This paper was presented at The XXXIII ISPIM Innovation Conference "Innovating in a Digital World", held in Copenhagen, Denmark on 05 June to 08 June 2022.
Event Proceedings: LUT Scientific and Expertise Publications: ISBN 978-952-335-694-8

Suppliers' technological newness: Source of uncertainty in manufacturing technology innovations

Pooja Chaoji*

Tampere University, P.O. Box 541, 33014, Finland.
E-mail: pooja.chaoji@tuni.fi

Prof. Miia Martinsuo

Tampere University, P.O. Box 541, 33014, Finland.
E-mail: miia.martinsuo@tuni.fi
* Corresponding author

Abstract: Radical manufacturing technology innovations involve the introduction of a new technology in a firm's core production process. They require significant learning and knowledge transfer between the technology supplier and the technology introducing manufacturing firm. This study explores the technological newness for equipment supplier firms and linked technology uncertainties in high-novelty manufacturing technology innovation projects which feature technological newness not only for the technology introducing manufacturing firm but also for the equipment supplier firm. The findings reveal a four-dimensional construct for equipment suppliers' technological newness and linked technological uncertainties emerging in the manufacturing firm's innovation process. The findings pave the way for better planning and preparation for addressing technological uncertainties and linked inefficiencies in high-novelty manufacturing technology innovation projects. Implications for research on knowledge transfer for innovation are discussed.

Keywords: Technological uncertainty; technology newness; radical innovation; manufacturing technology.

1 Introduction

Radical manufacturing technology innovations (RMTIs) involve the design and introduction of a new technology in a manufacturing firm's core production system and require manufacturing firms' proactive innovation effort (Reichstein and Salter, 2006). RMTIs present challenges for manufacturing firms due to technology newness, as unknown technologies may be slow to develop and adopt. RMTIs may imply technology newness also for the equipment supplier firm, for the industry, and even at the level of the world (Reichstein and Salter, 2006). Technology newness introduces uncertainty about the tasks involved in the innovation process (Eslami and Melander, 2019), due to incomplete information required for completing the tasks (Rönnberg-Sjödin et al., 2016; Rösiö and Bruch, 2018; Stock and Tatikonda, 2004). Technological uncertainty is considered to have a significant influence on the budget and schedule performance in RMTI projects (Rönnberg-Sjödin et al., 2016; Stock and Tatikonda, 2004; Tyre and

Hauptman, 1992). Further research is therefore needed to improve the efficiency and performance of RMTI projects under technological uncertainty (Rönnberg-Sjödin et al., 2016).

Previous research has studied technology newness for manufacturing firms (Barnett and Clark, 1996; Tyre and Hauptman, 1992) and related technological uncertainty in RMTI projects. RMTI is often treated as a technology adoption issue for the manufacturing firms that may face barriers to technology adoption. Knowledge and capability gaps may exist in the manufacturing firms concerning the new production technology, and this may create challenges in technology adoption decision making (Martinsuo and Luomaranta, 2018), and specifying requirements for equipment engineering (Rösiö and Bruch, 2018), and requires extra efforts for achieving the full benefits desired from the technology innovation (Bourke and Roper, 2016). Manufacturing firms need strategies and practices to manage technology uncertainty related to their technology newness (Rönnberg-Sjödin et al., 2016; Simms et al., 2021, Stock and Tatikonda, 2004; Tyre and Hauptman, 1992).

Manufacturing firms, however, are not alone in implementing the RMTIs, but they need external partners in such projects. Equipment supplier firms are important partners in RMTI projects (Rönnberg-Sjödin et al., 2016), either selling their existing equipment or innovating completely new technologies and processes. High-novelty RMTIs may involve technology newness also for the equipment supplier firm (Rönnberg-Sjödin et al., 2016). If equipment suppliers are only innovating and learning to design a radically new technology, this is likely to be reflected on the experiences of the manufacturing firm investing in RMTI, too. Technology newness for equipment supplier firms as part of RMTI projects has not been well understood. Overall, high-novelty RMTI projects have been under-investigated, and there are calls for further research on their unique challenges due to high technology uncertainty and the requirements for their successful management (Simms et al., 2021).

The purpose of this study is to explore equipment suppliers' technological newness as part of manufacturing firms' RMTI projects. The goal is to map the manifestations of equipment supplier firms' technological newness as a distinct source of uncertainty in RMTI projects. The study offers new knowledge on the managerial requirements stemming from technological uncertainty in the interplay of equipment suppliers (i.e., contractors) and manufacturing firms renewing their core production systems (i.e., customers) in RMTI projects. The study answers the following two research questions:

RQ1. What comprises technological newness for equipment supplier firms involved in RMTI projects?

RQ2. How do manufacturers experience uncertainty attributed to the technological newness of equipment supplier firms?

To tackle the exploratory research objective, this study adopted a qualitative exploratory research approach. Data on 16 RMTI projects involving newness for both manufacturing and equipment supplier firms were analysed for identifying what was new to equipment supplier firms and its linked technological uncertainties experienced as part of the RMTI creation process. The findings reveal a four-dimensional construct for equipment suppliers' technological newness and linked technological uncertainties. Implications for further research on RMTI projects and knowledge transfer for innovation are discussed.

This paper was presented at The XXXIII ISPIM Innovation Conference "Innovating in a Digital World", held in Copenhagen, Denmark on 05 June to 08 June 2022.
Event Proceedings: LUT Scientific and Expertise Publications: ISBN 978-952-335-694-8

2 Literature review

RMTIs: background

Manufacturing firms introduce new manufacturing technologies in their core production systems to expand their product portfolio and increase efficiency and quality (Milewski et al., 2015). In this paper, we use the term radical manufacturing technology innovation (RMTI) to refer to processes that manufacturing firms use to introduce a new technology in their core production system. RMTIs concern technology innovations in the core production system, and exclude other enabling operations in manufacturing plants, supply chain processes, and support systems. RMTIs involve new-to-manufacturing firm technology, whereas high-novelty RMTIs may be new also for the industry and the world (Chaoji and Martinsuo, 2019; Reichstein and Salter, 2006).

When manufacturing firms introduce new technology, they often set up a project for new technology equipment procurement, development, and implementation (Stock and Tatikonda, 2008). Equipment supplier firms are important partners providing the technology and equipment in these projects (Stock and Tatikonda, 2004). Low-novelty RMTI projects involve the procurement of ready and proven equipment solutions from the supplier firm, whereas high-novelty RMTI projects require joint development of new equipment (Chaoji and Martinsuo, 2019; Sjödin et al., 2016). The overall RMTI project consists of three broad phases: front-end, where the innovation idea and concepts emerge, partners are identified and a development project is initiated; development phase, where the detailed equipment and technology solutions are engineered, constructed and tested before being sent to the manufacturing site for installation; and start-up phase which involves installation and trial runs, followed by ramp-up of production using the new technology (Milewski et al., 2015; Stock and Tatikonda, 2004).

RMTIs, like other radical technology innovations, can be seen as a knowledge quest and creation process within the firm's networks (Hall and Martin, 2005). Due to technology newness for the manufacturing firm, these projects involve uncertainty and challenges regarding feasibility, performance, and integration with other technologies in the production system (Brown, 2001; Martinsuo and Luomaranta, 2018). Technological uncertainty is among key features of these projects. Reducing and mitigating the technological uncertainty and its linked difficulties are necessary in managing them (Simms et al., 2021; Stock and Tatikonda, 2004).

Technological newness and uncertainty in RMTIs

Uncertainty refers to insufficient information, understanding or knowledge for doing the task (Eslami and Melander, 2019; Simms et al., 2021). Technological uncertainty in RMTI relates to difficulties faced in introducing new technological knowledge in the firm's core production system, and such difficulties stem partly from technological newness and the firm's lack of knowledge and previous experience with the technology (Simms et al., 2021; Stock and Tatikonda, 2004).

Manufacturing firm's technological newness comprises of their lack of previous experience with the technology and degree of its dissimilarity from their previous technologies in terms of skill base and organizing principles (Stock and Tatikonda, 2004; Tyre and Hauptman, 1992). Manufacturing firms may face difficulties in technology

evaluation and decision making in the project front-end (Martinsuo and Luomaranta, 2018) and understanding and communicating requirements to equipment supplier firms for designing and developing the new equipment (Rösiö and Bruch, 2018). When implementing the RMTI projects, manufacturing firms need to accumulate experience and transfer knowledge among the personnel to enable an efficient ramp up of production and initial use of the new technology, and to fully utilize the technology in their production (Brown, 2001). Deficient knowledge transfer at any phase of the RMTI project will lead to delays and budget overruns. Therefore, managing technological uncertainty is central for improving the efficiency of RMTI projects (Sjödin et al., 2016).

Technological uncertainty will require mitigating practices in the RMTI projects, for example, in terms of learning and knowledge transfer to the manufacturing firm, particularly from the equipment supplier firms (Linder and Sperber, 2019; Simms et al., 2021). Useful practices include gathering of information from preliminary trials, collecting inputs from the production team, and learning from suppliers prior to actual technology implementation (Simms et al., 2021). Also, geographical proximity and close relationship with equipment supplier firms may enhance the efficiency and effectiveness of knowledge transfer and manufacturing firm's RMTI project (Linder and Sperber, 2019).

Manufacturing firms will need understanding, targeted planning, and management of such knowledge problems in high-novelty RMTIs (Simms et al. 2021; Sjödin et al., 2016). High-novelty RMTIs with their extreme technological uncertainty are accompanied with other knowledge problems related to complexity, ambiguity, and equivocality due to lack of ready technology solutions and novelty present also for equipment supplier firms (Simms et al., 2021; Sjödin et al., 2016). Existing studies on technological uncertainty in high-novelty RMTIs are few, and there is need for further research on the management of uncertainty and other knowledge problems in different types of RMTI projects (Simms et al., 2021).

While technology newness and uncertainty in RMTI projects have been consistently connected in previous research (Simms et al., 2021; Stock and Tatikonda, 2004; Tyre and Hauptman, 1992), technology newness has been considered mainly from the viewpoint of the manufacturing firms as technology adopters. Despite the equipment supplier firms' centrality in RMTI projects, their experience of technology newness as part of RMTI projects has not been covered sufficiently before. There is a need to consider how equipment supplier firms' technology newness is reflected in manufacturing firm's technology introduction projects and related uncertainties.

3 Research method

We explore equipment suppliers' technological newness as part of high-novelty RMTI projects. This study followed a qualitative research strategy which is suitable for exploratory research seeking understanding on previously less understood phenomenon (Bryman, 2012).

A broad search was initially made for collecting diverse examples of RMTI projects, involving the introduction of a new technology in core production system at a manufacturing firm. We contacted production directors and managers in firms in Finland to enquire about their recent RMTI experiences and identified some RMTI projects for data collection. We also searched for information on the internet for manufacturing firms that had been active in introducing contemporary novel manufacturing technologies such

as 3D printing and nanotechnology and found contact for some examples of RMTIs this way, too. Altogether, the search resulted in 23 examples of RMTI from diverse companies, such as ship building, pulp and paper manufacture, machinery manufacture, luxury goods manufacture etc.

From the total sample, 17 projects involved technological newness also for the equipment supplier firms and were initially selected for this research, following a purposive strategy (Bryman, 2012) where the selection criterion is the presence of the phenomenon of research interest. Data on one project was later deemed insufficient, and hence it was excluded from the analyses. Table 1 summarizes the 16 high-novelty RMTI projects analysed as part of this study.

Table 1 Data Collection

Project	*Project Description*	*Interviewees*
A	Thin film coating on silver luxury goods	Production Director, Manufacturing firm; Production foreman, Manufacturing firm; Vice President, Business unit, Supplier firm
B	Industrial particle coater based on nanotechnology	Vice President, Business unit, Supplier firm
C	Continuous-process equipment for thin-film coating	Vice President, Business unit, Supplier firm
D	Flexible/ multi-product testing tool	Head of Supply Chain Engineering, Manufacturing firm
E	Automation of a large furnace	Plant Manager, Manufacturing firm
F	New process for new side stream product extraction	Head of Innovation, Manufacturing firm
G	New equipment technology for paper web-heating	Production Director, Supplier firm
H	Automated pressure testing of a very large assembly	Production Development Manager, Manufacturing firm
I	Small-batch compatible slot cutting tool	Manufacturing Unit Manager, Manufacturing firm
J	Automated welding of ribs on large motor plates	Manufacturing Unit Manager, Manufacturing firm
K	Large-scale implementation of a chemical process	Vice President, Production, Manufacturing firm
L	Process equipment for using novel renewable fuel	Vice President, Production, Manufacturing firm
M	New technology in the manufacture of a material	Sr. Process development engineer, Manufacturing firm
N	Joining equipment for large pipe flanges	Business Director, Supplier firm
O	Insulation machine for coating large coils	Business Director, Supplier firm
P	Joining machine for making large coils	Sr. Production Development Manager, Manufacturing firm

The data for each RMTI project was collected through semi-structured interviews with key informants involved in the RMTI projects. The interviewees were typically production development managers or senior managers who had directed or participated closely in the RMTI project. For all the projects, we requested for further interviews with other closely involved persons and access to project documentation for enabling richer data and information on the projects. These were realized for some projects. The interviews followed a thematic outline which was consistently used across the interviews to allow for similar kind of information on all projects. The outline enquired information on the events, activities, actors, and also key enablers and challenges through all the phases of RMTI projects. The interviews typically lasted about an hour. All interviews were conducted in company premises in conference rooms and were recorded with the permission of the interviewees.

We also searched publicly available information on the studied projects for additional information and triangulation of the data. To validate the findings, we presented a summary from the data and its preliminary analyses to the interviewees. A results workshop was conducted and also other managers in addition to the interviewees were invited.

A qualitative abductive approach was used for data analysis. The initial reading of the interview transcripts pointed at the relevance of equipment suppliers' technology newness to the RMTI project experiences of managers. For example, manager in project L mentioned, "*…we have problems, and it's due to this technology and the equipment suppliers not having much experience in that area*". This prompted our interest in exploring what is new to equipment supplier firms participating in these projects and focusing on the linked difficulties and uncertainties in the RMTI projects. An open coding approach was followed, for studying both the equipment suppliers' technological newness and the uncertainties experienced in the projects linked with lack of knowledge and ready solutions at equipment supplier firm.

The initial codes were refined by comparing the codes with each other and matching them across the data from all the projects. In this way, four distinct categories of technological newness to equipment supplier firms in RMTI projects were obtained: context, application, construction and technology newness. The linked uncertainties and difficulties experienced in the projects also reflected these four themes. At this stage, we searched for previous literature on technological newness and uncertainty in RMTI projects (e.g., Barnett and Clark, 1996), and in other than RMTI literature (e.g., Hong and Hartley, 2011). However, existing frameworks were unsuitable and did not provide direction for further analyses.

4 Findings

Equipment suppliers' technological newness in RMTI projects

The studied projects varied in what exactly was new in the solution development from the equipment supplier firm's perspective. Analyses of the data for aspects in the RMTI project that presented unfamiliarity or first-time experience for the equipment supplier firm revealed four primary dimensions of technological newness: Context, Application, Construction and Technology.

The manufacturing firm's specific context, such as its core product and product-mix, layout and production system, and other surrounding processes in the manufacturing plant, was new to equipment supplier firms in projects A, B, C, E, H, J, M, N and P. For example, in project A, the equipment supplier firm was not familiar to the intricacies of luxury goods making process: "*There are lots of different things we do to the pieces before they go to the coating machine, and they [equipment supplier firm] don't know how that thing goes*".

In some projects, the kind of technology use involved in the RMTI project was new and presented many unknowns for the equipment supplier firm. Application newness involved application of the technology for unique or different materials, forms, volumes, and scale of production or new levels of operating requirements and conditions such as accuracy level, temperatures which generated higher-level generic requirements that need to be understood in order to make the technology application feasible. For example, as the equipment supplier firm manager in project B elaborated: "*We were in an area or unexplored area of process beyond the process window we used to be at…".*

In projects C, E, F, G, I, L, O, and P, the actual build of the equipment presented newness and first-time experience for the equipment supplier, for example in the type of structure, size, and scale of the equipment. In project E, the manager from manufacturing firm shared: "*The supplier didn't have so much experience with equipment of this size*".

Technology involved in RMTI projects F, G, L, and O was new for the equipment supplier firm. In Project O, it was a first-time experience for the equipment supplier to develop equipment utilizing the new automation featuring technology, and the technology itself was developed during the project in projects F, G, and L. Thus, technology newness concerned a lack of full understanding of the technology and engineering industrial equipment utilizing it for the equipment supplier firm.

The above four types of newness for the equipment supplier firms in RMTI projects are connected with each other, and yet emphasize distinct aspects related to the project. For example, where the technology itself presented newness and first-time experience for the equipment supplier firm, application newness followed. However, for some projects, the application of technology to such kind of novel circumstance (large scale, very different form and shape of material to be coated) was the main novelty to the equipment supplier, while they had expertise in the technology and thus no technology newness. The projects varied in the number of dimensions that were new for the equipment supplier. Also, within projects with similar type of newness, such as context newness for the supplier firm, the degree of newness varied based on whether the project involved significant unknowns about developing the solution or whether the kind of development work was also unfamiliar and presented a first-time experience for the supplier firm.

Technological uncertainties in RMTI projects

The studied high novelty RMTI projects involved technological uncertainty and related difficulties. The projects faced a lack of clarity on the needed technology equipment, and the interviewees linked some of the difficulties with a lack of ready solution and full knowledge needed for it at the equipment supplier firm. For example, a manager in manufacturing firm in project L noted, "*Now, if we look backward, this process is operating well, but in this drying process, we have problems, and it's due to this technology and the equipment suppliers not having much experience in that area*". Similar comments were noted in other projects, and this prompted the analysis of

difficulties linked with the lack of knowledge and experience at the equipment supplier firms. The issues dealt with the equipment suppliers' lack of knowledge related to the context, application, construction and technology involved in the RMTI project. Table 2 summarizes the range of uncertainty experiences across the phases of studied RMTI projects.

In project A, B, C, E, H, J, M, N and P, there was lack of clarity on context-related requirements to be captured in the concept of the equipment. This was linked with uncertainties and difficulties experienced during the different phases of the project. For example, in project P, the manager explained linked difficulties in the designing phase: "*When the supplier was finalizing the machine, we started to express some needs for additional functions to the machine… during the trials we find some new challenges there, the machine supplier needs to fix those*". The other projects involved similar delay and rework related to context requirements uncertainty and linked difficulties. For example, equipment supplier manager in project C noted: "*There were again some new things identified [at the start-up phase] that needed to be re-built. They wanted something different eventually.*".

Application requirements were unclear in projects A, B, C, E, F, H, I, K, L, M. This created uncertainty at the front-end of these projects related to the application feasibility and performance. For example, manager in Project K described: "*And actually, one risk was that can we operate the digester in that way, or were there problems in the digester process so that the stability is not so good?*". Similar uncertainty in the front end and development phase for project B were noted by manager in supplier firm: "*We were not sure how long was the time of diffusion we needed to allow and the kind of mechanical tumbling the particles, and the coated particles especially, can tolerate"*. The uncertainty and linked effort and difficulties were reflected in the delays and long period of time and rework in these projects.

Projects C, D, E, F, I, L, P involved uncertainty on the details of the design and construction of the equipment at the project front-end. Linked difficulties in the development of the equipment consisted of trial and error, and during start-up included parts and components not working properly. For example, the equipment supplier firm manager in project C noted, "*There was a big vacuum chamber...that was in a crucial role in making the real hardware work* [during development phase]. *There were long tests with that. Some re-work around that design*". For project E, the manager at the manufacturing firm noted difficulties in the start-up phase: "*For example, when we started to heat them up into the right temperature, we saw that there were lots of distortions in the inner parts of the furnaces. And they* [supplier firm] *had to make some changes in the design and changes for the structures, also here on site*."

Technology feasibility and performance uncertainty was present in projects where the technology was developed as part of project or was unproven (F, G, L), and where the technology was a first-time experience for the supplier (O). Linked difficulties were experienced in the design and engineering work using the technology. For example, manager in project L shared "*There was the technology problem there that how we can infeed the material to this belt so that, it is very stable in every part."*

Table 2 reveals the range of uncertainty experienced in manufacturing firms, following from technology newness to the equipment suppliers throughout the phases of the RMTI projects. The four types of uncertainty were consistently present across the project phases and, thereby, characterized the project's dominant uncertainty. The findings suggest that equipment suppliers' technology newness on one or more of the

four dimensions may explain the nature of knowledge gaps experienced by the technology-adopting manufacturing firm in the project.

Table 2 Technological uncertainties experienced across the RMTI project

Type of uncertainty	*Front end*	*Development*	*Start-up*
Context-related requirements	- Lack of clarity on context-related requirements - Lack of clarity on ideas for fitting the technology to the context - Feasibility and performance uncertainty	- Lack of clarity on context-related requirements and related difficulty in identifying requirements and accommodating them in late design phase	- Additional user requirements and/or context requirements are spotted
Application-related requirements	- Lack of clarity on application-related requirements - Technology bottlenecks - Feasibility and performance uncertainty	- Lack of clarity on technological requirements and related difficulties in making technology work and perform (e.g., trial and error in designing)	- Additional technology application requirements are spotted
Construction-related requirements and performance	- Lack of clarity on details of the full equipment solution - Construction feasibility and performance uncertainty	- Difficulties in designing the details and assembly and in making the construction (e.g., trial and error, re-work)	- Equipment does not work and/or perform as desired. Gaps in the construction design need to be resolved.
Technology requirements and performance	- Technology feasibility and performance uncertainty	- Difficulties in making technology work and perform (e.g., trial and error in designing)	- Technology in the equipment does not work and/or perform as desired. Gaps in the design need to be resolved.

5 Discussion and conclusion

This study drew attention to technological newness for the equipment supplier as a source of uncertainty in high-novelty RMTI projects. The study reveals a four-dimensional construct of technological newness for equipment supplier firms and reports how the newness appears across the studied RMTI projects. Manufacturing firms, in turn, experience analogous technological uncertainties stemming from the lack of knowledge and lack of previous experiences. As key result, the study reveals the diversity of informants' experiences of equipment supplier's technological newness throughout the life cycle of high-novelty RMTI projects.

Contribution

This study makes two key contributions to previous research literature on RMTIs: first, we present a project level perspective on knowledge transfer for RMTIs, against the previous firm level knowledge transfer models for RMTIs (e.g., Linder and Sperber, 2019). Second, the study contributes to previous knowledge on sources of technological uncertainty in RMTI project (e.g., Simms et al., 2021), by adding understanding on equipment suppliers' technological newness as a potential source of uncertainty in high-novelty RMTIs.

The findings highlight the need for a comprehensive project-level analysis of knowledge gaps and needed learning as part of the RMTI project, including the knowledge needs of the equipment supplier. For the manufacturing firm, this means also preparing to support the supplier firm in their knowledge accumulation needs, as it may contribute to reducing technological uncertainty experiences in the project and impact the performance of the manufacturing firm's RMTI project. Previous research on knowledge transfer for RMTIs emphasizes the importance of knowledge inflows from equipment supplier firm to manufacturing firm (Linder and Sperber, 2019). We argue that in high-novelty RMTI projects knowledge is accumulated also at the equipment supplier firm and within the project (equipment and solution that is jointly being built).

We contribute a four-dimensional framework on equipment supplier's technological newness. The findings, thereby, offer deeper understanding on the sources of difficulties in RMTI projects. Previous research on the management of technological uncertainty in RMTI projects consistently links technological newness to technological uncertainty (Simms et al., 2021; Stock and Tatikonda, 2004; Tyre and Hauptman, 1992). While technological newness for the manufacturing firm has been well understood (Barnett and Clark, 1996; Stock and Tatikonda, 2004; Tyre and Hauptman, 1992), this study complements such research by revealing the technological newness of equipment supplier firm as a source of manufacturing firm's uncertainty as part of high-novelty RMTIs.

The results show evidence of the presence of uncertainty over the life cycle of RMTI projects. The manufacturers' experience of uncertainty was sustained, to some degree, across the RMTI project phases, from front-end and development to start-up. This extends previous understanding on technological uncertainty in RMTIs from cross-sectional studies mainly investigating uncertainty in a specific project phase (Rönnberg-Sjödin et al., 2016; Simms et al., 2021) and reveals the continuity and evolution of uncertainty over the project life cycle. The exploratory research design mapping similarities and differences in technology uncertainty experiences across various high-novelty RMTI projects complements previous in-depth investigations of a few selected contexts (Simms et al., 2021).

Practical Implications

For managers and industrial practitioners, the findings have implications for identification and planning for technology uncertainties in high-novelty RMTI projects. The findings provide insights into equipment supplier's technological newness as part of high-novelty RMTI projects. Understanding supplier firm's technological newness and its links with difficulties faced in manufacturing firms' RMTI projects is useful for manufacturing firm managers managing high-novelty RMTI projects, as it may explain problems and failures of technology implementation.

The findings urge manufacturing firms to take a broad look at the knowledge accumulation needs as part of high-novelty RMTI projects, to include also the knowledge accumulation needs of equipment supplier firm. Thereby, a comprehensive project level rather than firm level assessment and planning of needs for knowledge transfer and accumulation in the project will enable planning for uncertainties involved in high-novelty RMTIs. Clearer understanding of equipment supplier's knowledge gaps can enable manufacturing firms to proactively support them in their knowledge accumulation, thereby impacting the performance of manufacturing firm's RMTI project.

The findings have implications also for supplier evaluation and selection as part of high-novelty RMTI projects. Manufacturing firms' RMTI project will experience uncertainties linked with equipment suppliers' degree and type of technology newness. The four-dimensional construct offers a fine-grained understanding on areas where to enquire and probe for supplier's previous experience and preparedness for the project. This can open up new ways of identifying appropriate equipment supplier for high-novelty RMTI project, compared to the ordinary supplier search, for example, based on long relationship or cost bidding.

Limitations and further research

The exploratory research design enabled capturing broad patterns in equipment suppliers' technology newness and linked technological uncertainties in a wide variety of RMTI projects, but the research design is limited in the depth with which every individual RMTI project was studied. There are some validity limitations to consider regarding the cross-sectional single-informant data collection for many projects and the accuracy and completeness of the respondents' accounts. Various efforts were taken to ensure the validity of the findings, including the informants' close involvement with and understanding of the project, viewing of related documents, such as presentations, where possible, a search for publicly available reports and articles on the project to triangulate the data, and testing of tentative findings by presenting them to informants in a results workshop. Deeper involvement through multiple informants and longer visibility for the project (e.g., through in-depth case studies) would result in richer project data. The exploratory research design, however, enabled the mapping of patterns of technological uncertainty in different projects and contexts. In this way, the study complements previous in-depth investigations of a few selected contexts and answers the call for a wider scope investigation (Simms et al., 2021).

The findings from this study encourage further investigation of suppliers' and manufacturers' task division and collaboration in high-novelty RMTI projects. The study calls for attention to project level needs for knowledge accumulation, besides firm level models for knowledge transfer for radical innovation. This research paves the way for future studies on increased efficiency in implementing RMTI projects. Further research could connect the degree of technological newness for supplier firms with assessments of efficiency and manufacturers' activities of problem solving in RMTI projects. Identifying the knowledge and capability gaps in high-novelty RMTI projects will assist further in the agenda of making RMTI projects and processes more efficient (Linder and Sperber, 2019; Rönnberg-Sjödin et al., 2016; Simms et al., 2021).

References

Barnett, B.D., Clark, K.B. (1996), "Technological newness: an empirical study in the process industries", *Journal of Engineering and Technology Management*, Vol. 13, pp. 263–282.

Bourke, J., Roper, S. (2016), "AMT adoption and innovation: an investigation of dynamic and complementary effects", *Technovation*, Vol. 55–56, pp. 42–55.

Brown, S. (2001), "Managing process technology – further empirical evidence from manufacturing plants", *Technovation*, Vol. 21, pp. 467–478.

Bryman, A. (2012), *Social research methods*, 4th Edition, Oxford University Press, NewYork.

Chaoji, P., Martinsuo, M. (2019), "Creation processes for radical manufacturing technology innovations", *Journal of Manufacturing Technology Management*, Vol. 30, No. 7, pp. 1005–1033.

Eslami, M.H., Melander, L. (2019), "Exploring uncertainties in collaborative product development: managing customer-supplier collaborations", *Journal of Engineering and Technology Management*, Vol. 53, pp. 49–62.

Hall, J., Martin, M. (2005), "Disruptive technologies, stakeholders and the innovation value added chain: a framework for evaluating radical technology development", *R&D Management*, Vol. 35, No.3, pp. 273–284.

Hong, Y., Hartley, J. (2011), "Managing the supplier-supplier interface in product development: the moderating role of technological newness", *Journal of Supply Chain Management*, Vol. 47, pp. 43–62.

Linder, C., Sperber, S. (2019), "Towards a deeper understanding of the emergence of process innovations: which role do inter-organizational learning and internal knowledge exploitation play?", *Journal of Engineering and Technology Management*, Vol. 53, pp. 33–48.

Martinsuo, M., Luomaranta, T. (2018), "Adopting additive manufacturing in SMEs: exploring the challenges and solutions", *Journal of Manufacturing Technology Management*, Vol. 29, pp. 937–957.

Milewski, S., Fernandes, K., 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.

Reichstein, T., Salter, A. (2006), "Investigating the sources of process innovation among UK manufacturing firms", *Industrial & Corporate Change*, Vol. 15, pp. 653–682.

Rönnberg-Sjödin, D., Frishammar, J., Eriksson, P.E. (2016), "Managing uncertainty and equivocality in joint process development projects", *Journal of Engineering and Technology Management*, Vol. 39, pp. 13–25.

Rösiö, C., Bruch, J. (2018), "Exploring the design process of reconfigurable industrial production systems: activities, challenges, and tactics", *Journal of Manufacturing Technology Management*, Vol. 29, pp. 85–103.

Simms, C., Frishammar, J., Ford, N. (2021). The front end in radical process innovation projects, *Technovation*, Vol. 105, article 102214.

Stock, G., Tatikonda, M. (2004), "External technology integration in product and process development", *International Journal of Operations and Production Management*, Vol. 24, No. 7, pp. 642–665.

Tyre, M., Hauptman, O. (1992), "Effectiveness of organizational responses to technological change in the production process", *Organization Science*, Vol. 3, No. 3, pp. 301–320.