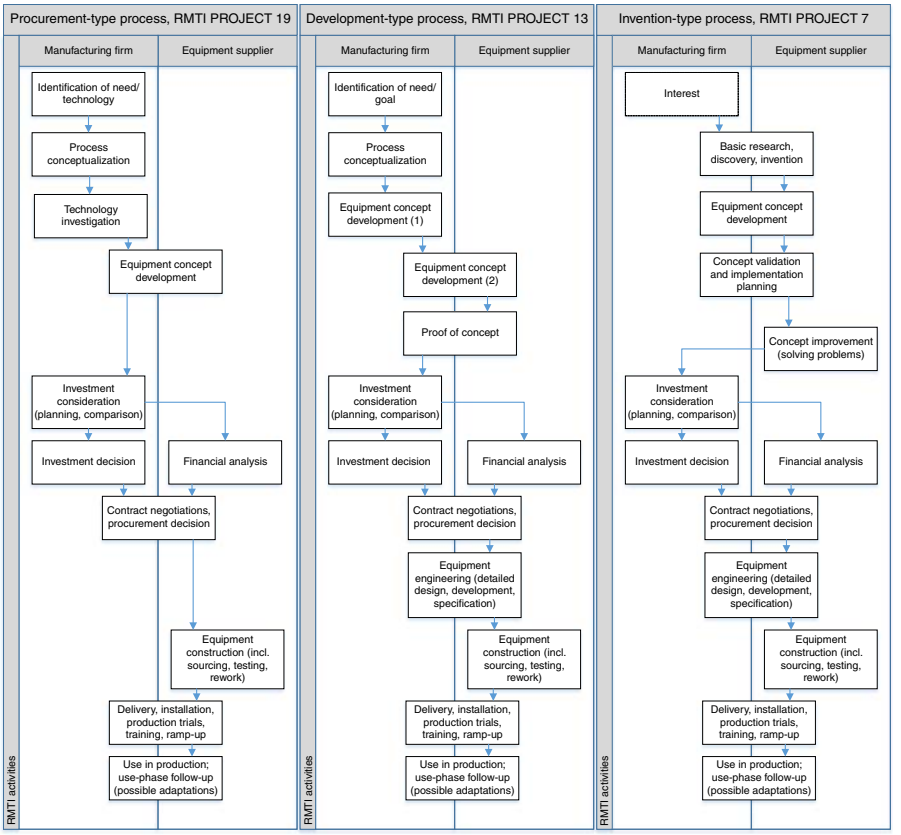

Figure 3. Mapping of manufacturing firms' and equipment supplier firms' activities for the three types of RMTI creation processes (example Projects 19, 13 and 7)

collect information used to identify the best available equipment and supplier during equipment concept development. The later phases after the investment decision involved the independent construction of the equipment at the equipment supplier firm, collaborative installation and training phases, and ongoing learning during the first year of using the new technology in the manufacturing firm. This was the dominant pattern for all projects with procurement-type process. The only exceptions were whether dialogue with the equipment supplier occurred before need identification and process conceptualization within the manufacturing firm (Project 10) and whether the equipment supplier supported and participated in the ongoing learning of the use of the equipment after ramp-up and when adaptations were needed (Projects 2, 10 and 17).

During the early phases of the RMTI projects that included a development-type process, such as Project 13, there was a more collaborative approach during equipment concept development compared with the procurement-type process; however, there was a larger variation across the RMTI projects in the ways the equipment concept phase was carried out. Of the ten projects, the manufacturing firms either shared their needs with the equipment supplier firms (specialized tool builders) and asked them to develop and provide equipment concept solutions (Projects 6, 12, 20 and 21), developed their own equipment concepts and interacted with equipment supplier firms at a later stage (Projects 13, 15, 18 and 22), or jointly developed the concept by involving the equipment supplier firm in early stages (Projects 5 and 11). The additional equipment engineering phase following the

contract between firms was concentrated within the equipment supplier firm for five projects in this cluster and was more interactive and collaborative for the other five.

For RMTI projects with an invention-type process, such as Project 7, the early period involved scientific research and new knowledge generation. There were considerable variations regarding where the discovery occurred: during R&D activities within manufacturing firms (Project 14), within the equipment supplier firms (Projects 1, 3, 4 and 9) or within research projects in an industry network of firms and research institutes (Projects 7 and 23). Accordingly, the process was initiated by either the manufacturing or equipment supplier firm or was initiated outside of the two firms (in a research network). The early process phases involving process conceptualization, equipment concept development and validation could be carried out within either firm (7, 9 and 14), in close collaboration (4), or with some interaction between the two firms (1, 3 and 23). The seven projects with an invention-type process also varied regarding whether the detailed engineering and development phase was completed primarily within the equipment supplier firm (1, 3, 9 and 14) or involved more interaction between firms (4, 7 and 23). Overall, the participation of the equipment supplier firms in the invention-type processes was quite active during the early phases and clearly more active than in the two other types of processes. The manufacturing firm consistently played the role of a financer (and thereby the risk taker) for the detailed engineering and development of the equipment concept, as actual development work on the details of the equipment concept began after the contract was made.

The above analysis suggests that collaborative activities between the manufacturing firm and the equipment supplier firm increase in the project front end from procurement-type to development-type to invention-type processes. For example, the long pre-study phase is largely concentrated within the manufacturing firm for the procurement-type process, while equipment supplier firms are actively involved in the stage of equipment concept development for the development-type process and in the basic technology discovery and application R&D phases for the invention-type process. Furthermore, Figure 3 illustrates that RMTI creation activities differ slightly from the perspectives of manufacturing and equipment supplier firms. While some activities in the overall process, such as investment consideration, decisions within each firm at the time of contract and equipment construction, are concentrated within either firm, both firms play a role in the initiation, conceptualization and development of the RMTI until its implementation.

4.4 Different process types for different RMTI types

The three types of RMTI creation processes differ in the number of phases and the intensity and number of activities in similar phases. The number of phases increases from the procurement-type to development-type to invention-type processes. For example, the equipment concept development and equipment engineering/design phases are missing in the procurement-type process but play an important role in the development-type process. Similarly, the discovery, application R&D and process concept validation phases are missing in the development-type process but are highlighted in the invention-type process.

The use of different process types across the different RMTI types was mapped to identify potential patterns in the RMTI processes. Figure 4 summarizes the processes for the different types of RMTI projects. The mapping reveals a pattern: an overlap between RMTI types and RMTI process types. Of the high-novelty RMTI projects (1, 3, 4, 7, 9, 12, 14, 15, 18 and 23), seven projects had the invention-type RMTI creation process (1, 3, 4, 7, 9, 14 and 23). Of the eight medium-novelty RMTI projects (2, 5, 6, 11, 13, 20, 21 and 22), seven projects included the development-type process (5, 6, 11, 13, 20, 21 and 22). While there were five low-novelty RMTI projects (8, 10, 16, 17 and 19), six projects included the procurement-type process (2, 8, 10, 16, 17 and 19). Exceptions to the pattern are indeed the four Projects 2, 12, 15 and 18 described earlier in Section 4.1

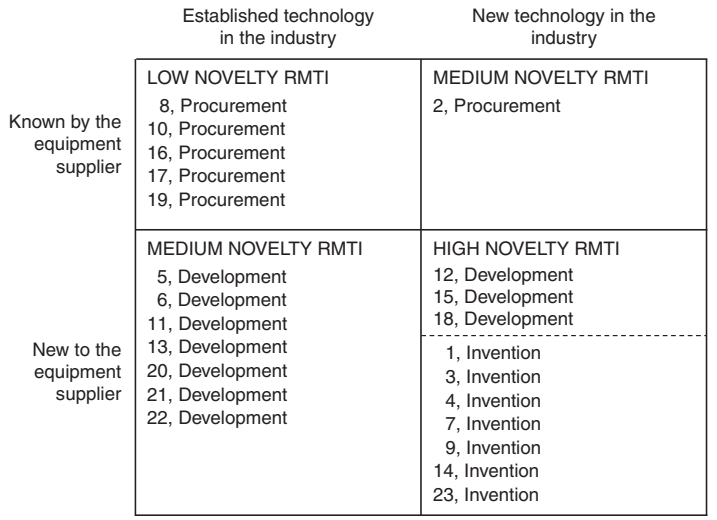

Figure 4.
Types of creation processes identified in the studied RMTI projects, divided by the type of novelty

The overall pattern revealed the exceptions of Projects 2, 12, 15 and 18, and we analyzed them further to identify potential explanations. The procurement-type process for Project 2 is understandable through its familiarity for the supplier but novel application domain in a new industry for the manufacturing firm and, thereby, the need for piloting in a high-volume industrial use. It, however, did have a fairly long pre-study, long implementation and ramp-up period, and needs for later technology adjustments, compared to ordinary procurement-type processes in the category of low-novelty RMTI. Projects 12, 15 and 18 involved novel applications of existing technology for a different use requiring considerable engineering efforts for the development of the equipment. These high-novelty RMTI projects did not need the long research phase typical to invention-type processes as the firms sought for technologies outside of their own industry, used in other applications aligned with their need. Thereby, they appeared to utilize the development-type RMTI process. While this implied suppliers' low knowledge of the application and high requirements for engineering and design for the manufacturer's specific system, it saved time in the research and pre-study phase.

5. Discussion

5.1 Different types of RMTI projects

In this study, we have purposely centered on the radical innovations in manufacturing firms' core production technologies, to develop knowledge on the processes and practices needed, for the manufacturing firms to benefit from equipment suppliers' offerings. The differentiation of RMTIs from innovations concerning peripheral or enabling processes (Bessant, 198) and incremental innovations (Milewski *et al.*, 2015) imply that, through RMTI, manufacturing firms invest into their core productive capabilities and capacity (i.e. critical resources), which requires their proactiveness also in ideation and development. Thereby, RMTI cannot be treated just as technology adoption (Raymond and St-Pierre, 2005), implementation (Khazanchi *et al.*, 2007) or diffusion (Antonelli, 2006). As also RMTI projects vary, we need to understand how each of them can be managed successfully and why, depending on the project type.

The preparatory step for responding to the research questions included mapping the RMTI projects in terms of their novelty. Three types of RMTI were identified based on the

level of novelty involved. Our inductive analysis revealed that "newness to equipment supplier firms" together with "newness-to-manufacturer's-industry" enables categorizing radical innovations into those with low, medium and high novelty and, thereby, supplements the adopter's view that may be restricted through the manufacturing firms' limited awareness of existing technologies. This approach was useful in differentiating between the 23 RMTI projects, and there was considerable within-category homogeneity regarding the process experiences of the managers involved in the creation of RMTI. The results suggest that the categorization system used could be helpful in assessing and mapping RMTI creation projects in firms and thereby selecting the appropriate processes.

The developed novelty categorization offers a solution to the challenge described in previous studies on radical innovations regarding the broad gray area of innovations between new-to-world innovations on one extreme and new-to-adopter firms only on the other (e.g. Reichstein and Salter, 2006). Taking into account the technology novelty for the supplier as well as to the manufacturing firm's specific industry more broadly offers a logical categorization for radical innovations, thereby evading the ambiguous criteria for medium-novelty innovations, such as those with a moderate degree of changes in products and production processes (Sergeeva, 2016) or those with incremental changes in plant equipment with incremental newness to the world (Lager, 2002).

5.2 Three alternate processes for RMTI creation in firms

The first research question inquired the types of processes manufacturing firms use for RMTI creation. While previous research has partly covered the front end phases of process innovations (Kurkkio *et al.*, 2011) and core phases in new equipment procurement (Rönnberg-Sjödin, 2013), this study investigated the RMTI creation process broadly, revealing different types of RMTI processes, here labeled as procurement-type, development-type and invention-type processes based on their core challenge.

The comparative analysis yielded a broad and detailed picture of the processes for RMTI creation and, thereby, contributes by offering additional information on the activities within the different RMTI processes. The procurement-type process is similar to the process described by Rönnberg-Sjödin (2013) and involves a long pre-study phase within the manufacturing firm, including identification and investigation of alternate technologies for a core production operation, followed by ordering and implementation phases. Development-type process resembles the process discussed by Adrodegari *et al.* (2015); it involves concept development and engineering of the equipment, besides the pre-study and implementation phases. Invention-type process includes similar features as the iterative process reported by Lim *et al.* (2006) and emphasizes front end activities as reported by Kurkkio *et al.* (2011), as it involves the development of new process know-how and new technology as part of the front end phases. The implementation stages (testing, production trials and ramp-up) involve re-work and possibly redesign and development for the development-type and invention-type RMTI processes.

The findings add to previous research by offering detailed knowledge for each of the process types involved in creating RMTI. While the generalizability of previous RMTI process research has been limited to a specific industry, technology or innovation phase (Kurkkio *et al.*, 2011; Frishammar *et al.*, 2013; Rönnberg-Sjödin, 2013; Milewski *et al.*, 2015), the current findings offer rich evidence of different technologies and industries, cover the entire RMTI processes, and provide empirical evidence for the applicability of each process type. One of the key contributions, in particular, deals with emphasizing the manufacturing firm's proactive role and collaboration with equipment suppliers in all types of RMTI, which is discussed next.

5.3 Roles of manufacturing and equipment supplier firms in the RMTI creation process

Among the key contributions of this study is the identification of manufacturing firms as active and influential actors in creating RMTI. Prior research has focused on the role of

manufacturing firms as lead users and idea generators (Von Hippel, 1978) and adopters and implementers of technology developed elsewhere (e.g. Raymond and St-Pierre, 2005; Khazanchi *et al.*, 2007; Swink and Nair, 2007; Sinha and Noble, 2008; Stock and Tatikonda, 2008; Karlsson *et al.*, 2010; Da Rosa Cardoso *et al.*, 2012; Gomez and Vargas, 2012). Manufacturing firms are perceived to have a small or non-existent role in the RMTI creation phases (Damanpour and Wischnevsky, 2006; Lager and Frishammar, 2010) or they have been seen as first prototype developers, sharing their technologies with other manufacturing firms and transferring the technology to be further developed by suppliers (Baldwin *et al.*, 2006). In contrast, the results of this study highlight the role of manufacturing firms as active co-creators of RMTI, as they initiated particularly the procurement and development-type RMTI processes, took contact with equipment supplier firms, financed the development and engineering work, and took an active role in collaboration during concept development and engineering work. This co-creation aspect is novel and will deserve also further research attention.

Where previous research has studied the technology innovation process often from the equipment supplier's perspective (Rönnberg-Sjödin, 2013; Adrodegari *et al.*, 2015), this study has emphasized the manufacturing firms' view, also to suppliers' activities. Even if the equipment supplier firms would initiate the RMTI creation process, they require interested manufacturing firms to participate in further development of the equipment concept, to invest both money and effort in the new technology, and to take the risk with piloting the use of the novel technology and its processes. As the initiation, sponsoring and context-specific use of a novel technology are strategic tasks of RMTI creation, a manufacturing firm's role in RMTI creation becomes critical. By adapting a framework used in another context (More, 1986) with RMTI specific content, the manufacturing firm's and equipment supplier's patterns of action and interaction were revealed and differentiated by the RMTI process type. The more refined role of manufacturing firms in RMTI creation presents new opportunities for further research to complement the product development centric equipment suppliers' viewpoint.

The findings also emphasize the role of equipment supplier firms in RMTI creation as experts in technology and the construction of industrial equipment. The findings thereby deviate from studies suggesting that RMTI are internally developed within manufacturing firms (Gopalakrishnan and Bierly, 1999; Milewski *et al.*, 2015; Baldwin *et al.*, 2006). Rather, an integrated view on the creation sub-processes occurring within and between manufacturing and equipment supplier firms is proposed (e.g. More, 1986). Understanding the collaboration between the manufacturing firm and the equipment suppliers as well as its different patterns across different RMTI projects offers a valuable perspective for further research on the processes and strategies of RMTI creation.

5.4 RMTI creation process types based on the level of novelty

The second research question asked the ways RMTI creation processes vary across different RMTI projects. The findings revealed a clear pattern of employing specific RMTI creation processes for specific RMTI project types, namely, the dominance of procurement-type processes for low-novelty RMTI, development-type processes for medium-novelty RMTI and invention-type processes for high-novelty RMTI. While previous studies have reported divergences of RMTI creation processes for different types of RMTI projects in limited industrial settings (Kurkkio *et al.*, 2011; Rönnberg-Sjödin, 2013), this study has contributed by offering illustrative empirical evidence on the differences in processes across a variety of RMTI types. The results suggest adopting a contingency view to RMTI creation, i.e., differentiating between RMTI creation processes depending on the novelty and engineering effort required by the equipment supplier firm and the requirement to invent novel process technology.

The findings indicate that the collaborative activities between the manufacturing firm and the equipment supplier increase from procurement-type to development-type and invention-type innovations, and thereby also from low to medium to high degrees of novelty. This trend offers empirical support concerning open innovations: if radical innovations benefit from openness and require partners' access to organization-specific knowledge (Huizingh, 2011; Van Lancker *et al.*, 2016), this understanding could be well-designed into differentiated RMTI processes, depending on the degree of novelty. With the focus on RMTI specifically, our findings emphasize that novelty must be understood in a holistic way to select the right RMTI process – novelty is not just newness to the manufacturing firm, but newness to suppliers and the manufacturer's specific industry as well. The activity descriptions in Figure 3 offer a starting point for developing the partners' roles in the RMTI processes further. The findings, in particular, encourage differentiating the innovation support mechanisms and collaborative practices depending on the RMTI process type.

6. Conclusion

6.1 Contributions

With the goal of increased understanding of the creation processes for RMTI in firms, this study has responded to the call for additional empirical studies on the processes by which technology and process innovations take place in manufacturing firms' core processes (Kurkkio *et al.*, 2011; Lager and Frishammar, 2010). As the first contribution, the study has offered a nuanced characterization of novelty in radical innovations, complementing the manufacturing firm's own understanding with the additional perspectives of the equipment supplier and industry more generally. Different degrees of novelty in the RMTI reflect the extent of available knowledge and respective uncertainties in the industry, causing unique demands for the manufacturing firms' technology development and acquisition task. Thereby, the study responds to a previous call for better innovation categorization systems (Lager, 2002) and complements studies that have focused only on the adopter's perspective (Milewski *et al.*, 2015; Frambach and Schillewaert, 2002) or the industry level (Reichstein and Salter, 2006).

Second, this study has contributed by revealing the patterns of activities used for RMTI creation at the level of the RMTI project, across a variety of RMTI projects. The categorization of procurement-type, development-type and invention-type RMTI and their connection with the type of novelty offers a useful foundation not just for structuring forthcoming research, but also for designing processes and support routines for companies' practice. Previous research on RMTI creation processes has focused on firm-level practices, examining RMTI along with incremental development in limited empirical settings (Kurkkio *et al.*, 2011; Rönnberg-Sjödin, 2013). We complemented the previous case studies by covering a larger number of RMTI projects and promoting a contingency view for using appropriate RMTI processes for the respective level of novelty in the RMTI project, taking into account the novelty for both the manufacturing firm and the equipment supplier, and the industry more broadly.

Third, the findings contribute by revealing the role of manufacturing firms as active creators of RMTI and collaborators in RMTI processes in addition to their previously acknowledged role as adopters and implementers of RMTI. Manufacturing firms contribute as initiators, sponsors and active participants in the technology and process development work and are thereby necessary partners for equipment suppliers. We found that the collaborative activity increased with increased novelty of the RMTI and when moving toward invention processes, and thereby offered contributions toward open innovation research (Huizingh, 2011; Van Lancker *et al.*, 2016; West and Bogers, 2014). The results extend empirical research on radical innovations, particularly by enriching the understanding of manufacturing technology innovation processes.

6.2 Implications for practice

This study has several implications for practice. First, the descriptions of phases in the RMTI creation process provide a framework for planning RMTI projects and help in developing established processes for RMTI. Second, the findings showed that different types of RMTI creation processes are needed depending on the novelty levels of the RMTI. Rather than establishing generic and broad processes and systems for manufacturing innovation and development, the findings support a differentiated approach toward establishing processes and systems that best support the different types of RMTI. The proposed categorization framework for separating the low/medium/high-level novelty projects provides practical guidelines for establishing the differentiated processes.

Third, when planning RMTI processes, firms can be strategic regarding the roles and activities within and between them and the partner firms. For manufacturing firms, determining the needed technical support from the equipment supplier firm can help in selecting the most appropriate equipment supplier and in identifying the most appropriate phase for their involvement. For equipment supplier firms, negotiating and planning for the appropriate resources and time required for allowing the learning related to the first-time experience has strategic implications for the success of the firms. They must understand their different roles in the process, depending on the novelty of the RMTI. The approaches used in this study to map the activities and roles may be useful as a framework for targeting the efforts of the partners involved in the RMTI project.

6.3 Limitations and further research

The data collection method involved retrospective interviews, which include the risk of important facts being forgotten or misinterpreted (Eisenhardt and Graebner, 2007). To improve the validity and comparability, the companies were consistently advised to propose successful and recent RMTI projects and to focus on the knowledgeable informants involved in the RMTI projects with first-hand knowledge. The data on RMTI processes related to activities and stages were obtained from interviews with just one, or in some cases, two to three persons per company. Therefore, there is a limitation related to the depth of knowledge and data per company; however, due to the sampling strategy used, data could be collected for multiple RMTI projects and industrial contexts instead of only a few projects in a specific context. The study thereby complements previous research and serves as a broad pre-study, allowing for a broad mapping of the types of RMTI and RMTI processes across industrial, organizational and technological boundaries. Further studies are encouraged to combine the interview-based findings with such data as patents, industry articles and suppliers' post-innovation technology sales data, to develop further knowledge on suppliers' actual achievements with the RMTI.

The findings support the accumulation of knowledge on RMTI creation processes from different industries, against the dominant approach of studying processes within either assembled products industries or process industries only. The results pave way toward developing a theoretical model on novelty and RMTI processes, and testing it with a broader sample of RMTI projects, potentially involving also unsuccessful RMTI projects. The findings support an integrative, open innovation view toward RMTI creation processes, and future research should examine the different actors' roles more broadly, as RMTI creation typically requires the active involvement of both manufacturing firms and technology suppliers. This would enrich current research, which has been limited to investigating RMTI processes as product development for equipment supplier firms or adoption-implementation for manufacturing firms. This would also expand the research of open innovation to process innovations that require organization-specific knowledge and may cause a challenge to involving external partners (Huizingh, 2011). Because other organizations were involved in invention-type RMTI process, further research could explore the roles of research institutions and other technology partners as additional actors for an integrated view of RMTI creation process.

References

Adrodegari, F., Bacchetti, A., Pinto, R., Pirola, F. and Zanardini, M. (2015), "Engineer-to-order (ETO) production planning and control: an empirical framework for machinery-building companies", *Production Planning and Control*, Vol. 26 No. 11, pp. 910-932.

Akgun, A., Keskin, H., Byrne, J. and Lynn, G. (2014), "Antecedents and consequences of organizations' technology sensemaking capability", *Technological Forecasting and Social Change*, Vol. 88, pp. 216-231.

Antonelli, C. (2006), "Diffusion as a process of creative adoption", *Journal of Technology Transfer*, Vol. 31 No. 2, pp. 211-226.

Appleyard, M. (2003), "The influence of knowledge accumulation on buyer-supplier co-development projects", *Journal of Product Innovation Management*, Vol. 20 No. 5, pp. 356-373.

Baldwin, C., Hienerth, C. and von Hippel, E. (2006), "How user innovations become commercial products: a theoretical investigation and case study", *Research Policy*, Vol. 35 No. 9, pp. 1291-1313.

Baptista, C. (2013), "Interaction processes in long-term relationships in the metal mining industry: longitudinal case studies of capital equipment buying", *Industrial Marketing Management*, Vol. 42 No. 6, pp. 969-982.

Barth, C. and Koch, S. (2019), "Critical success factors in ERP upgrade projects", *Industrial Management & Data Systems*, Vol. 119 No. 3, pp. 656-675.

Bessant, J. (1982), "Influential factors in manufacturing innovation", *Research Policy*, Vol. 11 No. 2, pp. 117-132.

Bryman, A. (2012), *Social Research Methods*, 4th ed., Oxford University Press, New York, NY.

Damanpour, F. and Wischnevsky, D. (2006), "Research on innovation in organizations: distinguishing innovation generating from innovation-adopting organizations", *Journal of Engineering and Technology Management*, Vol. 23 No. 4, pp. 269-291.

Da Rosa Cardoso, R., Pinhiero de Lima, E. and Guovea da Costa, S. (2012), "Identifying organizational requirements for the implementation of advanced manufacturing technologies (AMT)", *Journal of Manufacturing Systems*, Vol. 31 No. 3, pp. 367-378.

Datta, A. and Jessup, L. (2013), "Looking beyond the focal industry and existing technologies for radical innovations", *Technovation*, Vol. 33 Nos 10/11, pp. 355-367.

Dewar, R. and Dutton, J. (1986), "The adoption of radical and incremental innovations: an empirical analysis", *Management Science*, Vol. 32 No. 11, pp. 1422-1433.

Dulluri, S. and Raghavan, N. (2008), "Collaboration in tool development and capacity investments in high technology manufacturing networks", *European Journal of Operations Research*, Vol. 187 No. 3, pp. 962-977.

Eisenhardt, K. and Graebner, M. (2007), "Theory building from cases: opportunities and challenges", *Academy of Management Journal*, Vol. 50 No. 1, pp. 25-32.

Ettlie, J., Bridges, W. and O'Keefe, R. (1984), "Organization strategy and structural differences for radical versus incremental innovation", *Management Science*, Vol. 30 No. 6, pp. 682-695.

Frambach, R. and Schillewaert, N. (2002), "Organizational innovation adoption: a multi-level framework of determinants and opportunities for future research", *Journal of Business Research, Special Issue on Marketing Theory in the Next Millennium*, Vol. 55 No. 2, pp. 163-176.

Frishammar, J., Ericsson, K. and Patel, P.C. (2015), "The dark side of knowledge transfer: exploring knowledge leakage in joint R&D projects", *Technovation*, Vols 41/42, pp. 75-88.

Frishammar, J., Lichtenthaler, U. and Richtner, A. (2013), "Managing process development: key issues and dimensions in the front end", *R&D Management*, Vol. 43 No. 3, pp. 213-226.

Gomez, J. and Vargas, P. (2012), "Intangible resources and technology adoption in manufacturing firms", *Research Policy*, Vol. 41 No. 9, pp. 1607-1619.

Gopalakrishnan, S. and Bierly, P. (1999), "A re-examination of product and process innovations using a knowledge-based view", *Journal of High Technology Management Research*, Vol. 10 No. 1, pp. 147-166.

Guest, G., Bunce, A. and Johnson, L. (2006), "How many interviews are enough? An experimentation with data saturation and variability", *Field Methods*, Vol. 18 No. 1, pp. 559-582.

Harborne, P., Hendry, C. and Brown, J. (2007), "The development and diffusion of radical technological innovation: the role of bus demonstration projects in commercializing fuel cell technology", *Technology Analysis & Strategic Management*, Vol. 19 No. 2, pp. 167-188.

Hausman, A. and Stock, J. (2003), "Adoption and implementation of technological innovations within long-term relationships", *Journal of Business Research*, Vol. 56 No. 8, pp. 681-686.

Huizingh, E.K.R.E. (2011), "Open innovation: state of the art and future perspectives", *Technovation*, Vol. 31 No. 1, pp. 2-9.

Karlsson, C., Taylor, M. and Taylor, A. (2010), "Integrating new technology in established organizations: a mapping of integration mechanisms", *International Journal of Operations and Production Management*, Vol. 30 No. 7, pp. 672-699.

Keupp, M.M. and Gassmann, O. (2013), "Resource constraints as triggers of radical innovation: longitudinal evidence from the manufacturing sector", *Research Policy*, Vol. 42 No. 8, pp. 1457-1468.

Khazanchi, S., Lewis, M. and Boyer, K. (2007), "Innovation-supportive culture: the impact of organizational values on process innovation", *Journal of Operations Management*, Vol. 25 No. 4, pp. 871-884.

Kurkkio, M., Frishammar, J. and Lichtenthaler, U. (2011), "Where process development begins: a multiple case study of front end activities in process firms", *Technovation*, Vol. 31 No. 9, pp. 490-504.

Lager, T. (2002), "A structural analysis of process development in process industry: a new classification system for strategic project selection and portfolio balancing", *R&D Management*, Vol. 32 No. 1, pp. 87-95.

Lager, T. and Frishammar, J. (2010), "Equipment supplier/user collaboration in the process industries: in search of enhanced operating performance", *Journal of Manufacturing Technology Management*, Vol. 21 No. 6, pp. 698-720.

Lager, T., Hallberg, D. and Eriksson, P. (2010), "Developing a process innovation work process: the LKAB experience", *International Journal of Innovation Management*, Vol. 14 No. 2, pp. 285-306.

Lee, A., Wang, W. and Lin, T. (2010), "An evaluation framework for technology transfer of new equipment in high technology industry", *Technological Forecasting and Social Change*, Vol. 77 No. 1, pp. 135-150.

Leonard-Barton, D. (1988), "Implementation as mutual adaptation of technology and organization", *Research Policy*, Vol. 17 No. 5, pp. 251-267.

Lim, L., Garnsey, E. and Gregory, M. (2006), "Product and process innovation in biopharmaceuticals: a new perspective on development", *R&D Management*, Vol. 36 No. 1, pp. 27-36.

Linton, J. and Walsh, S. (2008), "A theory of innovation for process-based innovations such as nanotechnology", *Technological Forecasting and Social Change*, Vol. 75 No. 5, pp. 583-594.

McKinsey Global Institute Report (2012), "Manufacturing the future: the next era of global growth and innovation", November, available at: www.mckinsey.com/business-functions/operations/our-insights/the-future-of-manufacturing (accessed August 10, 2017).

Maine, E., Thomas, V.J. and Utterback, J. (2014), "Radical innovation from the confluence of technologies: innovation management strategies for the emerging nanobiotechnology industry", *Journal of Engineering and Technology Management*, Vol. 32, pp. 1-25.

Milewski, S., Fernandes, K. and Mount, M. (2015), "Exploring technological process innovation from a lifecycle perspective", *International Journal of Operations and Production Management*, Vol. 35 No. 9, pp. 1312-1331.

More, R. (1986), "Developer/adopter relationships in new industrial product situations", *Journal of Business Research*, Vol. 14 No. 6, pp. 501-517.

Ng, I., Ding, D. and Yip, N. (2013), "Outcome-based contracts as new business model: the role of partnership and value-driven relational assets", *Industrial Marketing Management*, Vol. 42 No. 5, pp. 730-743.

Oke, A., Burke, G. and Myers, A. (2007), "Innovation types and performance in growing UK SMEs", *International Journal of Operations & Production Management*, Vol. 27 No. 7, pp. 735-753.

Parikh, M. and Joshi, K. (2005), "Purchasing process transformation: restructuring for small purchases", *International Journal of Operations & Production Management*, Vol. 25 No. 11, pp. 1042-1061.

Raymond, L. and St-Pierre, J. (2005), "Antecedents and performance outcomes of advanced manufacturing systems sophistication in SMEs", *International Journal of Operations & Production Management*, Vol. 25 Nos 5/6, pp. 514-533.

Reichstein, T. and Salter, A. (2006), "Investigating the sources of process innovation among UK manufacturing firms", *Industrial & Corporate Change*, Vol. 15 No. 4, pp. 653-682.

Robertson, P.L., Casali, G.L. and Jacobson, D. (2012), "Managing open incremental process innovation: absorptive capacity and distributed learning", *Research Policy*, Vol. 41 No. 5, pp. 822-832.

Rönnberg-Sjödin, D. (2013), "A lifecycle perspective on buyer-supplier collaboration in process development projects", *Journal of Manufacturing Technology Management*, Vol. 24 No. 2, pp. 235-256.

Sergeeva, N. (2016), "Radicality of innovation: perceptions of organizational members", *International Journal of Innovation Management*, Vol. 20 No. 2, pp. 1-17.

Sinha, R. and Noble, C. (2008), "The adoption of radical manufacturing technologies and firm survival", *Strategic Management Journal*, Vol. 29 No. 9, pp. 943-962.

Sjodin, D.R., Eriksson, P.E. and Frishammar, J. (2011), "Open innovation in process industries: a lifecycle perspective on development of process equipment", *International Journal of Technology Management*, Vol. 56 Nos 2/3/4, pp. 225-240.

Stock, G. and Tatikonda, M. (2008), "The joint influence of technology uncertainty and inter-organizational interaction on external technology integration success", *Journal of Operations Management*, Vol. 26 No. 1, pp. 65-80.

Swink, M. and Nair, A. (2007), "Capturing the competitive advantages of AMT: design-manufacturing integration as a complementary asset", *Journal of Operations Management*, Vol. 25 No. 3, pp. 736-754.

Terwiesch, C., Ren, Z., Ho, T. and Cohen, M. (2005), "An empirical analysis of forecast sharing in the semiconductor equipment supply chain", *Management Science*, Vol. 51 No. 2, pp. 208-220.

Tyre, M.J. and Orlikowski, W.J. (1994), "Windows of opportunity: temporal patterns of technological adaptation in organizations", *Organization Science*, Vol. 5 No. 1, pp. 98-118.

Van Lancker, J., Mondelaers, K., Wauters, E. and Van Huylenbroeck, G. (2016), "The organizational innovation system: a systemic framework for radical innovation at the organizational level", *Technovation*, Vols 52/53, pp. 40-50.

Von Hippel, E. (1978), "A customer-active paradigm for industrial product idea generation", *Research Policy*, Vol. 7 No. 3, pp. 240-266.

Von Hippel, E. and Tyre, M. (1995), "How learning by doing is done: problem identification in novel process equipment", *Research Policy*, Vol. 24 No. 1, pp. 1-12.

West, J. and Bogers, M. (2014), "Leveraging external sources of innovation: a review of research on open innovation", *Journal of Product Innovation Management*, Vol. 31 No. 4, pp. 814-831.

Winter, S. and Lasch, R. (2016), "Recommendations for supplier innovation evaluation from literature and practice", *International Journal of Operations & Production Management*, Vol. 36 No. 6, pp. 643-664.

Zelbst, P., Green, K., Sower, V. and Reyes, P. (2012), "Impact of RFID on manufacturing effectiveness and efficiency", *International Journal of Operations & Production Management*, Vol. 32 No. 3, pp. 329-350.

Appendix 1

Project	RMTI name	Technology shift involved	Time
1	Anti-tarnish coating on silver	Chemical bath → ALD coating technology equipment	2000–2009
2	3D printing of casting dies	Creating wax mold for casting by pressure-injection equipment using rubber dies → direct 3D printing of wax mold for casting	1997–2012
3	Industrial particle coater based on nano-technology	CVD, PVD coatings → ALD coating technology	2006–2010
4	Continuous deposition process for thin-films	0 → new process enabling industrial application of thin-film coatings in continuous production environment	2005–2009
5	Flexible automation of testing tool	Manual testing→ rigid automated testing equipment → flexible equipment	2000–2005–2014
6	Automation of large furnace	Manual and smaller → automated and large furnace process line	2000–2010
7	New process for lignin extraction as side stream in wood pulp manufacture	0 → new process and equipment technology	1990–2015
8	Implementation of new assembly process for electronic device manufacture	Old → new assembly technology (interviewee regards names as confidential)	2013–2015
9	New concept for heating web in paper manufacture	Old heat roll → calendaring roll technology	2010–2015
10	Automation of stacking process in transformer core manufacture	Manual stacking of sheets in core → automated stacking	2008–2013
11	Automation of large engine head assembly	Manual operations → automation of process steps (e.g. testing) and robotization	2007–2010
12	Cheaper cutting tool for slots on circumference of motor plates	high volume equipment available only → create a low volume tool with innovative engineering	2014–2015
13	Automation of spot welding process for round plates in motor	Manual welding→ automated, robotized welding; holding tool redesign (big impact)	2006–2014
14	Paper pulp making technology	Process using traditional catalyst → modified equipment and process for using new catalyst	1990s–2013
15	Energy plant to utilize production plant by-product as renewable fuel	0 → new process equipment to enable use of less homogeneous fuel	2013–2014
16	Automation of production plant	Manual operations → robotized	1995–2009
17	Automation of production plant	Plasma cutting → laser cutting with automation; manual welding → robotized welding	2001–2014
18	New technology in manufacture of specialized silicon wafer	Interviewee considered names of technologies as confidential	2013–2016
19	3D laser technology sheet metal cutting equipment	Punching machine → 3D 6-axis laser cutting technology equipment	2000–2001
20	Special-purpose equipment: joining machine for large pipe flanges	Old tools → tailored joining equipment	2010–2012
21	Special-purpose equipment: insulation machine for generator coils	Manual insulation winding → semi-automatic equipment	1996–2002–2006
22	Special-purpose equipment: Inductive-heating based semi-automatic joining machine for generator coils	Manual gas soldering equipment → semi-automated induction heating equipment	2007–2009
23	Novel technology equipment for electronics component manufacture	Wet etching technology → dry etching technology	2005–2011

Table AI.
Description of the 23 RMTI projects

Appendix 2. Interview outline

(1) Introductions and background:

- Introduction of interviewer and interviewee.
- Company background and information.
- Existing systems, processes, practices in the firm for radical vs incremental development in production.
- Overview of an example of radical change in production technology in the firm and how it was implemented:
  - What does the technology deal with?
  - What is its role in the manufacturing system of the firm?
  - How was it discovered and implemented (background, start, activities, end and current state)?
- Further discussion on the above example, with help of the following questions.

(2) Emergence of the new process/equipment idea:

- What was the key driving factor for the emergence of the idea?
- Was the new technology well-established at the time? Extent of uncertainty that it would work well for the intended application?
- Were there many competing ideas at the time when this idea emerged?
- What was the role of the equipment supplier – motivator and driver vs technical expertise and support provider vs something else?
- Comments on the timing of the technology adoption with respect to competitors or general industry level.
- Special role, if any, of an individual, team, event or other factors in triggering the emergence of the idea for changing the production technology.
- Was the decision making for adopting a novel technology smooth and fast? Any turning points?

(3) Creation of the new process/equipment:

- Key activities.
- What was the scope of work, creation responsibilities at the manufacturing firm, equipment supplier firm, other partners?
- What was the composition of the project team in different stages – who did what?
- Extent of inventive effort, work done for creation of the needed equipment, e.g., how similar or different was the new equipment compared to previous equipment made by the equipment supplier firm, before this project.

(4) Implementation of the new process/equipment into production:

- How did it happen – was it an easy journey to make a change in the way of production?
- Did it involve significant experimentation and piloting during the installation and commissioning stage?
- Comments on competence destroying impact, e.g., were there any layoffs, old assets removed, new training, new personnel?
- Outcome: is the new technology now in smooth, routine operation?

- Were the desired benefits achieved? Were there any unexpected benefits or challenges after implementation?
- What was the role of customers and their feedback in the overall process for implementation?
- Any comments on critical enablers and barriers for this change, e.g., technical specialists, visionary leader, any resources?

(5) Closing:

- Any additions regarding the example project.
- Upon need, discussion on another radical innovation project (if available), in line with the above questions.
- Comments on the importance of ongoing minor changes in production equipment vs major changes in equipment technology for the firm.

Corresponding author
Miia Martinsuo can be contacted at: miia.martinsuo@tuni.fi