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Managers' search practices at the front end of radical manufacturing technology innovations

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Managers of manufacturing firms have important tasks in choosing novel technology solutions for the firm's production process. The emergence of ideas for radical manufacturing technology innovations and managers' proactive search for radical ideas and concepts for developing production processes have not been well understood. This study concentrates on managers' search practices at the front end of radical manufacturing technology innovations. We analyzed managers' practices in the early phase of nine radical manufacturing technology innovation projects across three firms. Radical manufacturing technology innovations require acknowledging both process innovations for the manufacturer and product innovations for the equipment supplier. The findings of this study revealed alternative patterns regarding the use of directed and autonomous search processes, internal and external information sources and open and closed supplier searches. This study offers new knowledge on the nature of the information processing task that managers face and on the search practices that managers use at the front end of radical manufacturing technology innovations. The study contributes by differentiating the managers' search practices based on the specific innovation scope in terms of the technology, equipment and production concept. Propositions are offered concerning the drivers and use of managers' search practices at the front end of radical manufacturing technology innovations.

KEYWORDS
front end, idea and concept development, information search, manufacturing technology, practices, radical innovation

1 | INTRODUCTION

Manufacturing firms introduce new technologies in their production processes to enable the manufacture of next-generation products or dramatically enhance the performance of current products (Milewski et al., 2015; Simms et al., 2021). Radical manufacturing technology innovations (RMTIs) imply that the technologies are new to the product manufacturer, and they may potentially be new for the equipment suppliers and the world, too (Chaoji & Martinsuo, 2019). RMTIs, thereby, involve high uncertainty and complexity (Simms et al., 2021), represent a demanding information processing task (Kleinschmidt et al., 2010) and require skilled management. Introduction of new manufacturing technology in a firm's core production processes calls for significant investments in technology equipment, causes disruptions to existing production routines and may require adaptations to existing operations, new skills and capabilities to fully integrate and

enable benefits from the new technology (Brown, 2001; Martinsuo & Luomaranta, 2018; Milewski et al., 2015). The failure to introduce the needed technologies in production in a timely manner poses threats to business profitability and survival (Sinha & Noble, 2008). Despite their business criticality and management challenges, previous knowledge on the management of RMTI projects in manufacturing firms is sparse and further research has been called for (Kurkkio et al., 2011; Rönnberg-Sjödin et al., 2016; Simms et al., 2021).

This study concentrates on the RMTI front end, that is, the early phases of RMTI projects, where the emergence of RMTI ideas remains weakly understood (Linder & Sperber, 2019). The decision to invest in RMTIs is a strategic decision, requiring various investigations and consideration of alternative solutions at the front end of innovation. The front end of RMTIs can be considered a fuzzy phase, where personnel search for and process information and evaluate, develop and screen ideas that they can eventually propose for investment (Simms et al., 2021), leading to setting up a RMTI project for developing, procuring and installing novel technologies and processes for production (Frishammar et al., 2013, 2016). Generally, the typical front-end processes in RMTIs are already well known (Frishammar et al., 2013; Kurkkio et al., 2011; Milewski et al., 2015; Simms et al., 2021), but the processes whereby the ideas for RMTI emerge and the role of manufacturing firms and equipment suppliers in them remain unclear (Linder & Sperber, 2019).

In this study, we treat the front end of RMTI as a manufacturing firm's information processing task involving high degrees of uncertainty (Galbraith, 1977; Tushman & Nadler, 1978) and requiring integration of information both within the manufacturing firm and from external suppliers. Previous research on the emergence of radical innovation ideas highlights information search and processing by individuals and teams, resulting in novel combinations of knowledge (Acar & van den Ende, 2016; Aloini et al., 2013; Bessant et al., 2010; Nicholas et al., 2013, 2015). Equipment suppliers are key partners at the front end of these innovations (Chaoji & Martinsuo, 2019; Reichstein & Salter, 2006; Rönnberg-Sjödin et al., 2016).

This research is motivated by two major knowledge gaps in extant research. First, the manufacturing firms' perspective on ideas emerging at the RMTI front end remains unclear and requires further research. Equipment suppliers are often considered in a central role as sources of new manufacturing technology (Reichstein & Salter, 2006), and also consulting firms may bring in novel ideas (Frishammar et al., 2016; Kalogerakis et al., 2010). However, manufacturing firms as technology users play an important role in generating ideas for radical process innovations (Linder & Sperber, 2019), through their access to firm-specific process knowledge that is not easily available to outsiders. The work in the development and implementation of novel technology equipment clearly requires collaboration between the manufacturing firms (as technology users) and equipment suppliers (as technology providers) (Rönnberg-Sjödin et al., 2016), and the manufacturer's process knowledge is crucial for the ideas. There is a need to understand how ideas for RMTIs emerge within manufacturing firms that invest in their future production capacity and capability.

Second, there is a need to understand what happens in practice among the managers involved in RMTI initiation, that is, how managers participate in the information search for RMTI ideas. Although new product development tends to start from identifying a market opportunity (Kim & Wilemon, 2002), the need for manufacturing innovations may emerge within the firm's internal processes from problems in efficiency, functionality or quality (Kurkkio et al., 2011). Radical innovation ideas emerge in the problem-solving activities of individuals and teams, through various processes of analysis and information search (Frishammar et al., 2016; Reid & de Brentani, 2004). Managers' effort to search for relevant information is necessary to discover the right idea and develop the solution concept (Acar & Van den Ende, 2016; Frishammar et al., 2016; Reid & De Brentani, 2004). The emergence of radical innovation ideas is often understood as adhoc results of exceptional, unique circumstances and motivated individuals (Pihlajamaa, 2017; Reid & de Brentani, 2004; Rice et al., 2001). Managers are in key roles by bringing in possibilities for discontinuous innovations and structuring relevant information prior to decision making (De Brentani & Reid, 2012; Gemünden et al., 2007; Reid & De Brentani, 2004). Although previous research points at the key role of managers in the emergence of radical ideas, the search practices of managers in manufacturing firms at the front end of RMTI remain less understood and need further research (Simms et al., 2021).

The goal of this study is to obtain new knowledge on managers' practices in idea and concept development in manufacturing firms that renew their technology base. The main research question is: *What kinds of search practices do managers in manufacturing firms use for new ideas at the front end of RMTI?* The study contributes to the literature on the front end of radical innovations by characterizing the information processing task specific to the front end of RMTI and by offering empirical evidence on managers' information search in handling that task successfully. More specifically, the study 1) reveals the scope and nature of RMTI ideas from the manufacturing firm's perspective and, thereby, informs on its information processing task (complementing, e.g., Kleinschmidt et al., 2010); 2) characterizes patterns of managers' information search practices stemming from the amalgamation of process innovations for the manufacturer and product innovations for the equipment supplier (responding to explicit needs, e.g., by Simms et al., 2021); and 3) shows evidence of the task division and its underlying reasons between top and middle managers in the RMTI front end (offering nuanced information, e.g., in relation to Linder & Sperber, 2019).

We next introduce RMTIs, their early phase tasks and previous research on managers' practices at the innovation front end. Then a nested multiple-case study is introduced, covering nine RMTI projects in three firms. The findings revealed the multi-dimensionality of the RMTI concept scope, four different information search tactics and two supplier search tactics of managers. Finally, we discuss these findings considering previous knowledge and develop five propositions concerning managers' search practices and factors differentiating them at the front end of RMTIs. Implications for further research and practice are discussed in this study.

2 | LITERATURE REVIEW

2.1 | Radical manufacturing technology innovations

Firms pursue radical innovations to create new capabilities, find and serve new customers and markets and enhance their competitive position. Radical innovations imply the creation and use of novel technologies to grasp or create new market opportunities (Tushman & Nadler, 1986). Radical novelty can either take shape or be restrained already at the front end of innovations (Robbins & O'Gorman, 2015). Research concerning the front end of innovations has predominantly dealt with new product development, its idea search and commercially attractive product concepts that match customer needs (Eling & Herstatt, 2017; van den Ende et al., 2015). However, firms may create a significant shift in their business by innovating the technologies and processes that they use to manufacture their products (Frishammar et al., 2013; Kurkkio et al., 2011; Milewski et al., 2015; Simms et al., 2021). Some radical innovations may also be discontinuous, in that they open up a completely new trajectory compared to what the firm is used to (Bessant et al., 2010). This study concentrates on the front end of RMTIs.

RMTIs enable firms to revise their product portfolios more dramatically than with just one product innovation. They may occur through creating or acquiring new industrial equipment (Milewski et al., 2015; Reichstein & Salter, 2006) or implementing new production processes (Frishammar et al., 2013; Kurkkio et al., 2011; Simms et al., 2021). The invention, development and piloting of new technology-based solutions in production require the manufacturing firm to interact with external technology suppliers (Chaoji & Martinsuo, 2019).

A higher degree of technology novelty is reflected in higher uncertainty, higher information processing needs (Tushman & Nadler, 1978) and a more complex process at the front end of such innovations (Chaoji & Martinsuo, 2019). In the simplest cases, the product, that is, the required equipment and technology are ready and available from an equipment supplier firm. Then, the front end of RMTIs merely requires a pre-study for designing the process and investment planning by the manufacturing firm (Rönnberg-Sjödin, 2013). The manufacturer can decide the investment based on competing offers from alternate suppliers and commercial negotiations that clarify the features of the suppliers' solution (Rönnberg-Sjödin, 2013). High-novelty RMTIs, in turn, represent newness also for the equipment supplier firms. Both the technology-based equipment and the process are new for the manufacturer and the supplier. There may be no ready, proven solutions known in the industry or also in the world (Chaoji & Martinsuo, 2019; Reichstein & Salter, 2006). The front end of high-novelty RMTIs involves more unknowns, and a greater search and development effort is needed (Chaoji & Martinsuo, 2019; Rösiö & Bruch, 2018; Simms et al., 2021; Sjödin et al., 2016). The front end of high-novelty RMTIs has remained under-investigated, and managers' practices require further research (Simms et al., 2021).

2.2 | Front end of radical manufacturing technology innovations

Previous research on RMTI covers the process at the front end of innovation and reveals the phases, activities (Frishammar et al., 2013, 2016; Kurkkio et al., 2011) and nature of detailed information to be developed (Frishammar et al., 2013). The front end of product innovations tends to concentrate on ideas, customer needs, product concepts and market opportunity (Eling & Herstatt, 2017; Kim & Wilemon, 2002). In turn, the RMTI front end is more focused on strategic assessments (Frishammar et al., 2013), problem mapping, creation and solving (Frishammar et al., 2016) and solution exploration and planning (Frishammar et al., 2013). The front end of process technology innovations tends to be iterative and already features technology experimentation (Kurkkio et al., 2011). The knowledge problems at the front end create challenges for managers in deciding on the investment (Flores-Garcia et al., 2021; Martinsuo & Luomaranta, 2018; Simms et al., 2021).

The front end of both radical product and process innovations typically ends in a decision to start the actual development project, but the nature of the innovation differentiates the decision concerning the scope of the project. For product innovations, the front end typically ends in defining and selecting the product concept to be implemented in the project and setting up a project team (Kim & Wilemon, 2002; Kurkkio et al., 2011). In contrast, Kurkkio et al. (2011) show that the front end of process technology innovations also includes various tests and experiments, requiring direct work with the processes being developed. Besides a product definition of pieces of equipment, there is a need to achieve a sufficient process definition and plan for its implementation in the manufacturing firm, including awareness of alternative process technologies by competing suppliers (Frishammar et al., 2013). This implies significant financial investments into the technologies and process implementation work, both inside the firm and with partners (Bruch & Bellgran, 2012; Rönnberg-Sjödin, 2013). Therefore, the front end of RMTIs includes identifying the needed technology, defining the process, defining and selecting the technology solution concept and identifying the supplier with whom the details of the process will be developed. For high-novelty RMTIs, the front end additionally includes the development of the technology, process and equipment concepts needed for their implementation.

2.3 | Managers' search practices at the front end of radical innovations

RMTIs represent significant investments to the firm's future production capacity. They require managers' efforts in identifying the right process problem, scouting for alternative solutions and negotiating with suitable equipment suppliers. They represent a forward-looking search concerning the manufacturing firm's future production capacity and, therefore, require new information for the consideration of future courses of action (Jissink et al., 2019). The information

processing view generally acknowledges that relevant information may be accessible both within the firm and among its external stakeholders (Kleinschmidt et al., 2010; Tushman & Nadler, 1978). Specifically, scanning of technological factors externally has been associated with innovation success (Frishammar & Hörte, 2005). Such studies, however, do not deal with RMTI or the front end of innovation specifically. Previous research on the front end of radical innovations has covered the search modes, search space and supplier search primarily for product-related innovations and only in limited ways for RMTIs, as summarized below.

Previous research identifies two main modes concerning the search of the core concept for radical innovations, which we refer to as directed and autonomous search. In directed search, the idea flows from the organization to the individuals, and it has also been referred to as a structured search process (Reid & De Brentani, 2004). In directed searches, top management sets a formal project and delegates information searches to technical managers (Reid & De Brentani, 2004). A study on radical sustainability-oriented product innovations revealed some organizational, strategy-driven heuristics that drive the search and emergence of radically novel ideas (Kennedy et al., 2017). According to empirical studies with process technologies, directed search and early phase strategic alignment may be needed for long-term process development projects due to their strategic nature (Frishammar et al., 2013; Kurkkio et al., 2011).

In autonomous search, the problems and ideas emerge among individuals who take the initiative to analyze the problem without initial top management input, referred to as an unstructured search process (Reid & De Brentani, 2004). Technical-level managers play a key role in generating radical innovation ideas due to their boundary-spanning position (Gemünden et al., 2007). High autonomy and working outside of organizational routines are typical to skunkworks projects that require certain human resource practices, as was shown in an automotive case study (Oltra et al., 2022). This understanding on how radical innovation ideas emerge is informative for the development of firm-level practices to encourage innovations (Bessant et al., 2010). For example, firm-level practices for recruitment and team-member selection can be developed for encouraging and supporting individual-level radical idea generation processes (Aagaard, 2017; Oltra et al., 2022; Pihlajamaa, 2017). Although Kurkkio et al. (2011) have mentioned the use of informal processes in short-term projects, the use of an autonomous search, specifically in RMTIs, is not visible in earlier empirical studies.

The search of new information during the front end of radical innovations is sometimes considered in terms of the search space (Lopez-Vega et al., 2016; Nicholas et al., 2013) or search strategy (Chiang & Hung, 2010; Terjesen & Patel, 2017), that is, where the firm searches for new information for the innovation. The search space often covers the external environment as a source of information, including markets, suppliers, competitors and research institutes. (Terjesen & Patel, 2017). The firms' market-oriented culture has been positively associated with radical product innovations (Naranjo-Valencia et al., 2017). Forward-looking external search has been positively associated with project innovativeness in a broad survey study of product innovations (Jissink et al., 2019). For radical product innovations, proactive exploration is needed and the search may be bounded to an existing cognitive frame or unbounded, seeking a new cognitive frame (Nicholas et al., 2013). A study on open product innovations differentiated between local search spaces that concern familiar technology fields and distant search spaces that concern previously unexplored domains (Lopez-Vega et al., 2016). A survey study across different manufacturing industries found a negative connection between search breadth (number of external information sources) and process innovation, and a positive connection between search depth (importance of the information sources) and process innovation (Terjesen & Patel, 2017). Collaborative open search is considered as particularly useful for discontinuous innovations that require out-of-the-box thinking (Wiener et al., 2020). Such examples emphasize external search but tend to consider either product innovations or process innovations.

The search space for RMTIs specifically requires the consideration of both product and process innovations and contextualizing the information appropriately to the manufacturing firm (Linder & Sperber, 2019). The survey study of Linder and Sperber (2019) on production process innovations found that *internal* knowledge sources are more influential for radical process innovations than external knowledge sources. They justify this through the contextual uniqueness and the necessity for the organization to implement profound changes in the processes (Linder & Sperber, 2019). Some studies, however, suggest that equipment suppliers are important external sources of new information for RMTIs, too, as they know the technologies (Reichstein & Salter, 2006; Rönnberg-Sjödin et al., 2016). Also, consulting firms have the experience to create novel ideas for radical manufacturing innovations (Frishammar et al., 2016; Kalogerakis et al., 2010). The manufacturer and supplier need to cooperate in information processing, to ensure early user involvement and joint problem solving for reducing uncertainties (Rönnberg-Sjödin et al., 2016) to serve the manufacturer's needs. More research has been requested on the contextual conditions of manufacturer–supplier relationships and related information transfer (Linder & Sperber, 2019) and the manufacturing firm's perspective on developing RMTI ideas and concepts (Frishammar et al., 2016).

External suppliers are not only used as sources of information at the front end of RMTI but also their involvement is needed in defining the equipment and process concept, prior to the top management's investment decision. The supplier search, therefore, has to occur at the RMTI front end. The study by Chaoji and Martinsuo (2019) showed that manufacturers seeking high-novelty RMTIs included the suppliers earlier in the front end, due to the novelty of the technology for the suppliers and the need for inventions. Manufacturers cooperate with equipment suppliers to explore and then exploit the new technologies and competences in their processes and solve emerging problems (Gemünden et al., 2007; Rönnberg-Sjödin et al., 2016). However, they may find it difficult to commit to one supplier immediately, as they need flexibility in resolving technological, commercial and organizational uncertainties (Melander & Tell, 2014). Manufacturers may be tempted to use their existing technology partners for

TABLE 1 Characteristics of companies and interview data

	Firm A	Firm B	Firm C
Range of firm sizes (revenue MEUR)	>100 MEUR	>1 BEUR	>2 BEUR
Size	Small (<500 employees)	Medium (about 1000 employees, part of a larger corporation)	Large (about 5000 employees, part of a larger corporation)
Industry	High-tech raw material industry	Process industry	Assembled products industry
Market position	Niche market leader, among top 10 global firms	Market leader, among top global firms	Market leader, among top global firms
Number of interviewees	5	7	5
Job positions of interviewees (examples)	Process engineering manager, Sr. VP products and Sr. process engineer	Sr. VP production, Sr. VP business development, project manager and plant manager	Production development manager, manufacturing manager and Sr. R&D engineer
Average duration of interviews	> 60 mins per interviewee (total duration: 413 minutes)	> 60 mins per interviewee (total duration: 504 minutes)	> 60 mins per interviewee (total duration: 416 minutes)

their RMTI, but some studies indicate that familiar suppliers with known technologies may primarily support incremental innovations to existing technologies (Linder & Sperber, 2019). In turn, a large gap between the supplier's new technology and the target application would enable high-novelty ideas (Linder & Sperber, 2019). A collaborative foresight study showed that technological complementarity is particularly helpful for the partners to learn from each other, but some extent of similarity and nearness is needed, to find common understanding and shared language (Gattringer et al., 2017). The study by Terjesen and Patel (2017) on search breadth versus depth indicates that in-depth cooperation with selected partners is more relevant for process innovations than the number of partners. The previous studies tend to take an organizational view of supplier search, whereas the managers' practices in exploring supplier alternatives as part of the RMTI front end remain less clear.

3 | RESEARCH METHOD

3.1 | Research design and cases

We conducted a multiple-case study on the front end of nine RMTI projects in three manufacturing firms. Multiple-case studies enable the comparison of the focal phenomenon across different empirical cases, to understand core patterns in how the phenomenon unfolds and to discover theoretical explanations (Thomas, 2011). The firms were identified from a set of 17 manufacturing firms in a preceding study on RMTIs. As RMTIs are rare in firms and management of innovations is context dependent, we specifically sought for firms that had implemented multiple RMTI projects in recent years, to enable both within-firm (different RMTI projects) and cross-firm comparisons (the firms' overall RMTI approach). We also sought for clearly different firms in terms of size, type of technology and manufacturing and industry, to account for contextual variety. The three firms thus selected included a semiconductor manufacturing firm (Firm A), a process-based manufacturing firm (Firm B) and an assembly manufacturing firm (Firm C). The three firms are among market leaders and well recognized in their industry. Table 1 provides more information on the three firms.

We decided to investigate specific RMTI projects in each firm, to capture an in-depth view of the firms' RMTI approach, to access accurate information on practices (i.e., what managers actually do) and also to enable within-firm comparison, thereby taking a nested case-study approach (Thomas, 2011). Three RMTI projects were studied as nested cases within each firm. The projects represent the context for managers' search practices at the RMTI front end and enable capturing a holistic understanding. Although each project is unique, as nested cases, the projects also followed the established processes and routines of the case firm. A summary of the nine projects is given in Table 2.

Three RMTI projects were selected with a key contact manager at every firm using three main criteria. First, the projects had to be recent, that is, completed within the past years or near completion so that they would enable access to knowledgeable informants still within the firm. Second, the project had to represent new technology equipment in the firm's core production processes, thereby making them strategic investments. Third, the innovation had to be radical, in terms of the introduction of a new-to-the-firm production method. Also, the innovations that had been completed were considered as successful in that the solutions were taken into use in production. The projects had been completed (implemented in production), with the exceptions of C-1 in the concept development phase and B-3 in the late implementation phase (installation). In the projects, access was possible to nearly all managers involved closely at the project front end. Exceptions were in Project B-2 (manager involved in detailed concept development unavailable), in Firms A and C projects (purchase manager unavailable) and in Firm C project (unavailable top managers). Equipment supplier firm managers were purposely excluded from the data collection because our interest was to capture the manufacturing firms' internal search practices. The projects in Firms A and C were implemented in the same manufacturing site, whereas in Firm B, two projects were implemented at the same

TABLE 2 Description of studied RMTI projects and interview data collection

Projects	Project description (new technology in core production process)	Number of interviewees
Firm A: Semiconductor manufacturing		
A-1: Alternate process technology needed for next-generation product	Introduce new technology that would enable higher accuracy in certain product features beyond those enabled with previous technology and tooling (needed for making next-generation product).	3
A-2: A better process and tool	Introduce new technology and tooling that would enable a neat finish on certain product features, compared to the present technology and tooling that left a crude finish (customers complained of imperfect finish).	2
A-3: Alternate process approach needed for next-generation product	Introduce a new process approach and linked tooling for generating higher performance semiconductor raw material (needed for making next-generation product).	2
Firm B: Process-based manufacturing		
B-1: A superior process approach	Introduce new chemical process and needed equipment for achieving the same product from raw materials with higher yield and quality (for meeting company's strategic production development targets).	5
B-2: Unique application spin	Introduce new processes (and related technology and equipment) for generating renewable fuel using unique biowaste side-streams to replace previous fossil fuel-based processes.	5
B-3: A breakthrough process idea	Introduce technology to recycle and reduce effluents released into the environment (for meeting company's strategic production development targets).	4
Firm C: Assembly manufacturing		
C-1: An attractive alternate process approach	Introduce alternate assembly approach (switch from cutting-and-joining to bending) and linked technology to improve process efficiency and quality.	4
C-2: A superior process approach	Introduce new process technology and related equipment for automating previous manual process.	1
C-3: A superior process approach	Introduce new tooling and technology to replace previous manual and slow process.	1

manufacturing site (B-1 and B-2), and one project was at a different site (B-3).

3.2 | Data collection

Data were collected from multiple sources on each firm's processes for the initiation of RMTI, including 17 semi-structured key informant interviews (Table 1), and internal documentation at the RMTI front end. Some interviewees had participated in more than one project, and all such projects were covered within a single interview meeting, each project separately (Table 2). Some interviewees were interviewed more than once on the same project, but these were not counted as separate interviews. The interviews were conducted on the company premises and were recorded with the permission of the interviewees. Three interviews were conducted via online meetings due to the distant locations of the interviewees.

Data collection for the individual projects involved semi-structured interviews with all closely involved persons at the front end of the project, to cover various perspectives and collect rich information. The data collection per project was thus limited to the front end of the project, until the point where the decision to give a contract to an equipment supplier was made.

The interview outline (Appendix 1) was developed based on experiences from a pre-study with a broader sample of firms, and the focus was on the front end of RMTI. It included questions on the timeframe, practices, events, people involved, search process, the evaluation and selection processes for the selected RMTI projects in which the interviewees had participated and the established processes and routines for the initiation of RMTI within the firm. The interviewees were allowed to give an uninterrupted account of the events and practices at the front end of the RMTI project, as they remembered. Further questions were asked to ensure comprehensive coverage of all topics and to delve deeper into issues that seemed central to idea emergence and concept development in each project.

Project documentation and firm documentation were shown and described during some interviews or shared after the interview. Information on some projects was sought through the internet, the company website and the equipment supplier's website. The supplementary documentation was used to enrich and triangulate the data.

3.3 | Data analysis

The data analyses followed an abductive approach (Dubois & Gadde, 2002), including sensitivity to the data and repeated interplay

with previous literature on the front end of radical innovations generally and managers' practices in them specifically. During the initial reading of the data, the events and timeline of the RMTI front end of the projects were mapped to identify interesting events and recurring themes. A summary of the firm-specific overview was shared with the firms' contact person to get feedback and clarify any missing details.

Then, an open coding approach was targeted at the overall idea and concept development task and managers' related practices. During and after the open coding, we reflected on the data already present in literature, searching for support, for example, from Frishammar et al. (2016) on the centrality of the problem at the front end of radical innovations and Bessant et al. (2010) on engaging, enabling and experimenting practices in selecting discontinuous innovations. After the open coding, we formed a tentative picture of the idea and concept development task, featuring problem formulation, idea search (including technology, production and equipment idea) and process and equipment concept definitions. As this offers an understanding of the special nature of the RMTI front-end task compared to other types of radical innovations, we report these findings in Section 4.1 as background to the managers' search practices. To understand the patterns of these issues across projects, we used cross-tabulation of the coding, wrote short project narratives and sought similarities and differences across projects and firms. This phase led us to focus our attention on managers' search practices in more detail.

The analysis was then continued with pattern coding, in which we grouped detailed issues discovered during the earlier analysis into three clusters of search practices. Each project was carefully coded according to the information source, mode of information search and supplier search practices, each of which was grouped into two main categories. Again, during the coding, we returned to suitable literature, especially acknowledging the information search at the front end of radical innovations (see Section 2.3). Table 3 summarizes the main categories from the analysis, which were used for structuring the results in Sections 4.2–4.3. The analysis was concluded into a two-dimensional framework of four different information search practices during idea and preliminary concept development and two supplier search practices during concept development. Each project's dominant pattern concerning managers' practices was identified by using and refining the previously developed project narratives, in addition to the pattern coding.

4 | FINDINGS

4.1 | Scope of the front end of RMTI

The nine projects that were studied represented radical departures from existing methods, tools and technologies used in production, and the starting points and scopes of their concepts differed. The primary

TABLE 3 Pattern codes, their definitions and example quotes in the analysis

Main categories of analysis	Description	Example quotes
Information source		
Internal	The technology idea was known and emerged within the firm.	'*We did not have to survey the technology. We knew the technology. That was clear from old patents*'. (manager, A-3)
External	The technology idea was not known and it was sought from outside the firm.	'*The mission of that project was to identify which technologies we could introduce which would make. Two-micron tolerance realistic. So, it was basically a technology survey*'. (manager, A-1)
Mode of information search		
Directed search	Information search was initiated at the top manager level, delegated to lower organizational levels and followed established phases and routines.	'*It was, given to me to solve the problem*'. (manager, B-3)
Autonomous search	Information search was initiated and carried out at the middle-manager level, through their own initiative, in an informal manner and without pre-planned phases.	'*It was, actually it was kind of, the planning started along this other project. When we started these discussions (with the supplier) and we get these ideas*'. (manager, A-2)
Supplier search		
Open supplier search	No previous knowledge of suitable suppliers. Open and broad investigation of supplier and solution alternatives, before detailed concept and investment planning and negotiation.	'*This supplier which we chose we came into contact with through (our) old equipment which we have plenty, they had a supplier which discontinued production. But there was one key guy who then instructed us to contact this company...*' (manager, A-3)
Closed supplier search	Previous knowledge of preferred suppliers. Narrow and limited supplier and solution analysis and comparison merged with detailed concept and investment planning and negotiation.	'*We always go to these main suppliers and ask them what they, do they have this kind of process we had chosen*'. (manager, B-1)

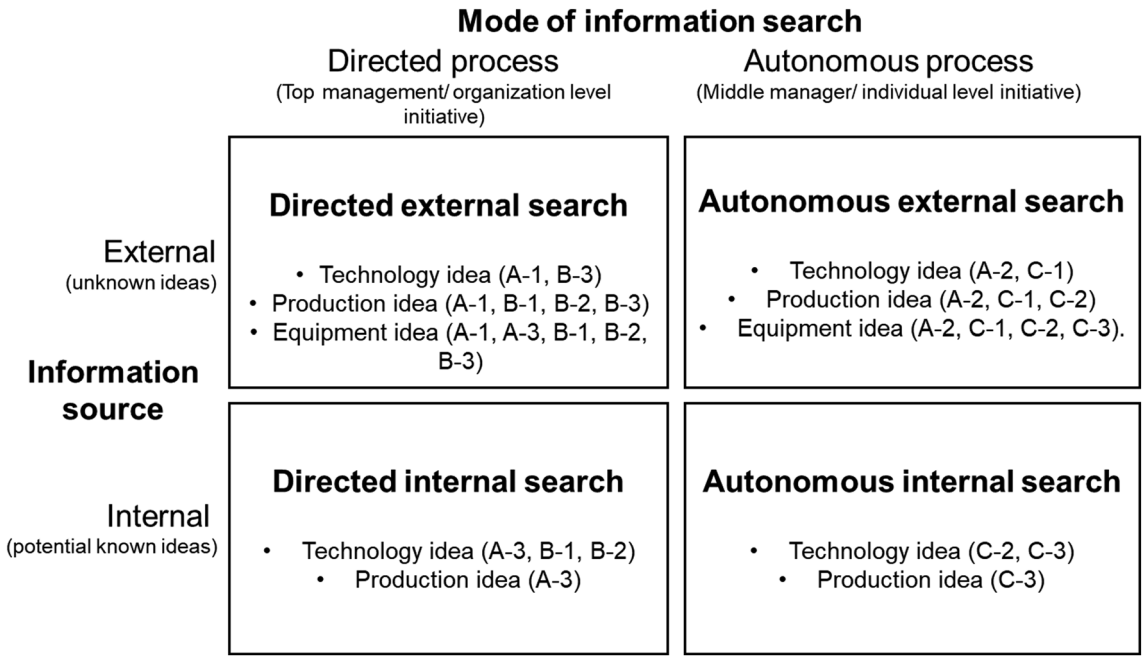

FIGURE 1 Four patterns of managers' information search practices at the front end of RMTI projects.

innovation *idea* featured a new type of production process and a new technology and targeted a specific problem. For projects A-1, A-3, B-1, B-2 and B-3, the process or technology problem drove investigations to identify a suitable technology. In projects A-2, C-1, C-2 and C-3, the idea for solving the problem emerged through an opportune event rather than as an output of planned investigations.

Three key ideas formed the full concept of RMTI, which were new technology, production idea and equipment idea. In some projects, a potential technology idea was identified already when the initial problem was noticed. Information collection and subsequent discussions on the technology followed, including a comprehensive assessment related to technology fit, feasibility, risks and benefits. This information search gave shape to specifying the production concept (i.e., process innovation for the manufacturer) and equipment concept (i.e., product innovation for potential suppliers). Detailed concept development was done for production (how to implement the aspired production utilizing the new technology) and equipment (what is the needed equipment and how to get it). In addition to the comprehensive concept description, investment planning required further information collection and market and supplier studies in cross-functional teams. The manufacturers needed to identify potential equipment suppliers, engage in deeper discussions with them and make requests for offers to potential suppliers.

4.2 | Information search practices in RMTI front end

The emergence of technology, production and equipment ideas differed to some extent across the projects. One or more of these three key ideas for every project was not evident at the beginning, and managers took action to search for and identify them. We identified four dominant patterns of search practices that managers used in information search at the RMTI front end, as shown in Figure 1.

4.2.1 | Directed external search

In many projects, idea and concept development started with a strategic production problem attracting top managers' attention. In some projects (such as A-1 and B-3), the problem was very holistic, requiring ideas for technology, production and equipment, whereas in other projects (such as A-3, B-1 and B-2), the technology need was more apparent, and only production and equipment ideas were needed. Top managers initiated formal investigations, installed cross-functional steering committees and activated information collection on markets, technologies and knowledge inside the organization.

The search and investigation were delegated to middle management. Middle managers led a team of experts from production, process development, R&D and other functions, possessing relevant information concerning the technology and the original problem. They initiated discussions with knowledgeable colleagues, encouraged broad Internet and literature searches, activated informal brainstorming and explored application solutions from existing and new supplier contacts. In project B-3, the manager mentioned, '*I asked them (supplier firm colleagues) what they have in their idea box*.' In addition, chance events or serendipity were perceived as useful in discovering information for idea creation. The interviewee in this same project, B-3, elaborated: '*the early discussion (at the supplier) was with that type*

of fellow who was working, as partly retired. If he had been totally retired, I don't know what in that case. It was very good luck in that way. Because there was only one fellow, remembering, what they have done, 16 years earlier [laughs]'.

Once the technology idea was identified, managers and their expert teams pursued further information through literature searches, benchmarking visits to installations of similar equipment elsewhere, asking suppliers and/or making test pieces using the supplier's demonstration equipment. The information collected was used for developing a broad understanding of the production concept and equipment concept, as well as assessing the fit and feasibility of using the technology in the manufacturer's own production.

4.2.2 | Directed internal search

Also here, top managers initiated a discussion based on an identified technology problem, but attention was immediately directed at previously known technology alternatives. In projects B-1 and B-2, strategic production development process brought focus and attention to potential alternative production processes, whereas project A-3 started with a meeting of a middle manager and top manager to discuss the problem and clarify the technology idea. These projects, therefore, had slightly different paths for the technology idea compared to the production and equipment ideas that followed, as indicated in the directed external search.

Middle managers brought in technology ideas through their ongoing tasks, projects, interactions and knowledge on alternate technologies. The manager in project A-3 mentioned: *'Basically we have done quite much production scale research and development in this area. Of course, we have studied all the research or papers involved in this area. And we have, lucky to have, quite capable personnel to even have an idea what direction we have to take and what kind of tooling we would need to accomplish that particular task, to get this kind of product capability higher.'* Here, the information needed for the technology ideas was known to managers.

Once an idea was identified, the top manager(s) launched an investigation to develop the technology concept to understand whether and how to implement it. As part of this, middle managers investigated the selected idea, collected information and made assessments. In projects A-3, B-1 and B-2, the production idea and/or the equipment idea were unknown, and these projects followed directed external search practices.

4.2.3 | Autonomous external search

In some projects, the production problem was first identified and reacted to among middle managers, for example, in a production or product unit (A-2 and C-1), or as customer feedback and requests for developing product features (A-2). The operational problems were also linked with strategic goals and development plans. The managers did not have a technology, production or equipment idea to begin with. Instead, serendipity and opportune events occurred in middle managers' open discussions with suppliers on their inventions and other projects, their own equipment needs and visits to other manufacturing plants.

Middle managers had to deal with the problems in their daily operations, which motivated them to search for new technology ideas. In project C-1, a senior R&D engineer was dissatisfied with the present production method for a product, and this experienced problem encouraged him to search for a radically novel approach. Some managers mentioned their individual interest and disposition in finding ideas for better production processes. A manufacturing manager in projects C-2 and C-3 mentioned: *'It's my personality. I always try to think how to make these easier'*.

Compared to directed search, managers' discussions with suppliers were not necessarily driven by a specific problem. Rather, managers explored technologies openly and broadly, and this exploration led to an idea. In project A-2, a manager discussed with a supplier when ending a previous project with them, and he noticed equipment that could be a viable alternative for one of their problematic processes: *'When we were discussing and they were showing their development work, we saw this kind of picture [of a technology solution]. And it's really something similar that we are doing here. And that was the, where we got this idea … We were able to combine and start thinking that could we somehow use this kind of a process.'* Similarly, in project C-3, the production unit had a routine of visiting an equipment supplier of specialized machine tools, and the manufacturing manager came across prototype equipment that could function as a potential solution for their problematic operations.

The middle managers sought additional information to assess the feasibility of the technology and fit it with the production context. In project C-3, the manager selected a customer order where such equipment could be utilized, identified the requirements and ordered a prototype tool to assess whether and how it performed. In project A-2, the manager ordered test pieces with the supplier's equipment to assess the technology performance.

4.2.4 | Autonomous internal search

In two projects, managers experienced an important problem in their unit, and they already possessed knowledge of some technology directions that would resolve the problem. In projects C-2 and C-3, the technology idea was clear from the outset: they were well-known superior technologies in use for mass production (automation and press-tools). However, some ideas needed for concept development were unknown.

Top managers were not involved in these projects. Middle managers experienced the negative effects of the problem, attempted to solve them and discussed them in their unit. They promoted concept development by asking suppliers for their solution ideas (C-3) and devising ideas for the production concept (C-2). Although the technology idea was clear to begin with, concept development stalled temporarily when searching for implementation ideas.

4.3 | Supplier search practices in RMTI concept development

Moving to detailed concept development involved a greater commitment from the firm to the RMTI investment. In Firms A and B, the RMTIs required larger investments and continued with a directed process. Hence, top management decided on a concept planning project, established a cross-functional team and allocated a steering committee to monitor progress. In Firm C, middle managers developed the unit's investment proposals for top management, and they also led the detailed concept development, continuing with an autonomous process.

All projects required external supply for the manufacturing technology and process. To discover suitable alternatives, middle managers made inquiries and collected detailed offers from equipment suppliers. With suitable candidates, managers made accurate calculations and detailed production plans. Competing suppliers' alternate equipment concepts were compared, and commercial negotiations were initiated, especially in Firms A and B.

The RMTI projects differed from each other in the openness of the supplier search: three projects engaged in an open supplier search for the equipment solution, including a search for new suppliers, whereas six projects restricted their supplier and solution search to familiar main suppliers. The patterns were largely similar within each firm regarding open versus closed search for suppliers, and exception to the practice was linked with individual projects.

4.3.1 | Open supplier search

In projects A-1, A-3 and C-1, managers did not have definitive knowledge of potential equipment suppliers when they started the equipment and production concept development. The supplier search occurred through an open-ended inquiry among knowledgeable colleagues, consultants and familiar suppliers. Such an open-ended search was typical of Firm A due to its niche technology business and lack of dedicated suppliers. Managers and their teams made broad ongoing searches on the internet, participated in conferences and industry fairs and went to observe industrial equipment in other firms (e.g., customer firms) to identify alternatives. In project C-1, managers collaborated with a familiar equipment supplier during preliminary concept development, but they then realized the need for a specialized supplier for the new equipment and process and continued with an open supplier search.

Deep information was collected on the identified equipment suppliers and their plans for the needed equipment. For example, the investigating team in project A-3 included a friendly consultant who questioned the supplier's plans to find a better solution: '*he (the consultant) was kind of challenging the supplier's designs and calculations and expectations and material selections, if for no other reason than at least for the reason of making them make it double sure that they know what they are saying [laughter].*" Similarly, in project A-1, a manager provided examples of many interactions with alternate suppliers. Supplier's expertise and willingness to develop the technology led to selecting one supplier and their solution, even if the supplier did not meet all assessment criteria during supplier comparisons and negotiations.

4.3.2 | Closed supplier search

After idea generation and preliminary concept development, managers of six projects (A-2, B-1, B-2, B-3, C-2 and C-3) had a clear idea of possible equipment suppliers. Closed supplier search was more typical to Firms B and C. Firm B had two main equipment suppliers with close knowledge of the manufacturer's production, and detailed offers were requested only from them. Firm C had close ties with some suppliers (machine tool designers and builders, robotics and automation specialist firms), appropriate for the type of equipment involved. Even if they did not have a detailed and complete understanding of the equipment and production concept (including technologies, requirements and needed adaptations for production), managers requested full solution offers from known suppliers who were also expected to cooperate with the manufacturing firm in solution development.

Managers in projects B-1 and B-3 collected deep information on equipment technology and plans of alternate suppliers, whereas managers in projects A-2 and B-2 did not have full information on the suppliers' plans for the equipment during concept development. They compared the offers and selected the most attractive offer and willing suppliers to continue negotiations for the solution development. For projects C-2 and C-3, there was only one credible equipment supplier, so the detailed concept development concentrated on equipment and process specifications and detailed investment planning.

5 | DISCUSSION

In this study, we investigated what kinds of search practices managers use in manufacturing firms at the front end of RMTIs when renewing their core production process, which is considered as a highly uncertain and demanding information processing task. The findings revealed the unique scope of RMTIs when the solutions are new not only for the manufacturer but also for the supplier: the developed concept must cover *both* process innovations for the manufacturing firm *and* product innovations for the equipment supplier firm. The analysis of nine RMTI front-end projects differentiated top and middle managers' practices across firms and projects. Below, we will discuss these issues along with some propositions for future research.

The study frames RMTIs as an amalgamation of the manufacturing firm's process innovation and the equipment supplier's product innovation, tied together with the novel technology. This result offers novel information on the nature of the information processing task faced by managers at the front end of RMTI, complementing studies on innovations more generally (Frishammar & Hörte, 2005; Kleinschmidt et al., 2010). Our findings highlighted three separate components within the RMTI idea, namely, technology, equipment

and production, each requiring their respective information searches and analyses. Previous research has tended to concentrate on either a focal firm's key product idea needed for radical innovations offered on the market (Bessant et al., 2010; Reid & de Brentani, 2004) or the process problems of a firm driving the innovation in process technologies (Frishammar et al., 2013, 2016; Kurkkio et al., 2011). As process technology innovations are embedded in their organizational context (Milewski et al., 2015) and represent unknown technologies for the equipment supplier (Chaoji & Martinsuo, 2019), the technology study needs to be complemented with investigations of its use in the firm's specific production context. Therefore, the front end of RMTIs is portrayed as a more complex ground of information search, compared to product-centric radical innovations.

> **Proposition 1.** RMTIs imply a combination of product innovations for the equipment supplier with process innovations for the manufacturing firm. The information search of manufacturing firms' managers will need to tackle both types of innovations and connect with suppliers already during the front end of RMTI, to provide a credible foundation for the investment decision.

Our findings showed that RMTIs emerge both based on strategic and operational grounds, and the starting point specifies the managers' mode of information search. The case firms differed in their use of autonomous versus directed search processes for RMTIs. Specifically, the directed searches started on strategic grounds, whereas the autonomous searches were initiated based on a production problem or customer feedback. The use of both search modes at the RMTI front end is in contrast to the assumption of mainly autonomous search processes at the front end of radical product innovations (De Brentani & Reid, 2012; Gemünden et al., 2007; Reid & De Brentani, 2004; Rice et al., 2001) and directed searches in process development projects (Frishammar et al., 2013; Kurkkio et al., 2011). Our findings demonstrate that firms may use both search approaches, depending on the circumstances.

> **Proposition 2.** Strategic and operational needs define the mode of information search at the front end of RMTI. Top managers take a directive role in information search for RMTIs when the firm strategy includes ambitious goals for production, development and performance. Middle managers' autonomous search for RMTIs occurs based on operational performance problems and direct customer feedback.

The RMTI projects differ in their information search space, depending on unknown issues in the RMTI concept scope (technology, production and equipment) at the beginning. This deals directly with the combination of product and process innovations, demanding situation-specific equipment-related contextualization of information (Linder & Sperber, 2019). In manufacturing firms, process problems and related knowledge emerge inside the firm (Linder & Sperber, 2019), whereas a significant share of solution (i.e., equipment) ideas needs to be sought from external sources, equipment suppliers in particular (Reichstein & Salter, 2006; Rönnberg-Sjödin et al., 2016). Thus, our findings differentiate the information search space at the front end of RMTI based on the RMTI concept scope and related unknowns.

> **Proposition 3.** The extent and type of unknowns in the RMTI scope specify the managers' search space. Managers rely on internal information first, to exploit ideas easily accessible. Managers initiate an external search, as a response to the unavailability of ideas and the need for breakthroughs.

The findings distinguished between the practices of top and middle managers, contributing to previous broad understanding of the practices of managers in the front end of RMTIs (Kurkkio et al., 2011; Simms et al., 2021). Top managers' active involvement was emphasized with strategic initiatives at the front end of RMTIs. This supports previous findings where top managers initiate external search investigations for strategic pressing needs (Kennedy et al., 2017). Middle managers not only acted on strategic tasks delegated by top managers but also engaged in autonomous searches to tackle local operational problems and propose investments to top managers. Middle and top managers' specific access to information flows and supplier relations defines their influence at the front end of RMTI.

> **Proposition 4.** The division of work between top and middle managers at the front end of innovation is specified by the initial mode of information search. Directed searches initiated by top managers set requirements for middle managers' search efforts. Autonomous searches initiated among middle managers require top managers' approval, both for detailed concept development and investment decision. Middle managers are uniquely positioned to develop comprehensive insight on the entire RMTI concept, covering the technology, production and equipment and supplier alternatives.

Our findings revealed the early involvement of suppliers in RMTI concept development, dominance of closed supplier searches with known suppliers, purposive use of open supplier search for unknown technology niches and the interplay between the manufacturing firm and supplier in developing the process solution concept jointly. The search for suppliers and assessing suppliers' alternative equipment solution concepts appeared to be important in the detailed concept development to exploit the suppliers' knowledge and solve problems (Gemünden et al., 2007; Rönnberg-Sjödin et al., 2016) and, thereby, bring in the product (equipment) innovation to support the process innovation. Also, the collaboration during supplier search helped the supplier to become familiar with the manufacturer's unique process conditions, achieve benefits from complementary knowledge and develop common understanding and shared language, which

resembles findings concerning collaborative foresight (Gattringer et al., 2017). The findings concerning open versus closed supplier search lend support to the importance of search depth in process innovations (Terjesen & Patel, 2017), whereas also suggesting that supplier familiarity does not necessarily hinder radical innovations (contrasting Linder & Sperber, 2019). Rather, the findings indicate that novel niche technologies without dedicated suppliers forced manufacturers towards an open search, due to suppliers being an additional unknown for the RMTI concept.

> **Proposition 5.** Manufacturing firms interact with equipment suppliers already during RMTI front end, both to identify alternative solutions and to help the suppliers familiarize themselves with the manufacturer's processes. Manufacturers use a closed supplier search to enable in-depth cooperation, reduce risks and benefit from previous knowledge. They will use open supplier search when the manufacturing technology niche is unknown, without dedicated suppliers, to collect rich knowledge on alternatives, test the suppliers' willingness to cooperate and build mutual commitment.

As an overall finding, this study brings together the amalgamation of product and process innovations, four patterns of managers' information search and supplier search and involvement as key features of manufacturing firm's RMTI concept development. These issues together clarify the nature of managerial work at the front end of RMTIs and assist in structuring its information search and assessment tasks. The focus on managers' practices offers a new viewpoint on the front end of RMTIs, complementing the problem-solving-centred (Frishammar et al., 2016; Simms et al., 2021) and activity-centred (Kurkkio et al., 2011) process models. Our portrayal of managers' practices in the RMTI front end, as anticipation of a strategic investment into future capabilities and capacities, opens up new possibilities, both through connecting RMTI with strategy, considering task allocation across organizational levels, and connecting the manufacturing firms with suppliers.

6 | CONCLUSIONS

This study exposes managers' search practices within manufacturing firms during the front end of RMTIs, answering calls for further research on the front end of radical process innovations (Frishammar et al., 2016; Simms et al., 2021) and complementing the company-level routines at the RMTI front end (Frishammar et al., 2013; Kurkkio et al., 2011). As the primary theoretical contribution, this study portrayed the RMTI front end as a complex, uncertain information processing task at the manufacturing firm (following Galbraith, 1977; Tushman & Nadler, 1978; Kleinschmidt et al., 2010), where previous research has pointed out the need for more knowledge on managing the RMTI front end (Rönnberg-Sjödin et al., 2016), clarifying the manufacturing firm's position (Linder & Sperber, 2019) and understanding managers' practices (Simms et al., 2021). Consequently, we offer new knowledge on the managers' information search in handling that task successfully in different manufacturing firms and different RMTI projects while cooperating with equipment suppliers. This study yielded three more detailed contributions.

First, we characterized the nature of the search for information at the RMTI front end and explained differences in the search practices by merging knowledge concerning radical product and process innovations. The findings, thereby, offer new information concerning the contextual conditions for managers' search practices, contributing to previous understanding on sources of radical process innovations (Linder & Sperber, 2019; Reichstein & Salter, 2006; Rönnberg-Sjödin et al., 2016). RMTI requires three different ideas to be developed into full concepts at the front end of RMTI: technology, equipment and production process. Each of these ideas and concepts may have its own search space, depending on the extent of unknown factors, as was shown in our findings. Research on product innovations tends to concentrate on the product only (Kurkkio et al., 2011; Reid & de Brentani, 2004), whereas process technology innovation research tends to handle process developments, not the product (Frishammar et al., 2013; Kurkkio et al., 2011). We showed that in the case of RMTIs there is a necessity to treat process innovation for the manufacturer and product innovation for the equipment supplier simultaneously, which connects two streams of research in a unique way.

Second, we revealed the scope and nature of managers' search practices in the early phases of RMTIs from a manufacturing firm's perspective. Managers were portrayed as active agents in renewing a firm's production processes through purposive information search, which adds to previous knowledge on practices at the front end of radical innovations (Bessant et al., 2010; Frishammar et al., 2016; Simms et al., 2021). Mapping the search practices according to the mode of information search, information source and supplier search revealed the nature of managers' search and characterized the front end of RMTI specifically. The idea source and problem type yielded project-specific patterns of information and supplier search, which adds to previous knowledge on the selection of managers' practices in the front end of radical and discontinuous innovation (Bessant et al., 2010).

Third, we offered new information on top and middle managers as active agents and task divisions between them at the front end of RMTIs. Top managers were involved in RMTI idea generation and solution decisions, and both directed and autonomous processes were used. This contradicts some previous findings on top managers' absence and use of autonomous processes in product-centric radical innovations (De Brentani & Reid, 2012; Gemünden et al., 2007; Reid & De Brentani, 2004; Rice et al., 2001) and directed searches in process development projects (Frishammar et al., 2013; Kurkkio et al., 2011). Our findings demonstrate that firms may use both search approaches and the top and middle managers' initial roles may vary, depending on the strategy, production performance problems and explicit customer needs driving the RMTI project.

As managerial implications, the study offers a framework that could be used to guide managers' information and supplier search

practices at the front end of RMTIs. The framework acknowledges the starting points for RMTI in the manufacturing firm (strategic vs. operational), unique scope in the RMTI front end (technology, equipment and production concept) and necessity to involve the supplier early to learn the firm-specific processes. The search practices reported here, thereby, can help managers to see the alternative approaches for managing the front end of RMTI and stimulate actions in their own context. Both top and middle managers are active agents at the RMTI front end. Our findings encourage firms to enable both directed and autonomous routes for RMTI, to engage top managers into process development and empower middle managers to use their technical expertise in solving production performance problems. Our findings also encourage managers' openness towards opportune events during the information search, to enable discovery of radical, future-oriented ideas. Understanding of the equipment supplier's product innovation by the side of the manufacturer's own process innovation will help in planning for the RMTI project. Depending on technology familiarity and the expected degree of novelty, managers need to engage in open or closed supplier searches to commit equipment suppliers to the innovation project. Our findings suggest using information sources and modes of information search appropriate to the specific situation to develop the RMTI ideas into concepts.

Limitations are caused by the accuracy and comprehensiveness of the retrospective interview data. Further research and development are needed in broader and more versatile samples, to turn the propositions from this study into testable hypotheses. Although we delimited case selection purposely to RMTIs and sought variety in the projects, further research opportunities exist in comparing managers' practices across different RMTI project types and contexts. In this study, the focus was on individual managers' practices of information search. As the organizational context shapes the individuals' opportunity space and innovations may involve teamwork, the contextuality of managers' practices could be investigated further. This study did not cover the strategy alignment or discontinuity caused by RMTI projects, so further research could explore the strategy linkage of RMTI. Further research could assess the consequences of the various search practices and their fit to certain problems, types of RMTI ideas or contexts. Also, the division of tasks and coordination between top and middle managers in different RMTI projects will deserve further attention.

DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

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APPENDIX A: INTERVIEW OUTLINE

1. Introduction
   a. Overview of the purpose of the whole study, the interview and topics.
   b. Background of the interviewee: Could you describe your role, work in the firm and how you came to be involved in this project? Was this project exceptional compared to your other projects?
2. The initiation of the selected case example of radical manufacturing technology innovation
   a. Could you describe what happened in the early period of this project, before a contract was signed for its development with an equipment supplier firm?
      i. Timeframe
      ii. Who was involved and how?
      iii. Activities, phases, challenges, critical things and surprises
      iv. Trigger, beginning point and motives
      v. Search period: was there a search of any kind during this period? What was searched, by whom, why, how and alternative ideas?
      vi. When were equipment supplier firms contacted, and how were they identified? How different were their offerings, and how was the evaluation process?
      vii. Difficulties, challenges, for example, when there was no active work, no action taken on the idea, communication effort and difficulties in search and selection.
      viii. Critical things, for example, events, persons and practice seen as very important to successful idea emergence and development in this project.
      ix. Decision making and selection of idea and concept: how did this happen, any exceptions compared to normal decision making in such projects?
   b. Available documentation, for example, reports, plans, minutes of meetings and emails.

   If the interviewee was familiar with multiple projects, this section was repeated for other projects.
3. RMTI initiation processes in the firm
   a. Is there a common way, standard process or system that drives work on ideas involving newer technologies for use in production in this firm?
      i. Any department, any persons (special roles?) dedicated to following up on such options?
      ii. How about firm strategy and senior management? How do they promote, encourage and emphasize activities for exploring new processes and technologies in production?
      iii. How about the organization, for example, processes, systems and culture? How do they promote and support in some way or discourage such idea development?
4. RMTI initiation sources in the firm
   a. What are the main ways in which novel production technology ideas like this project come up?
      i. Network?
      ii. Suppliers?
      iii. Production inputs?
      iv. Sales/CRM inputs?
      v. Any other?
5. Closing
   a. Are there any other issues you would like to add?
   b. Next steps of the research
   c. Thank you