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Sen Fang, Antonio Moreno Brenes & Stefano Brusoni

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Technology Intelligence and Digitalization in the Manufacturing Industry

More organized and systematized technology intelligence processes can help manufacturing companies make better decisions about which digital technologies and digitalization initiatives to adopt.

Sen Fang, Antonio Moreno Brenes, and Stefano Brusoni

OVERVIEW: This study discusses the readiness of established companies in mature industries to revamp and reorganize their technology intelligence processes as they adapt to digitalization. Technology intelligence is a crucial activity for firms that are trying to keep abreast of rapid technological change. Yet technology intelligence is hardly integrated into companies' strategic decision-making processes—particularly in manufacturing companies. We explore how the case study firms' existing processes compare to those of the ICT industry. We discuss the challenges manufacturing companies face regarding their technology intelligence activities, especially in adopting digital technologies and leveraging the potential advantages of digitalization. We provide suggestions to practitioners on how to address these challenges—notably more organized and systematized technology intelligence processes than those we observed in our sample of firms.

KEYWORDS: Technology intelligence, Digitalization, Manufacturing, Digital transformation

Digital transformation is accelerating technological developments and making them both more interconnected and more systematic. Companies are finding it increasingly difficult to discern which technologies they should focus on or invest in or how to integrate them. Digitalization, the technological trend that drives digital transformation, poses particular challenges for established companies in mature industries, because often the key digital technologies involved are not core to their operations. Such firms must put more effort into understanding recent technological trends, selecting which technologies to integrate. Gathering information on digital technology is becoming more strategic than ever. Technology intelligence is a systematic approach to collecting and applying technology information. While many high-tech companies apply technology intelligence to manage the uncertainties arising from novel technologies, we argue that manufacturing firms lag behind.

Technology intelligence activities are central to the Information and Communications Technology (ICT) industry because of the repeated technological disruptions that firms in this sector have experienced in recent years. Established companies in mature industries like manufacturing have less structured technology intelligence processes, and they struggle to identify and adopt digital technologies due to the immense amount of information available. Few studies have examined the technology intelligence practices in the manufacturing industry, yet manufacturing companies need to adjust their technology intelligence processes to succeed in

Sen Fang is a technology strategist who specializes in continuous innovation through the lens of technology intelligence and organizational ambidexterity. He has a PhD in technology intelligence from the Chair of Technology and Innovation Management in ETH Zurich, Switzerland. His research focuses on conducting single and multiple case studies to explore how enterprises stay innovative continuously under digital transformation, especially in mature industries. fangsenabroad@gmail.com

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Antonio Moreno Brenes is a product specialist for ABB Switzerland, where he drives the development of medium-voltage wind turbine converters. He earned his bachelor's and master's degrees in industrial engineering at Universidad Politécnica de Valencia, Spain, with a specialization in industrial organization and management. During his studies, he spent one year at UNSW Sydney, Australia, and completed his master's thesis at ETH Zurich, Switzerland, in the field of technology innovation and management. antonio.moreno-brenes@ch.abb.com

Stefano Brusoni is a professor of technology and innovation management at ETH Zurich, Switzerland. He studies how leaders in established industries can enable the adoption of new, potentially disruptive technologies or business practices. He has published in journals such as *Strategic Management Journal*, *Administrative Science Quarterly*, *Organization Science*, *Academy of Management Journal*, *Research Policy*, and many others. He is senior editor of *Organization Science*. He is also a founder and entrepreneur, currently active in the EdTech space. sbrusoni@ethz.ch

digital transformation. We present the current status of technology intelligence in 10 multinational manufacturing companies and compare them to similar practices in the ICT industry. We illustrate the challenges manufacturing companies face as they perform technology intelligence. We also provide managerial implications that will enable manufacturing companies to have faster and more robust technology intelligence activities.

Theoretical Background

Prior research has used several terms to refer to the acquisition and analysis of information about externally generated technologies, including "technology scouting" (Bodelle and Jablon 1993; Wolff 1992), "technology intelligence" (Mortara et al. 2010), "technology foresight" (Rohrbeck and Gemünden 2011), and "technology forecasting" (Martino 1992; Porter et al. 1991). In this study, we use the term "technology intelligence" since it offers a closer and clearer link to technology decisions (Lingens et al. 2016) based on the information collected. We define technology intelligence as a structured approach to collecting, selectively documenting, evaluating, communicating, and maintaining relevant technology information in order to support technological decisions and follow-up actions.

Even successful companies can fail if they overlook critical technological changes that may impact their competitive positions (Henderson and Clark 1990; Garud and Rappa 1994; Tripsas and Gavetti 2000). CTOs commonly use technology intelligence to manage the profound uncertainties around technology and innovation and keep up with relentless technological change. Companies use technology intelligence to foresee relevant technology trends and support internal technology planning by actively seeking information on novel technologies and making evaluations based on the corporate context (Rohrbeck and Gemünden 2011; Spitsberg et al. 2013). ICT companies such as Cisco Systems and Deutsche Telekom have invested significant effort into technology intelligence through technology radars—that is, a regularly published and updated visualization tool that groups together novel technologies of potential importance to their companies (Boe-Lillegraven and Monterde 2015; Rohrbeck 2007).

Studies about technology intelligence tend to examine practices in ICT companies, where the recent history of technological disruption has strengthened perceptions of the need for it (Rohrbeck 2010). These studies about the ICT industry provide some insights into tools and processes for performing technology intelligence in other industries—for example, the adoption of technology radars in non-ICT companies (Golovatchev, Buddle, and Kellmereit 2010; Veugelers, Bury, and Viaene 2010). However, optimal technology intelligence processes should also consider the industry clock speed and the level of complexity of the environment (Raymond, Julien, and Ramangalaby 2001; Rohrbeck and Gemünden 2011), as such factors impact the urgency and effort needed to manage related technology information. By examining industries where technology intelligence processes have been recently adopted, we can develop a richer understanding of technology intelligence in general.

We focused our study on manufacturing firms for two reasons. First, technology intelligence activities in manufacturing companies have been less organized than those in ICT and pharmaceutical firms (Lichtenthaler 2003). This gap provides learning opportunities to examine technology intelligence in industries with slower clock speeds. Second, manufacturing companies are facing formidable transformation challenges due to digitalization, which signals the urgency for learnings on technology intelligence. With digital trends permeating every industry, previously distant digital technologies are becoming more relevant for manufacturing, obliging manufacturing companies to adopt a wider lens in their technology planning.

Case Study

We conducted a qualitative multi-case study (Yin 2010; Eisenhardt 1989) to examine the processes and impact of technology intelligence in a sample of manufacturing firms. To ensure relevance, we selected technology-intensive manufacturing companies that compete globally, so they have a genuine need to track the development of many novel technologies. Meanwhile, to present a broad view of the general status of the manufacturing industry, we included companies with headquarters in different geographic regions, from different product sectors, and of different sizes. We included 10 case companies and their technology intelligence processes in our study (Table 1). We also added one ICT company (Company K) for comparison in our analysis.

Method

We collected data from the end of 2017 to mid-2019, mainly through semi-structured interviews. We used Rohrbeck's (2010) four stages of technology scouting to examine four sequential stages of technology intelligence processes:

1. *Search,* in which the company's technology scouts, either employees of the company or consultants (Wolff 1992), identify technology information by searching a range of channels;
2. *Selection,* in which collected technology information is filtered to keep only those parts that are relevant to the company;
3. *Evaluation,* in which companies assess the selected technology information to determine its current status and its implications for the company; and
4. *Distribution,* in which companies distribute evaluated technology information to stakeholders to promote visibility and discussion of critical novel technologies.

In addition, we examined the follow-up of the novel technologies after they were distributed, because technology intelligence only contributes to corporate strategy when companies apply the collected and evaluated technology

TABLE 1. Information on interviewed companies

Company	Product and Service Offerings	Headquarters	Employees (number)	Interviews Conducted (number)
A	Railway vehicles, automation, etc.	Germany	>200k	1
B	Automobiles, automotive parts, etc.	USA	>150k	1
C	Industrial automation, electrification, robotics, etc.	Switzerland	>100k	3
D	Tires, high-tech materials, etc.	France	>100k	2
E	Automotive seating, automotive interiors, etc.	France	>100k	4
F	Electronic manufacturing services, manufacturing solutions, etc.	Philippines	>10k	1
G	Machining solutions, casting solutions, etc.	Switzerland	>10k	2
H	Food processing, equipment manufacturing, etc.	Switzerland	>10k	1
I	Fasteners, bolts, etc.	Germany	<5k	4
J	Tools, molds, etc.	Germany	<1k	2

information in their organizational decisions. We added a fifth stage:

5. *Follow-up,* in which companies apply filtered and evaluated technology information in their technology planning decisions.

We conducted 21 individual interviews with 10 manufacturing companies, with an average interview duration of 60 minutes. The interviewees included R&D engineers and managers who are in charge of identifying and developing novel technologies, and product managers and senior managers who make further decisions on the integration of such technologies. We completed data triangulation using our interviews with different stakeholders of technology intelligence processes and online sources (company websites and media coverage) about technology intelligence in these case companies.

Company K's technology intelligence practices are mainly based on existing research in the ICT industry such as Rohrbeck (2007, 2010), Boe-Lillegraven and Monterde (2015), and ICT companies like Thoughtworks, which allow open access to their technology intelligence processes.

We recorded and transcribed all interviews. We followed the thematic coding strategies from Flick (2014). We familiarized ourselves with the interview data and mapped the technology intelligence stages from technology information search to follow-up actions. Based on this initial analysis, we wrote case stories for each of the case companies, which helped us develop an overall view of how each manufacturing company in our study performs technology intelligence.

Then we further analyzed and compared all our case companies (Miles and Huberman 1994) to identify the thematic structure of technology intelligence in the manufacturing industry in general. Based on the themes, we examined in detail how different companies execute technology intelligence processes and how different technology intelligence stages connect with relevant stakeholders. By comparing case companies, we identified the challenges of performing technology intelligence in the manufacturing companies.

We identified digitalization as a common challenge across all case companies. All the firms were tracking digitalization as a trend, and all anticipated far-reaching changes in the manufacturing industry in order to adapt to it. To further examine the technology intelligence processes from the perspective of digitalization, we analyzed the discussion on digitalization in each case company, with the aim of identifying the challenges and possible solutions for manufacturing companies in digital transformation.

We sent our findings to the interviewees with the analysis of their company, comparison to other case companies and recommendations, and asked for their feedback on whether they observe discrepancies from our results. They reported no inconsistencies.

Results

We present the mapping of the technology intelligence processes in the case companies, including a comparison among case companies as well as between the manufacturing and ICT industry. We also highlight the challenges of performing technology intelligence from two perspectives: systemization of technology intelligence and the needed adaptation to digitalization.

Technology Intelligence Processes

In our case companies, R&D—either centralized at HQ or decentralized across different business units—mostly handles technology intelligence activities. Larger companies (>100k employees) normally have a separate corporate unit that focuses specifically on radical and/or futuristic technologies, while smaller companies (<15k employees) make no distinction between technology intelligence for short- and long-term technologies. We describe how our case companies search for, select, evaluate, distribute, and follow up on technology information (Table 2). We provide criteria for degree of systemization in technology intelligence processes (Table 3).

Technology Information Search

All the manufacturing companies in our sample use a range of channels to collect technology information. The most common sources are publications and patents, where technology information is well documented. While some companies rely on

TABLE 2. Technology intelligence processes in case companies with comparison to ICT benchmark

		A	B	C	D	E	F	G	H	I	J	K (Benchmark from ICT)
Technology Information Search	R&D as the locus for technology intelligence		x	x	x		x	x	x	x	x	R&D and business stakeholders
	Part-time scouts only		x	x	x	x	x		x	x	x	Part-time and full-time scouts
	Core and adjacent technologies, driven by needs of existing customers	x		x	x	x	x	x		x	x	Focus placed on external technologies new to the company, including early-stage technologies (e.g., quantum computing)
	Multiple search channels but often limited to traditional ones, such as conferences		x		x	x	x	x	x		x	Multiple search channels, including systematic tracking of startups and technology-trend identification through patent analysis
	Degree of Systematization	High	Mid	Mid	Mid	Low	Mid	Mid	Mid	Low	Low	High
Technology Information Selection and Evaluation	Intertwined selection and evaluation	x	x	x	x	x	x	x	x	x	x	Initial selection to filter relevant technologies for the company, followed by in-depth evaluation of selected technology only
	Lack of consistent and objective criteria for technologies	x	x	x	x	x	x		x	x	x	Clearly defined criteria for selection (e.g., novelty) and evaluation (e.g., market impact and complexity of technological realization)
	Overfocus on cost savings and the needs of existing customers (e.g., preference for mature technologies)		x	x	x	x	x		x	x	x	Technologies novel to the companies are actively selected to ensure no potentially important technologies are neglected
	Degree of Systematization	High	Mid	Mid	Mid	Mid	Mid	High	Mid	Low	Low	High
Technology Information Distribution and Follow-up Actions	Multiple communication channels (e.g., newsletter) but often not standardized, with barriers between departments		x	x	x	x	x			x	x	Technology intelligence results centralized in a single platform (e.g., technology radar) with regular distribution and updates
	Efficient follow-up actions on ready-to-use technologies		x	x	x	x	x		x	x	x	Continuous monitoring, with limited efficiency of actions on all technologies, due to broad scope, including early-stage technologies
	Degree of Systematization	High	High	High	High	Mid	Mid	Mid	High	Low	Low	High

patent search to track technology trends, others use it only to confirm their "freedom to operate"—that is, there is no infringement regarding their ongoing R&D activities. Other relevant sources include market needs analyses and competitor analyses, where they can collect information at conferences and trade fairs, sometimes with assistance from consulting firms. Moreover, the search for technology information is strongly driven by offers from suppliers and purchase interest from buyers: suppliers' technology roadmaps often serve as a channel to search potential technologies; and two case companies (Company E and Company G) use design thinking processes to identify potential technology needs from end customers.

TABLE 3. Criteria for degree of systemization in technology intelligence processes

	High Systemization	Middle Systemization	Low Systemization
Technology Information Search	• Both R&D and business stakeholders • Part-time and full-time technology scouts • Focus placed on external technologies new to the company, including early-stage technologies • Multiple search channels, including systematic tracking of startups and technology trends identification through patent analysis • Use of dedicated technology intelligence tools	• R&D as the locus for technology intelligence • Part-time technology scouts • Core and adjacent technologies, driven by needs from existing customers • Multiple search channels but often limited to traditional ones such as conferences and patent analysis	• Isolated in either Product Management or R&D • No specific role of technology scout • Ad hoc innovation, mainly focused on core technologies • Limited search channels with high reliance on patent analysis
Technology Information Selection and Evaluation	• Initial selection to filter relevant technologies followed by in-depth evaluation • Clearly defined criteria for selection and evaluation • Technological novelty as positive criterion • TRL systematically used for technology assessment and further development	• Intertwined selection and evaluation • Lack of consistent and objective criteria for technologies • Strong influence of senior experts' gut feeling • Focus on cost savings and the needs of existing customers • TRL used for technology development	• No selection or evaluation process • Final decision by senior management • Cost savings as main driver for selection
Technology Information Distribution and Follow-up Actions	• Technology intelligence results centralized in a single platform with regular distribution and updates • Systematic documentation of technology information and trends • Clearly defined follow-up actions for scouted technologies • Agile–Stage-Gate model to explore novel technologies	• Multiple but unmanaged communication channels • Scattered documentation of technology information • Efficient follow-up actions on ready-to-use technologies • Selected technologies developed via Stage-Gate process	• Informal communication channels only • Technology information documented in reports with limited availability • No defined follow-up actions

The biggest differences concerning information collection relate to early-stage technologies. We found larger companies tend to have a more managed approach to such technologies: they have regular contacts (joint projects) with universities where early-stage technologies are being researched, and standard acquisition and investment evaluation on startups that are applying early-stage technologies in the market. In addition, because larger companies have more resources, early-stage technology holders may contact them, which facilitates the information-search process.

In eight of our ten case companies, only the R&D division conducts technology information searches, and usually in an ad hoc manner. In contrast, in ICT companies, part-time and full-time technology scouts from different divisions and geographical locations undertake technology information searches, in order to capture all technologies that are potentially relevant (Rohrbeck 2010). We compare the systemization of technology information search among the case companies (Figure 1).

The biggest differences concerning information collection relate to early-stage technologies. We found larger companies tend to have a more managed approach to such technologies.

Technology Information Selection and Evaluation

Companies tend to collect much more technology information than they need (Feldman and March 1981), so information needs to be filtered based on its relevance. For example, in Deutsche Telekom's technology radar, the submitted technologies are first filtered based on novelty, and then only those selected are further evaluated against market and technology factors (Rohrbeck 2010).

In contrast, our results show that the processes of selecting and evaluating technology information in manufacturing companies are intertwined rather than neatly separated. Some initial evaluation is necessary for the R&D expert to decide whether a technology is relevant; once that has been accomplished, selection and further evaluation are performed simultaneously in the R&D division. This process can be iterative, with the company gradually developing a deeper understanding of a novel technology. We found, however, that neither selection nor evaluation is supported with consistent, objective criteria.

Although companies generally apply technology readiness level (TRL) to assess the maturity of technologies, TRL is not systematically used in either selection or evaluation. More than half of the case companies report that the assessment of a novel technology depends largely on senior experts' gut feelings. Only Company G has clearly defined criteria for technology evaluation. Generally, cost savings and existing customers' needs are the two major factors considered during technology evaluation, and this is especially true for manufacturing companies in the upper supply line chain such as Company G and Company I. We compare the systemization of technology information selection and evaluation among the case companies (Figure 2).

> **Our results show that the processes of selecting and evaluating technology information in manufacturing companies are intertwined, rather than neatly separated.**

Technology Information Distribution and Follow-up

We found that manufacturing companies often use newsletters on technology trends, internal TV channels, or social networking platforms to distribute technology information. However, in many cases, these channels for innovation are not used effectively or updated regularly. For instance, the social network for innovation in Company E and Company I are considered "anecdotal," because they are not officially used for discussion on novel technologies. Most of the real dissemination of technology information happens informally—for example, at the coffee machine, as Company C's R&D team leader shared. Interviewees also indicated that the lack of standardized communication processes and the barriers between departments are significant barriers to leaner technology evaluation and selection processes. For example, two divisions in Company C were working on the same technology of cloud connectivity without interacting, which prolonged time to market and increased the cost of success.

The distribution of information should give stakeholders relevant information, yet technology intelligence efforts only bring a company value when the technology information collected and evaluated actually contributes to relevant technological decisions and corresponding organizational processes are adopted. Since many manufacturing companies have a clear focus on customers and cost savings, follow-

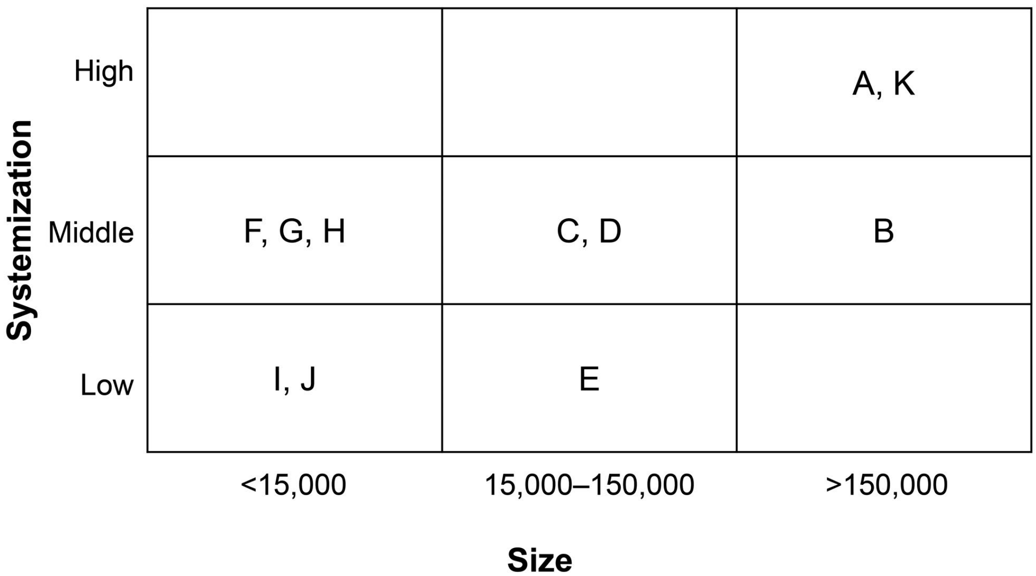

FIGURE 1. Comparison of technology information search

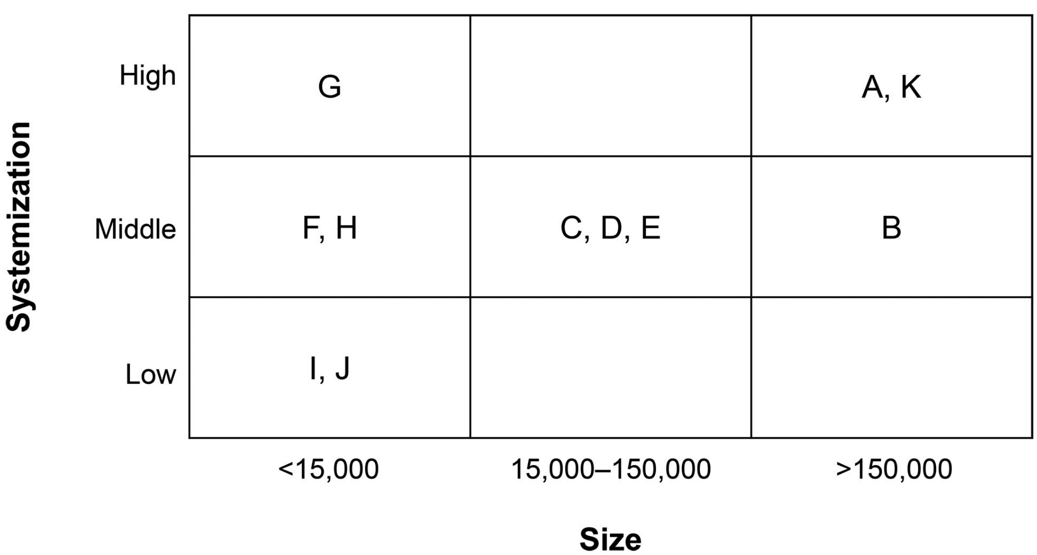

FIGURE 2. Comparison of technology information selection and evaluation

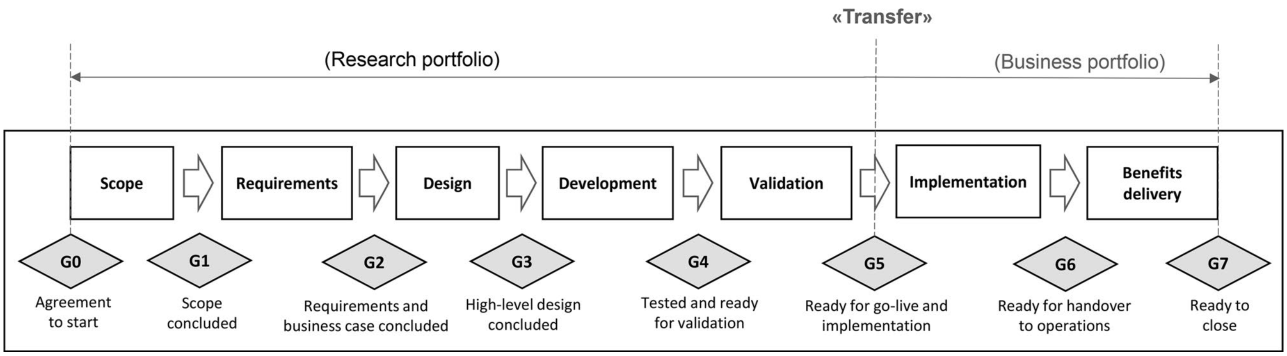

FIGURE 3. Company C's Stage-Gate process

up actions on ready-to-use technologies are taken efficiently using internal Stage-Gate processes (Figure 3). When the technology is relevant, but internal development is not ideal or feasible, manufacturing companies often seek external collaboration or acquisition. For example, Company G and Company D searched for acquisition and collaboration opportunities on additive manufacturing, and Company E acquired an electronic company. However, in situations where the technology is currently immature but might potentially be important in the future, only Company A and Company D have clearly defined actions (continual monitoring and an incubator project) to ensure they do not miss potential opportunities. One counterexample is Company G's experience with additive manufacturing. Although it recognized the relevant opportunities of this technology at an early stage, its muddled technology intelligence processes prolonged communication and extended the timeframe for evaluating the technology. When Company G finally decided to invest, its R&D lead said it could no longer enter the game "as ideally as it would have before" because of the larger number of players. Thus, it became more competitive and expensive for Company G to invest in or acquire additive manufacturing technologies.

For ICT companies, distribution is largely supported by predefined technology intelligence platforms like technology radars. This approach facilitates discussion among senior management on all relevant technologies with continuous monitoring and enables regular and transparent communication to all stakeholders inside the company. While the broad scope of technology intelligence in ICT companies enables a complete view of the technology landscape, it might also pose a challenge for effective follow-up actions. Sometimes, despite having a technology on their radar, ICT companies still miss the best time to act on it. We compare the systemization of technology information distribution and follow-up actions among the case companies (Figure 4).

Technology Intelligence Challenges in the Manufacturing Industry

Systemization and digitalization are two key technology intelligence challenges.

Systemization

In our study, larger companies have a clearer technology intelligence structure than the smaller ones. However, in comparison to ICT companies (Boe-Lillegraven and Monterde 2015; Rohrbeck 2010), technology intelligence processes in manufacturing firms tend to be less organized for several reasons.

1. Technology intelligence responsibilities are poorly defined, especially for small players.—R&D departments or divisions conduct technology intelligence because their experts have the most direct access to technology information. However, as R&D experts are often occupied with ongoing technology projects, we found that companies—small ones in particular—tend to devote extra time to searching out

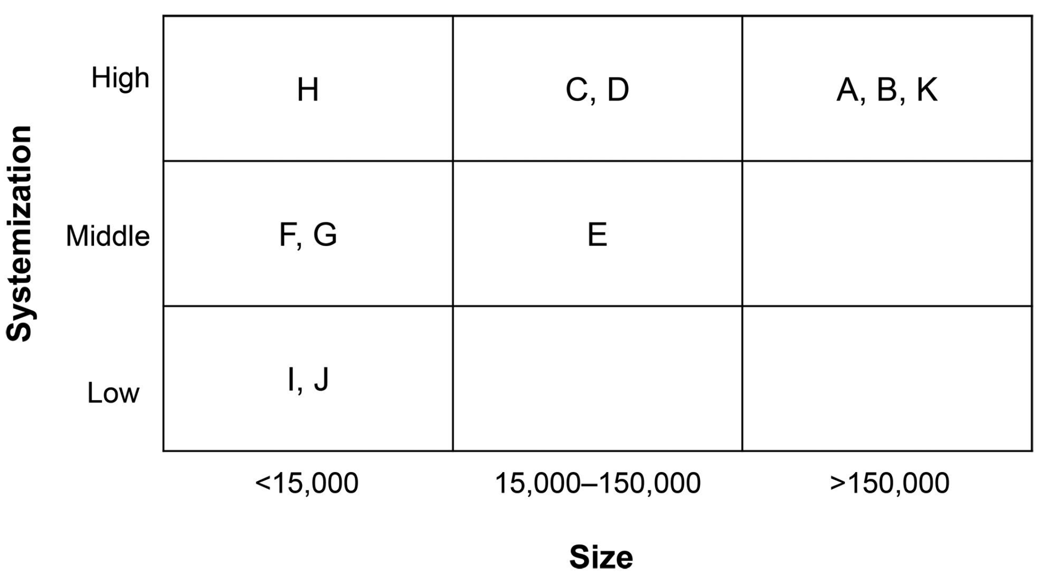

FIGURE 4. Comparison of technology information distribution and follow-up actions

novel technologies only if current ones fall short of performance expectations. Business units can also identify novel technologies through market and competitor analysis, but they rarely share information about these technologies or push for them to be evaluated further. Interviewees from three case companies (C, E, I), shared that technology intelligence tasks are "spread across the whole team." Our findings also revealed that, in practice, employees do not execute technology intelligence activities on a regular basis, and there is no key performance indicator (KPI) to measure technology intelligence within a company.

2. *Companies often define technology intelligence targets narrowly and over the short term.*—Technology information search is largely focused on ready-to-use technologies in an ad hoc manner, which makes it challenging to identify novel technologies that lie beyond current core capabilities. Without a shared goal for technology intelligence, no clear criteria exist for filtering relevant information, and information judgments are mostly based on gut feelings. As a result, technology intelligence in manufacturing companies often leads to deeper understanding of existing technologies instead of bringing in new insights on novel technologies beyond core areas.
3. *Technology intelligence processes are not streamlined.*—Although the case companies collect technology information through various channels, they do not store or share it effectively—employees on different teams may be working on the same technology without knowledge of each other's projects. This was the case with cloud connectivity in Company C. When technology information gets documented haphazardly, it is not re-evaluated and updated regularly. For instance, technology radar in Company G and Company H, respectively, was a one-time practice, because neither company set up a platform with pre-defined processes like Company K has. Without streamlined technology intelligence processes, a company's technology information can be incomplete or scattered across different parts of the organization and may never be used or implemented. Even though Company I's R&D division has quarterly meetings on progress, product management cannot integrate such information into its product planning, because it has no access to documentation and no information sharing takes place. The narrow scope of technology intelligence and the ad hoc approach could focus attention on those technologies that do make it to decision makers' desks. As the case of additive manufacturing in Company G reveals, valuable knowledge about novel technologies can fall through the cracks, and the information that ultimately catches managers' attention might not be the most relevant for the company's strategy.

Among our case companies, the four larger firms (A, B, C, and D) tend to be more systematic in their technology intelligence activities and report higher confidence in adjusting to external technological changes. For example, Company A actively grows its knowledge on early-stage technologies such as quantum computing systematically through technology intelligence activities. Company A's R&D director said it does so in order to "jump in when the devices are there on the market." Systematic technology intelligence enables companies to reposition themselves to implement novel technologies more quickly and efficiently. This ability is essential for digitalization. In contrast, companies with less systematic technology intelligence are slower to act because their technology information is scattered across the organization and they lack interdepartmental coordination. As a result, this could lead to ineffective actions to adopt digitalization, as was case with Company I, or duplicated work and extra costs incurred, as Company C experienced.

Digitalization

Seven case companies in our study appreciate digitalization's challenges and opportunities. Larger companies emphasize digitalization in their corporate strategy and often set up a separate unit devoted to the potential created by digitalization. Smaller companies, although taking smaller steps, are also active in transforming their production strategies to stay relevant in Industry 4.0. For example, Company C set up new programs, an innovative software platform, and alliances with digital partners to accelerate its digital transformation and establish its digital brands. Company G created a dedicated division focused on digitalization and Industry 4.0.

While our case companies recognized the importance of digitalization, they did not always examine its implications for the technology intelligence process. Fast-moving digitalization makes technology intelligence more important. With digitalization increasing the pace of technology development and making it more interconnected, it is harder for companies to capture the right technology, at the right time, in the right market context—especially manufacturing firms that need to compete in fields beyond their traditional core capabilities. This is true for both large players like Company C and small players like Company F: they consider digitalization more a challenge than an opportunity because they need to build up new capabilities. For instance, the predefined

Companies often define technology intelligence targets narrowly and over the short term; technology intelligence processes are not streamlined; and technology intelligence responsibilities are poorly defined, especially for small players.

stages and gates for traditional technologies may not be applicable to digital technologies that are advancing much more quickly, and which have more uncertainties surrounding their development and final application. Systemized technology intelligence processes are needed to manage the complexity of digitalization.

Digital technologies enable much faster and robust technology intelligence activities. One overwhelming challenge faced by technology scouts in our case companies is the huge amount of information. Merely working through and analyzing it all demands time and effort that most scouts cannot afford. Digital technologies such as AI and data analytics provide capabilities to process mass amounts of data—especially well-documented information such as patents and publications. Five case companies (A, C, I, G, and E) in our study are using, or are beginning to use, digital technology as an extra channel to perform technology information searches. For example, to identify technology trends, Company A has been actively exploring AI-enabled technology intelligence tools on the market (for example, Mergeflow) that analyze academic and media data. Such AI tools make it easy to search through papers, patents, and news coverage with great efficiency; however, companies still need to predefine their own search areas, and the search results usually reflect general trends without highlighting any company-specific implications. In the near future, AI will inevitably play a more integral role in the technology intelligence practices.

The manufacturing industry recognizes the importance of digitalization, but it needs corresponding technology intelligence processes to ride the innovation wave and keep pace.

Managerial Implications

Combining the findings that we derived from the company case studies, together with reflections from best practices in the benchmark company, we have the following recommendations for manufacturing companies seeking to adapt their technology intelligence processes to embrace and take advantage of digitalization:

1. *Define technology intelligence responsibilities clearly, assign them across different divisions, and do not restrict them to R&D*.—Doing so lays the foundation for diverse technology information to be actively collected by employees acting on clear guidelines. In the ICT benchmark company (Company K), a global network of scouts managed by both technology and business units handle technology submissions, while a panel of senior experts and managers select the submitted technologies. Such a setup can avoid ad hoc technology intelligence activities that are loosely organized in R&D.
2. *Specify technology intelligence goals and set up corresponding instruments (for example, technology radar, Delphi method) and culture to facilitate these activities*.—Technology intelligence in the ICT industry is set up to foster product and service innovations by identifying technological trends and shocks early on and to draw attention to technology development threats and opportunities. Compared to ICT companies, the manufacturing industry has a relatively slower industry clock speed for digitalization, and technology intelligence tends to focus on short-term technologies that will realize clear cost savings for existing customers. While cost savings and meeting existing customers' needs are important targets of technology intelligence, overemphasizing them can create another barrier to innovation and gaining customers in the future, which can prove problematic when adapting to digitalization. Manufacturing companies need to broaden their technology intelligence goals dynamically to be able to integrate digital technologies effectively and efficiently. Manufacturing companies should also set up corresponding instruments and culture to reach such goals—for example, establishing a technology radar to track relevant digital technologies, engaging in active patent search in digital areas, participating in events on non-core technologies, and granting scouts the freedom to explore radical innovations.
3. *Streamline technology intelligence processes to ensure that key technology information flows from those who identify technology to the decision makers*.—Manufacturing companies need to systematize each individual technology intelligence stage and the information transition between them. Companies need to select and evaluate collected technologies against consistent and objective criteria. For instance, at ICT companies, selection is based on the technology's novelty and assigned to an interdepartmental panel of experts, while scouts carry out further evaluation of selected technologies using predefined templates. Follow-up actions should be clearly defined to enable effective decision-making. We observed challenges in balancing the amount of information being tracked and the speed of decision-making, in both the manufacturing and ICT industries. While delayed decisions may mean missing the best opportunity window (as happened with additive manufacturing for Company G), rash actions that disregard market and ecosystem contexts could lead to the development of a brilliant product with no clear understanding of the necessary complementary changes. That happened in 1998 with Michelin's PAX System, an innovative run-flat tire with no sacrificed performance even if punctured: despite the superior technology, PAX System failed without sufficient repair and replacement facilities in place (Adner 2013). It is essential to define KPIs that are consistent with technology intelligence goals to track results and establish the feedback loop to improve follow-up actions continuously.
4. *Adjust the Stage-Gate model to adapt to digitalization by introducing Agile principles to enable shorter development cycles*.—For instance, Company C uses a dedicated "Stage-Gate model for projects following an Agile approach" to support incremental feature delivery and continuous system integration and testing. In practice, this is a "hybrid model" in which Company C uses traditional means to control major decision points and Agile principles to develop products rapidly and iteratively in each stage (Figure 5). By injecting Agile principles into the traditional Stage-Gate model, manufacturing companies can make faster

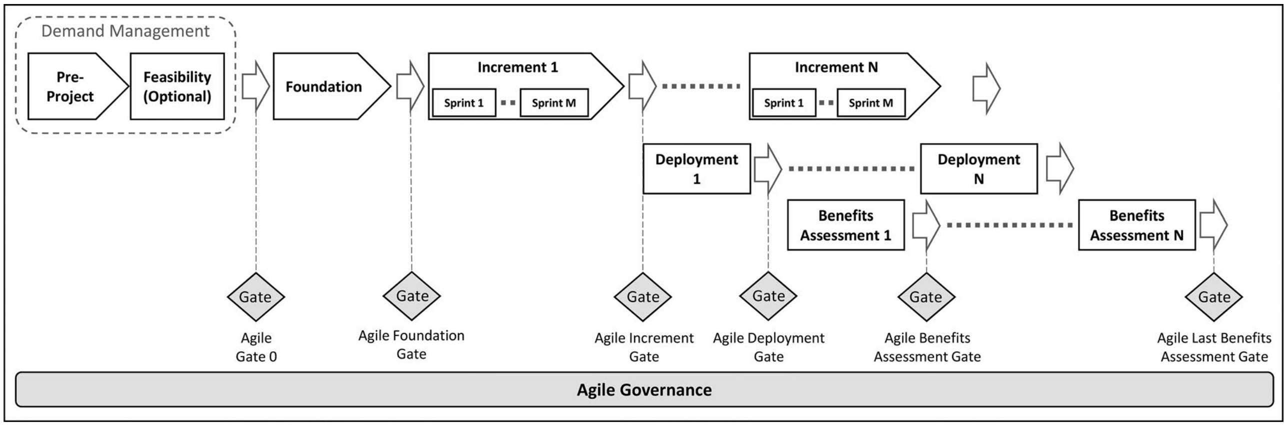

FIGURE 5. Company C's Agile–Stage-Gate process

decisions on traditional manufacturing technologies and novel digital technologies simultaneously and deliver projects at higher speed and lower transactional cost.

5. *Digital technologies, especially AI and data analytics, offer potential to facilitate technology intelligence processes*.—Given existing AI tools that support technology information search, we expect digitalization to play a part in the subsequent technology intelligence stages as well, along with data accumulation and increasing effort toward AI initiatives globally. Manufacturing companies should track and explore the potential to integrate AI into technology intelligence activities; systemized technology intelligence could help prepare the data potentially needed for future AI use cases.

Conclusion

Manufacturing companies tend to have unsystematized technology intelligence processes, which could be problematic in the technological wave of digitalization. Our study provides insights on how manufacturing companies can systematize their technology intelligence processes to embrace digitalization. Manufacturing companies should clearly define technology intelligence responsibilities, streamline the information flow, set up clear selection and evaluation criteria, and integrate relevant information into their decision-making.

Our study highlights the unique challenge that digital transformation poses for mature industries like manufacturing, where they need to capture and integrate technologies outside their core areas. The findings and recommendations here are relevant for manufacturing companies, regardless of their size, and are also applicable to other industries where the industry clock speed is slower than the digital trends.

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