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How to create dynamic capabilities: A design science study

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ABSTRACT

Dynamic capability (DC) theories are widely used by innovation scholars, but there is little empirical work that applies these theories in ways that can be used by practitioners. Moreover, DC studies tend to suffer from tautological issues when measurements of DC overlap with those of firm performance. To fill this void, this paper explores how scholars can help companies in creating a dynamic capability. We adopt a design science approach in which scholars and practitioners team up to address and resolve a focal firm's (micro-DC) challenge in managing a large number of product development projects that run simultaneously but all depend on the same resource pool. To address this challenge, we design and implement a process technology tool. This study thus demonstrates how one can solve a real-life DC challenge by developing a practically relevant solution, based on design science.

"In the varied topography of professional practice, there is a high, hard ground where practitioners can make effective use of research-based theory and technique, and there is a swampy lowland where situations are confusing 'messes' incapable of technical solution. The difficulty is that the problems of the high ground, however great their technical interest, are often relatively unimportant to clients or to the larger society, while in the swamp are the problems of greatest human concern" (Schön, 1984, p. 42).

1. Introduction

Innovation and management scholars have long been exploring how their theories can be formulated and shaped in ways that inform industrial applications (e.g., Shepard, 1956) because most scientific knowledge in this domain never gets applied (Zahra et al., 2018). In this respect, Donald Schön's (1984) quote above suggests that the theoretical problems of the high ground tend to be relatively unimportant to practitioners, although their swampy lowland provides the problems of greatest concern to practitioners and society at large.

An interesting case here is dynamic capability research. Dynamic Capability (DC) theories address the generation of new products and processes, drawing on the organizational ability to renew and recreate strategic capabilities in response to changing market conditions (Teece et al., 1997; Teece, 2007). Following Teece (2007) and Ferreira et al. (2020), DC is the capacity for methodically addressing and solving organizational challenges and problems, by sensing opportunities, seizing (some of) these opportunities, and when necessary reconfiguring the intangible and tangible assets – thereby ensuring the long-term viability of the company (see also Katkalo et al., 2010).

Innovation scholars often use DC theory (Chirumalla, 2021; Demeter et al., 2021; Khan, 1999; Mortati et al., 2023), for example, to study leading firms in particular industries (Subramanian et al., 2011; Enkel and Sagmeister, 2020) or their non-leading counterparts in these industries (Danneels, 2011). However, despite various attempts to decouple the definition and measurement of a DC from those of firm performance (e.g., Eisenhardt and Martin, 2000; Helfat et al., 2007; Zahra et al., 2006), many scholars have criticized DC theory for suffering from a *tautology* problem (e.g., Michaelis et al., 2021; Wang, 2007; Wheeler, 2002), especially when measurements of DC overlap, or are even equated with, measurements of firm performance.

Moreover, few scholars have studied how they themselves can systematically contribute to a company that seeks to enhance its DC. In this respect, the definition of DC given earlier (based on Ferreira et al., 2020; Teece, 2007) draws on the organizational ability to learn about competences or technologies new to the firm, assess their feasibility, and implement them (Danneels, 2008). More specifically, DCs may provide

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second-order competences that permit a firm to create new competences (Danneels, 2008), revamp its production methods and operations (Danneels, 2008, 2012, 2016), and enhance its strategic flexibility and performance (Chen and Lien, 2013; Yi et al., 2015), but it is unclear how these competences can (and should) be practically developed. As such, DC scholars have not *operationalized* DC theory in ways that can be directly applied by practitioners and scholars alike.

These tautology and operationalization issues can be contextualized in terms of Schön's (1984) distinction between the high ground and swampy lowland. That is, a major challenge for DC scholars and practitioners alike is how the puzzle of tautology and operationalization issues in DC theory can be solved by building a methodological bridge across the high ground of DC theorizing and the lowland of practitioners trying to grow their companies' dynamic capabilities. This study therefore explores how DC scholars can collaborate with practitioners to solve the latter puzzle. In doing so, we also respond to Kay et al. (2018), who called for inquiry into how DCs are actually created. The latter type of study helps develop a deep and practical understanding of how DCs can be generated. Our research question therefore is: *how can scholars help a company in developing a dynamic capability,* that is, the capacity to methodically address and solve organizational problems by sensing and seizing opportunities and, if needed, reconfiguring various assets of the company?

In answering this question, we draw on a longitudinal study of a Hungarian automotive company, which faced major problems in managing its multi-product development projects. To enhance the practical relevance of DC theorizing, we draw on a design science research (DSR) approach, arising from Simon's *The Sciences of the Artificial* (2019; first published in 1969). DSR methodology informs the creation of new and innovative artifacts (Hevner et al., 2004) and thereby offers solutions to real-world problems (Peffers et al., 2018; Romme and Holmström, 2023). An essential part of any DSR study is the design of solutions (as artifacts) that are instrumental in theorizing about the field problem at hand as well as practically supporting decision-makers in accomplishing their goals (Romme and Holmström, 2023; Walls et al., 1992). The artifact developed in this paper is a tool for improving the focal company's capability to simultaneously manage multiple product development projects—a so-called micro-DC (Teece, 2007) challenge.

This study contributes to the DC literature by demonstrating how practitioners and scholars can collaborate in creating or enhancing a micro-DC. As such, we apply DSR to develop knowledge that is grounded in DC theory as well as practically useful. More specifically, a step-wise DSR approach appears to effectively guide the sensing-seizing-reconfiguring cycle of DC development. We thus demonstrate how DC scholars can collaborate with practitioners to make high-level DC theories actionable.

2. Theoretical background

One of the earliest definitions of DC refers to a firm's capabilities in generating new products and processes and responding to changing market conditions (Teece and Pisano, 1994). A more recent and detailed definition of DC is "the potential to systematically solve problems, enabled by its propensity to sense opportunities and threats, to make timely decisions, and to implement strategic decisions and changes efficiently, thereby ensuring the right direction" (Ferreira et al., 2020, p. 1). Central to DC theory are adaptation, integration and reconfiguration activities (Teece et al., 1997) that support the firm's strategic intent and orientation (Pezeshkan et al., 2016; Shuen et al., 2014) and help it flesh out the details of this intent.

DC theory distinguishes between operational and dynamic capabilities (Teece, 2014; Mikalef et al., 2020). The former are linked to the exploitation of the current products and markets served, drawing on existing competences in this area (Helfat and Winter 2011). DCs go beyond (continuous improvements in) the exploitation of existing products and services (Helfat and Winter 2011) by systematically revamping operating routines in the pursuit of competitive advantage (Sher and Lee, 2004; Zollo and Winter 2002). DCs thus draw on organizational behaviors and competences which the firm can invoke to systematically generate and modify its operating routines (Zollo and Winter 2002), that is, alter how it earns a living (Helfat and Winter 2011; Winter, 2003) by systematically solving functional problems (Barreto, 2010). A key distinction between operational and dynamic capabilities is that the former can be bought, while the latter must be actively built (Katkalo et al., 2010; Shuen et al., 2014; Teece, 2014). In the remainder of this section, we explore the microfoundations as well as the role of design research in this area.

2.1. The microfoundations of dynamic capabilities

As a helpful tool for analytical purposes, Teece (2007) dissected DCs into three clusters: the capacity to (1) *sense* opportunities, (2) *seize* these opportunities, and (3) when necessary, *reconfigure* the intangible and tangible assets in order to improve competitiveness (Katkalo et al., 2010; Teece, 2007, 2018). Teece (2007) also noted that idiosyncratic microfoundations constitute the backbone of each of these clusters. That is, specific skills, processes, procedures, organizational structures and decision rules constitute these microfoundations (Teece, 2007). We explore each cluster's microfoundations in more detail here.

Sensing encompasses the firm's managers active engagement in identifying business opportunities, threats and new customer needs. Managers must "highlight what is important" (Teece, 2007, p. 1324), support the "testing [of] various hypotheses about emerging technologies" (Schoemaker et al., 2018, p. 16) and initiate and aid the explicit employment of some kind of analytical framework (Teece, 2007; Torres et al., 2018). In a recent study, Lin et al. (2020) unexpectedly found that structural formalization, a term referring to a high level of organizational devotion to rules, procedures, policies and structures (Patel, 2011; Zmud, 1982), positively affects the emergence of DCs. Sensing competences can also entail seeking novel knowledge in order to venture along new, unrelated technological trajectories (Atuahene-Gima, 2005). As such, sensing mobilizes processes that direct internal R&D and helps tap into external developments in science and technology (Enkel and Sagmeister, 2020; Teece, 2007).

After sensing, managers lead the company to *seize* the identified opportunity. For new products, services, activities or processes, the firm has to practice discipline in investing in both tangible and intangible assets and its commitment to R&D; moreover, it has to identify and achieve new resource combinations (Helfat and Peteraf, 2015; Katkalo et al., 2010). For example, Conboy et al. (2020) describe how firms in highly different industries (e.g. telecommunications, software development, computing services, humanitarian aid, and banking) invest significantly in business analytics technologies. In this respect, the seizing capability entails problem solving and reasoning by applying rational procedures (Helfat and Peteraf, 2015) and possibly overriding specific (e.g. cognitive or group pressure) dysfunctions in decision making (Hodgkinson and Healey, 2011; Shamim et al., 2019) by adopting decision-making and planning protocols and developing specific technological competences (Augier and Teece, 2009; Enkel and Sagmeister, 2020; Ellonen et al., 2009; Helfat and Peteraf, 2015; Teece, 2007). The latter decision-making efforts include decisions about the technologies to be employed and estimates of the revenue and cost structure of the new processes (Teece, 2007).

Finally, *reconfiguration* is the cluster of capabilities which is key to honing evolutionary fitness and performance by transforming the company (Gelhard et al., 2016; Teece, 2007). The goal of this third cluster is to implement the required technological competences and decision-making methods (identified in the seizing efforts) and revamp the operating routines (Helfat and Peteraf, 2015; Katkalo et al., 2010), possibly resulting in a comprehensive reconfiguration of core structures, procedures and decision-making protocols (Subramanian et al., 2011; Teece, 2007), as DC microfoundations. These reconfiguration efforts can also involve training and coaching activities, integration of various bodies of know-how, coordination activity across previously disconnected units, and deliberate efforts to build emotional commitment (Ellonen et al., 2009; Hodgkinson and Healey, 2011; Teece, 2007).

However, the extant literature does not specify how (any of these clusters of) DCs can be deliberately created. As such, one typically takes the initial creation of DCs for granted, by not detailing the path leading to a DC (Danneels, 2008, 2016; Mikalef and Pateli, 2017; Yi et al., 2015). This is also remarkable because many authors have argued that these capabilities cannot be purchased, but must be deliberately created and assembled (Katkalo et al., 2010; Shuen et al., 2014; Teece, 2014).

2.2. The tautology problem in DC research and the rise of design approaches

Many scholars have criticized DC theory for being rather vague, and more specifically, for suffering from a tautology problem (Hermano et al., 2022; Michaelis et al., 2021; Mulders and Romme, 2009; Wang, 2007; Wheeler, 2002), despite various attempts to decouple the definition and measurement of a DC from those of firm performance (e.g., Eisenhardt and Martin, 2000; Helfat et al., 2007; Zahra et al., 2006; Zott, 2003). In this respect, the tautological nature of DC theory involves three levels of analysis (Mulders and Romme, 2009): the output or outcome of DC, the DC itself, and its microfoundations. These levels of analysis are interwoven; especially DC and firm performance (as an outcome) are intertwined in many studies. For example, Zollo and Winter (2002: 340) argue that DCs "pursue improved effectiveness" and therefore are likely to improve (a) financial performance in terms of return on assets and return on sales and/or (b) business performance in terms of market share, sales growth, diversification, and product development. This raises a tautological issue by inferring measurements of DC from successful firm performance: if the firm performs well, it apparently possesses dynamic capability; if performance is not superior, then the firm apparently scores low on dynamic capability (Hermano et al., 2022; Mulders and Romme, 2009; Wilden et al., 2013; Zahra et al., 2006).

To address this fundamental challenge in DC studies, design-oriented research methods are very promising, as they enable scholars as well as practitioners to address DC microfoundations and their performance output as separate artifacts (Magistretti et al., 2021). Design research methodologies have been arising in the field of innovation, because they serve to extend the capability of scholars (often in collaboration with practitioners) to generate novel and innovative artifacts, by drawing on a systematic design process (Hevner et al., 2004; Oliveira et al., 2024; Romme and Holmström, 2023; Walls et al., 1992). In contrast to research that primarily seeks to describe and explain empirical phenomena (or 'facts') observed, design research is more prescriptive and seeks to create and test artifacts (March and Smith, 1995; Mortati et al., 2023; Thakur-Weigold, 2021), thereby developing courses of action which change existing situations into preferred ones (Simon, 2019).

Hence, there is a growing body of literature at the intersection of DC and design thinking (Carlgren et al., 2014; Mortati et al., 2023; Oliveira et al., 2024). These design-oriented studies explore and test solutions in the area of, for example, knowledge sharing (Carlgren et al., 2014) and enhancing a customer focus (Micheli et al., 2012). Other studies seek to exploit design thinking as a facilitator of (improving) the microfoundations of dynamic capability (Cautela et al., 2022), including individual competencies, procedural dynamics, interpersonal interactions, and structural arrangements (Magistretti et al., 2021). Through the DC lens, Hullova et al. (2019) underline the significance of considering the assessment and necessity of internal and external knowledge stocks, by (amongst others) leveraging knowledge acquired during projects, particularly in the context of developing complex new processes. Similarly, Lager and Simms (2023) caution that for effective reconfiguration of a company's innovation work, "it is advisable to design a work process that is adapted to inherent and contextual process-industrial conditions" (p. 1).

Finally, Magistretti et al. (2021) conceive of design thinking as a key microfoundation of DC, based on a systematic literature review that uncovers the dynamics of design thinking and the need for context-specific innovation capabilities. They also argue that design-driven research serves to create common ground for practitioners and scholars to collaborate on DC-related challenges. More specifically, Magistretti et al. (2021) highlight various questions for future research, such as how sensing influences overall project performance, how the brokering function of seizing actually operates, and how dedicated microfoundations interact and create value during their deployment. Additionally, Magistretti et al. (2021) call for longitudinal empirical studies guided by design thinking, also to control for the 'rigorous exogeneity' condition outlined by Stadler et al. (2013). This condition stipulates that any DC must be distinguishable from the outcomes obtained (Stadler et al., 2013), that is, avoid the tautology issue outlined earlier. Here, longitudinal empirical work can also replace conventional laboratory experiments (Wollersheim and Heimeriks, 2016), which are extremely difficult to conduct in real-life organizations, and can shed light on the DC dimensions of speed (Dykes et al., 2019) and creative action (MacLean et al., 2015).

Given this emerging body of research at the interface of DC and design, we thus argue that DC studies need to go beyond descriptive-explanatory work to actively (co)create microfoundations for DC – to control for the 'rigorous exogeneity' condition and avoid the tautology problem. A key microfoundation of DC involves how a firm manages its new product development projects (Conboy et al., 2020; Hermano et al., 2022; Teece, 2007). In the remainder of this paper, we therefore explore how scholars can help a company in building DC microfoundations in the area of managing NPD projects. In doing so, we also seek to extend the study by Conboy et al. (2020), who found that business analytics technology fuels the development of DC micro-foundations.

3. Methodology

This paper adopts a design science research (DSR) approach. One significant benefit of DSR is that it fosters collaboration between academics and practitioners, thereby bridging the relevance-rigor gap (Dimov et al., 2023). DSR is widely applied in the field of entrepreneurship (Romme and Reymen, 2018), operations management (Holmström et al., 2009; Van Aken et al., 2016) and information systems management (Hevner et al., 2004; Peffers et al., 2007), and has recently also been advocated for the field of technological innovation and innovation management (Romme and Holmström, 2023).

A typical DSR cycle incorporates design and science as complementary activities (Pascal et al., 2013; Romme and Reymen, 2018). Central to such a cycle are the processes through which artifacts (i.e., solutions to real-world challenges) are conceived and tested (Peffers et al., 2018; Romme and Holmström, 2023). In doing so, DSR is outcome- and performance-oriented (Peffers et al., 2018), whether through profit maximization (Walls et al., 1992), cost minimization (Hevner et al., 2004; Simon, 2019), or the provision of applicable tools for addressing specific problem contexts (Winter, 2008), thereby benefiting various stakeholders involved (Peffers et al., 2007). While DSR work can yield a highly diverse array of artifacts (Dimov, 2016; Gilsing et al., 2010; Romme and Reymen, 2018), tools for practitioners are the most promising ones (Romme and Holmström, 2023). Informed by this body of knowledge on DSR, we adopted the following iterative cycle:

1) we first *diagnose and define the key problem*;
2) then *conceive alternative design solutions and select the most promising one*;
3) subsequently flesh out the *details* of the selected design solution and test it before implementation; if the results of these tests are not satisfactory, restart the cycle with step 1 or 2;

4) *implement and evaluate the outcomes* of the design solution; and
5) specify *what learnings arise* from the solution designed and tested, particularly for the practitioners involved.

Interestingly, several of these phases correspond to key DC activities (see section 2.1), as theorized by Teece (2007) who, however, did not conceive of these activities as key components of a generic methodology for developing a DC.

3.1. Case setting

Telemat (a pseudonym) is an Hungarian automotive company that designs innovative technologies and systems for vehicle connectivity, navigation and entertainment services. Telemat therefore heavily invests in new product development in these areas, thereby initiating and managing many new product development (NPD) projects simultaneously. The major challenges in simultaneously managing these NPD projects provide the setting in which this study was conducted.

The main data used and analyzed in this study relate to two sets of Telemat's NPD projects. Data on the first set of 12 NPD projects informed the design and development of the tool (using simulation and other methods, described later), whereas a subsequent cohort of 13 NPD projects provided the opportunity to test a prototype of the tool. The first set of NPD projects were done from January 2014 to April 2015, and the second set from May 2015 to October 2016. All these NPD projects were similar in terms of technological and product development challenges and were managed with project templates.

In addition, we held various focus group sessions and workshops, conducted technology reviews, and collected data from various other sources. Table 1 provides the timeline of the events, activities and milestones. This timeline is structured in terms of the five phases of the DSR cycle described earlier. The specifics of various data sources are described in more detail in section 4.2.

3.2. Data collection and analysis

Telemat operates as a project-oriented company, entirely organized around project development. Each development task is organized into five phases and tasks within phases are organized in sprints. The five phases are: Concept and Analyze (phase 0), Specification (phase 1), Development (phase 2), Testing (phase 3), and Deployment and Maintenance (phase 4). Table 2 provides an example of the duration of these phases (and their activities), using the template of the company.

Telemat's Enterprise Resource Planning (ERP) system reports the sources of the tasks and project parameters, such as task duration, cost, and resource demands, as well as priorities arising from the task reports of previous projects. The reports from a specific time period were organized according to the ID numbers of tasks. Rows represent the individual runs of the projects, with each task (denoted in columns) containing information on its time, cost, and resource demands. If a task does not occur, the respective cell of demands is empty. Consequently, the template and the reports of resource demands help project managers and the researchers select and prioritize the tasks to be performed, plan the task, and calculate the project demands. Project managers also actively engage customers. The relative frequency of tasks reported in previous projects is usually considered in suggesting priorities, but the customer has the final say. The customer can either accept or modify the suggested priorities, thus creating sprint backlogs in each sprint, which contain the tasks to be performed within the sprint.

These ERP data were used in developing the M4 method, which is described in detail in the next section. Table 3 provides a summary of all NPD data used in this study.

Focus group discussions conducted at the beginning of the data collection process served to identify the main challenges and needs of the company specialists regarding project planning, scheduling and risk management. These focus groups involved participants from different

Table 1
Event listing for Telemat's design-based DC creation process.

Phase in DSR cycle	Date	Key events	Detailed description
Diagnosing & defining the problem	Jan 6, 2014	Start of the first 12 NPD projects	Telemat started a set of 12 NPD projects, scheduled to last for 464 days♠. Scholars from a local university were engaged to help address the anticipated organizational challenges related to KPIs such as lead time, costs, and resource allocation imbalances in NPD processes.
	Jan 2014	Focus group discussions	We held four sessions with participants from different departments, who informed us about challenges and needs of project planning in Telemat's operation.
	Jan 2014	Data collection and simulation	Company professionals were interviewed about the structure of a typical NPD project, its main phases, and corresponding activities and durations (per phase). We had access to Telemat's ERP system for ample data on tasks and project parameters (e.g. duration, costs, resource demand, priorities) to run simulations via Telemat's fixed project management template.
	Till June 2014	Technology reviews	We conducted technology reviews to evaluate the company's current software tools for project planning, scheduling, and risk management. This included assessing criteria for evaluation, strengths and weaknesses, handling ethical issues, and staying updated on industry trends.
	July 2014	Workshop conducted	A workshop (of about 1 h) was conducted to present and discuss the main findings thus far; with 15 participants from various departments and roles.
Exploring potential solutions & selecting the most promising one	July 2014	Workshops conducted	Two subsequent workshops (of 1 h each) were held to generate ideas for improving project planning, scheduling, and risk management. The same 15 participants as above

(*continued on next page*)

Table 1 (*continued*)

Phase in DSR cycle	Date	Key events	Detailed description
			joined these two sessions.
	Aug 2014	Problem-solving sessions	Six problem-solving sessions were conducted with company specialists to co-create a solution for project planning and risk management. These sessions involved six participants with extensive expertise; each session lasted approximately 2 h.
Fleshing out the details of the solution and testing it before implementation	Oct 2014	First prototype of tool completed	The first complete version of the tool, known as the matrix-based multi-project management model (abbreviated as M4), was created.
	Jan 2015	Replanning the original NPD projects	The initial 12 projects were replanned using the proposed M4 tool. This process involved restructuring the projects and balancing resources, with the intent to significantly improve the KPIs.
	Apr 2015	First 12 NPD project completed	After 475 days ♠, the first multi-project effort was completed, confirming the validity of introducing the M4 tool—a new matrix-based planning technique—over the template-based approach currently utilized in corporate practice.
	Apr 2015	Simulations for new 13 NPD projects	We conducted simulations on both template-based and matrix-based planning techniques for 13 new NPD projects, reaffirming the effectiveness of the developed tool in improving the company's KPIs.
Implement and evaluate the solution	May 2015	Commencement of 13 new NPD projects using M4	Telemat began its next set of NPD projects and implemented the design solution (M4) to reconfigure its NPD processes.
	Oct 2016	End of the 13 NPD projects	The designed (M4) tool functioned as expected in Telemat's project management practice, demonstrating its adequacy.
	Jan 2018–Dec 2019	Validity checks through 10 new NPD projects on the M4 tool	We conducted additional validity checks by assessing the durability of the M4 tool implemented. As a result, the tool demonstrated its efficacy in corporate practice by delivering the expected KPIs, while also contributing to a less tense work environment for engineers. As part of the DSR process, a cost-benefit analysis was also conducted, indicating a rapid payback time for the investment in the tool and corresponding management practices.
Specify the learnings arising from the solution designed & implemented	Oct 2014–Apr 2020	Semi-structured interviews	Across the entire research cycle, 20 semi-structured interviews were conducted to delve deeper into the experiences and perspectives of project managers, as well as to evaluate the long-term impact of the M4 tool at Telemat. In 2020, these data were analyzed to track and understand the learning experiences for Telemat's managers.

♠ Following Telemat's conventions, NPD duration is calculated in terms of seven days per week and four weeks per month.

Table 2
Duration of an example NPD project at Telemat (duration in work hours).

Phases	Activities	ID	Duration
Phase 0	NPA	A	1
	Developing the Concept	B	42
	Quotation from suppliers	C	3
	Production Concept	D	2
	Offering Price	E	2
	Sum		50
Phase 1	Developing Specification	F	160
	BOM-making	G	20
	Sum		180
Phase 2	Mechanical Engineering	H	135
	Hardware Development	1	64
	Software Development	J	130
	Suppliers Nomination	K	32
	DV/PV test list	L	7
	DV tests	M	40
	DV2 tests	N	2
	Drafting	0	16
	Production Planning	p	44
	Tool Series Start	Q	10
	Sum		480
Phase 3	Production lnstallations	R	48
	PV tests	S	50
	PV2 tests	T	10
	PV3 tests	U	2
	FDPR	V	80
	Sum		190
Phase 4a	SOP	W	50
	Sum		50
Phase 4b	Achieve Optimum Cycle Time	X	50
	Sum		50

Explanation of key terms: BOM = Bill of Materials, DV = Design Verification, FDPR = Full Day Production Run, NPA = New Product Architecture, PV = Product Validation, SOP = Standard Operating Procedure.

Table 3
Summary of the NPD data sources used.

Term	Description	Data source
Task	Task name and task ID.	The employed project template from the ERP system.
Precedence structure	The precedence of task occurrences within a project.	The employed project template from the ERP system.
Occurrences of tasks and projects	The relative frequency of task and project occurrences.	ERP system.
Task (and project) durations, cost and resource demands	The tasks, durations, costs, and resource demands of 48 former project runs that utilized the ERP system from 2008 to 2013.	Previous completed projects from the ERP system.
The four moments and the median of task durations and demands.	The four moments (mean, standard deviation, skewness, kurtosis) are employed in curve fitting, while medians are used in scheduling the tasks in later projects.	Task demands from previously completed projects, stored in Excel and calculated by Matlab.
Scheduled project duration and demands	Based on the medians, minimum, and maximum task demands, along with precedencies, the most likely, optimistic, and pessimistic scenarios of project schedules are calculated.	The medians, minimum, and maximum values of task demands from previous projects. managed in project planning software.
Simulated task demands	Using the four moments, curve fitting was employed to predict the empirical distribution of task demands. Subsequently, 1000 runs were conducted to determine the potential task demands based on the predicted empirical distribution.	Stored in Excel, calculated by Matlab.
Expected number of bursts	Based on the 1000 runs, (1000) project schedules and resource allocations were conducted both without and with the use of M4 methods. The number of bursts represents the occurrences of resource overruns.	Stored in Excel, calculated by Matlab.
Real number of bursts	Based on the realized project schedule, the real number of bursts refers to the actual occurrences of resource overruns during the project implementation.	ERP system, project planning software.
Expected project duration and total direct costs	Based on the 1000 runs, the project duration and total direct costs were calculated both with and without using the M4 method. The expected duration and total direct costs represent the most likely outcomes among the durations and costs observed in the 1000 runs.	Stored in Excel, calculated by Matlab.
Real project duration and real total direct costs	The real project duration represents the actual time taken for the implementation of the project, while the total direct cost denotes the actual expenses incurred during this implementation.	Implemented projects using the ERP system and project planning software.

departments and roles (i.e., 4 project managers, 4 testers, and 4 programmers), each taking about 90 min. The researchers moderated these discussions and recorded the main points. Four focus group sessions were held in January 2014.

Subsequently, we conducted technology reviews to evaluate the existing (e.g. software) tools that the company uses for project planning, scheduling and risk management. That is, the features, functionalities and limitations of these tools as well as their compatibility and integration with other systems were evaluated. These reviews were done by interviewing the technology providers and users as well as testing the tools themselves. The technology reviews were completed by June 2014.

After completing the focus groups and technology reviews, we presented and discussed the main findings and recommendations with company representatives in a workshop in early July 2014 (which completed the first DSR stage).

Two subsequent workshops later in July 2014 served to brainstorm and generate ideas for improving project planning, scheduling and risk management. Subsequently, six problem solving sessions were conducted to co-create solutions for project planning, scheduling and risk management with company specialists. Each of these sessions involved six participants, each with extensive experience and expertise in project planning, scheduling and risk management. The six sessions were held in August 2014.

Together, these various data sources informed the efforts to design a solution (in the form of a process technology tool for managing multiple projects). The first prototype of this solution served to estimate the resources, time requirements and priorities for future projects. These estimations used various methods such as expert judgment and analogous reasoning as well as parametric and bottom-up calculations. Two of the authors of this paper did the estimations, in consultation with several company specialists. For the estimation four moments of the distributions of the task demands from the previous runs were applied. The four moments characterized well with the empirical distributions of the task demands. The first complete version of the tool was available in October 2014. This tool was validated using Monte Carlo and discrete-event simulation methods. With using the four moments from the empirical distribution of the task demands was used to generate simulated task demands with Pearson's distribution family with using Matlab. The generated and the empirical distributions was compared by Kolmogorov-Smirnov test. Medians of the task demands applied as the outcome of the simulation, which were validated with company specialists.

In subsequent years, 20 semi-structured interviews were conducted to collect more in-depth data on the experiences and opinions of project managers as well as the long-term impact of the tool developed and implemented at Telemat. These interviews were based on a limited number of open-ended questions. The average duration of these interviews was about 45 min. In addition, we also obtained all relevant project data from Telemat on 10 NPD projects conducted from January 1st' 2018 to December 31st' 2019. These data served to evaluate the durability of the implemented solution.

4. Findings

4.1. Diagnosing and defining the problem

Telemat originally used a fixed project management template, with 24 tasks and 5 main phases (see Table 2 in section 3.2). When we started this study at Telemat, at least 4 projects were highly interdependent and were processed simultaneously, without their dependencies being defined. These projects drew to a large extent on shared human resources, such as testers and programmers (e.g. a programmer in one project was a tester in another project), resulting in peaks in resource demand and major delays in completing NPD projects (see Fig. 1). In one of the focus groups conducted, a software project manager observed: "Resource allocation has been a nightmare. Our programmers and testers are overloaded with work, leading to delays and quality issues" (focus group, January 10, 2014). Participants in another focus group (January 10, 2014) reflected as follows: "The lack of defined

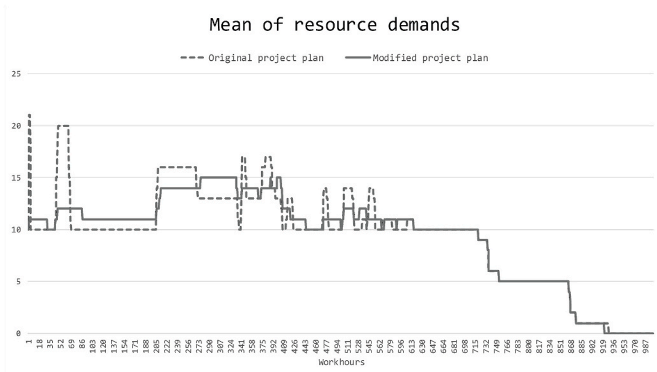

Fig. 1. Mean resource demands for Telemat's NPD project A.

dependencies between projects has created significant bottlenecks; we need a more flexible development process to adapt to priorities and interdependencies" (project manager); "switching roles between projects is exhausting; one moment I'm coding, next I'm testing someone else's work, which makes it difficult to maintain focus and productivity" (programmer); "the peaks in resource demand are overwhelming, we need a more balanced approach to resource allocation to avoid these crunch times" (tester).

Table 4 provides an overview of the 12 projects conducted in 2014–2015, in terms of their start time, project duration, and total cost in terms of human resources. For all 12 projects together, it took 464 days and more than 2.1M Euro to complete them. Telemat's problems in this area could possibly be remedied with a multi-project management approach, but Telemat's project managers were not familiar with such an approach, as observed in one of the focus groups: "Shared resources are a double-edged sword. While they offer flexibility, they also create competition for time and attention, which hampers overall progress. The interdependencies between projects are not adequately planned, leading to significant delays; we therefore need a more integrated approach" (project manager, focus group, January 10, 2014). To help solve this pressing problem, Telemat turned to experts at a local university, including one of the authors of this paper.

In January 2014, we started using a simulation method to demonstrate how resource demands and project durations can accumulate as a function of the corresponding task demands (i.e., costs/resources and time). The experience of Telemat employees with deep knowledge about core NPD processes and activities was critical here: they helped specify the minimum and maximum boundaries of the (human resource) demands as well as the expected time to completion of each project. The importance of these experiential data was emphasized by a software project manager: "Having clear parameters based on past projects means we can focus more on quality and less on firefighting; it would be a game-changer for our productivity" (multi-project manager, Technology Review March 11, 2014). An example is the duration times of project A, estimated by six experienced engineers (i.e., 4 programmers and 2 testers), displayed earlier in Table 2. One can reasonably assume that the demands here follow a β distribution (with p values denoting the relative frequencies of task completions and dependencies). We further validated the estimates obtained from Telemat's engineers by performing 1000 simulation runs, in which expected task durations and cost demands were calculated. The parameters of the distribution were governed by the distributions of the previous runs (regarding time, cost and resource data). For the simulation, we used the mean, standard deviation, skewness, kurtosis of the empirical distributions, and then generated the values based on Matlab's Pearson distribution family (Willink, 2009). This family of distributions can also involve exponential, normal and gamma distributions. The distributions generated with four moments (i.e., mean, standard deviation, skewness, kurtosis) showed a β distribution in most cases. We tested these distributions with the Kolmogorov-Smirnov test. In all cases, these tests showed that the generated and empirical distributions were not significantly different from each other. This served to generate more robust estimates of project durations and costs for each project as well as the complete set of 12 NPD projects (see line 2 in Table 7). After these 12 projects were completed in April 2015, we conducted an ex-post analysis by comparing the expected and realized task durations and resource demand costs (see lines 2 and 4 in Table 7). This analysis showed the difference between the expected and realized outcomes regarding both total project time (TPT) was less than 1%. Moreover, the expected and realized time and cost demands at the task level were significantly different ($p < 2e - 12$) in only five of the 292 tasks. Overall, we concluded that the various estimates provided by experienced NPD professionals provide a reliable source of information.

Table 4
List of the multiproject elements.

Elements -Projects	Project Duration (in days)	Start 0 = 01/06/14	Total human resource costs (EUR)♣
Project A	124	2	175, 654
Project B	125	15	176, 002
Project C	135	46	178, 786
Project D	141	100	182, 461
Project E	105	145	168, 247
Project F	114	184	171, 523
Project G	109	205	171, 682
Project H	152	221	188, 781
Project I	141	257	182, 642
Project J	155	279	189, 901
Project K	112	321	170, 047
Project L	97	367	166, 551
Multi-project total	**464**	**2**	**2, 122, 277**

Notes: ♣ The maximal value of resource demands within a multi-project is 10. The values for the multi-project duration and total cost are also displayed in line 1 of Table 7.

One of the main problems with Telemat's project management approach was that it focused on each project separately, instead of managing a large number of projects simultaneously. As a multi-project manager observed in one of the workshops: "Managing multiple projects simultaneously requires a strategic overview that is missing when each project is treated in isolation. The current approach makes it hard to prioritize tasks and manage dependencies effectively. We need a more integrated project management system to handle the complexities of multiple interrelated projects" (workshop July 14, 2014). Whereas such an approach is viable for managing a small number of (completely decoupled) projects, applying it to managing a large number of interdependent projects in a corporate environment with limited human resources is problematic. In the latter setting, an exclusive focus on the individual projects makes the entire NPD effort overly sensitive to small delays that escalate into major bursts, as shown in Fig. 1. In this respect, the templates used by Telemat (as its operating routine in NPD management) enabled such bursts to occur simultaneously. An analysis of the simulation data served to detect project overruns (overtime) in 954 of all 1000 simulations. The mean maximum values for resource demand was almost 29 percent higher than the planned maximum demand. Based on the estimates of experienced engineers, we inferred that the simulations could detect bursts, but did not directly improve multi-project management practice.

Having identified this complex problem, which threatened Telemat's ability to create value for its customers, Telemat's management *sensed* the need to explore novel knowledge by leveraging external expertise (Teece, 2007; Hullova et al., 2019), via the researchers already involved.

4.2. Conceive of alternative design solutions and select the most promising one

Agile project management methods have become widely used, as a tool countering the downsides of traditional planning methods (Serrador and Pinto, 2015; Conforto et al., 2014; Wysocki, 2009). Agile methods are especially used to manage all tasks and projects independently, while facilitating their parallel and simultaneous accomplishment (Fan et al., 2012). The agile approach is mainly used for developmental projects, such as in software (Kettunen, 2009; Dingsøyr et al., 2012), NPD (Fekri et al., 2008; Rahimian and Ramsin, 2008) and R&D (Pillai et al., 2002; Yang and Fu, 2014). Agile methods that draw on Scrum (Schwaber, 1997), Kanban (Hiranabe, 2012) and Scrumban (Ladas, 2009) serve to respond to quickly changing organizational and customer requirements; this involves rapid sprints (Ladas, 2009) that split a large project into smaller parts. Scrum limits the duration (2–6 weeks), while Kanban limits the number of parallel tasks, so-called work-in-progress (WIP) activities. Scrumban combines Scrum and Kanban techniques to fit the nature of the project. However, agile methods do not effectively address repetitive tasks and do not utilize the experience of project managers in their resource estimations (Miller, 2013).

The problem at hand, influenced by task dependency structures and the partial sharing of resources across parallel projects, shares similarities with both multi-box packing (Ragland, 1973; Sun et al., 2005; Dai et al., 2021) and resource-constrained multi-project scheduling problems (Sánchez et al., 2023). However, it diverges from both, due to the presence of fixed and flexible dependencies among tasks and projects. Additionally, specific tasks may be mandatory, optional, or subject to postponement across projects, based on (changing) priorities. Moreover, not all resources can be shared among parallel projects.

We therefore conducted an extensive literature review, which served to identify the project domain matrix (PDM) approach. The PDM approach appears to use project templates and manages time, cost and resource demands through a flexible project plan (Kosztyán et al., 2023). In this approach, the probability of task occurrence and the dependency between two tasks is estimated from data available in former project plans. The exact project ranking algorithm then selects the most desired, shortest or least expensive single project (Kosztyán, 2015). The result of the evaluation is a consequence of binary decisions on each supplementary task to either include or exclude it. In addition, a binary choice is made to include or exclude each flexible dependency.

Moreover, flexible matrix-based planning models and methods can be used to support the agile approach (Kosztyán, 2015). PDM is organized into what are known as domains (also termed submatrices), where the initial domain is the Logic Domain, the diagonals of which represent the task completion score. If the value of an element corresponding to a given task is 1 (e.g., in Table 5–a see tasks B_1, A_2 and D_2), then the task is mandatory; otherwise, it is supplementary. The score value is related to the priority level for the task, that is, its importance for achieving the project goals. The project scope lists specific project goals, deliverables, tasks, costs and deadlines. If a supplementary task (i.e., a task with a diagonal value less than 1; see in Table 5–a the tasks A_1 and C_1 of Project 1) is excluded from the project, then its time, cost and resource demands are also excluded; therefore, missing tasks reduce the scope of the project. Thus, one has to find the tradeoff between the time/-cost/resource demands and the scope of the project. Out-diagonal values symbolize the dependency score. If this takes a value of 1 (e.g., in Table 5–a the value between task B_1 and task C_1), then it depicts fixed dependency; otherwise, it captures flexible dependency (e.g., in Table 5–a the value between task A_2 and task D_2). In this way, managers can decide to disregard the fixed dependency to parallelize task completions or exploit it for the sake of serial completion, to temporarily save on resources and avoid peaks in resource demand. Parallel (serial) completion reduces (increases) project duration; however, the top resource requirement might then be greater (smaller).

Table 5 gives an example of extending the PDM to manage multiple projects. Table 5a shows that the extended PDM is a matrix-based template for managing multi-projects. We call this tool *M4*, a Matrix-based Multi-project Management Model. In M4, the logic domain contains all domains for each single project. There are two (sub)projects in the example presented in Table 5. The first letter indicates the task ID, and the number represents the project number. Multiple projects can require the same tasks (see Tasks A_1 and A_2, where both the task ID and the time/cost/resource demands are the same), but a project can also require other sorts of tasks (e.g., see Task D_2) with different time/cost/resource demands. Usually, in the case of multiple projects, there is no logic dependency between tasks coming from different projects, but M4 can be set in such a way that this is allowed. The time, cost and resource domains are also shared because they can use common resources (e.g., resource 2 in Table 5–a and are funded from a single budget. Therefore, at the multi-project management level, M4 serves to plan and schedule the multiple simultaneously running projects. While Table 5–a presents a flexible multiproject plan, Table 5–b depicts a possible result of a decision in which every supplementary task and flexible dependency are included in the project plan. According to the planned start of the (sub) projects (see date-of-start domain in Table 5) and the decision on which tasks should be completed in which order, the PDM matrix can be separated for the project managers (as in Table 5–b). The M4 and PDM matrices are seamlessly linked to each other, to enable changes to be tracked and the remaining multi-project tasks to be rescheduled or reorganized if necessary.

As such, M4 is the first multi-project template for planning and scheduling flexible projects. Without specifying all possible multi-project plans regarding the given constraints and target functions,

Table 5
Matrix-based multiproject management model (M4).

(a) Original multiproject template

M^4	Logic Domain: Project 1: A_1	B_1	C_1	Project 2: A_2	D_2	Time Domain	Cost Domain	Resource Domain: Resource 1	Resource 2	Resource 3	Date of start
A_1	.8	.8				4	4	1	3		1/1/2017
B_1		1	1			2	1	4	1		
C_1			.6			1	3	4	1		
A_2				1	.8	4	4	1	3		8/1/17
D_2					1	1	3		1	1	

(b) Proposed project templates

PDM	Logic Domain: Project 1: A_1	B_1	C_1	Time Domain	Cost Domain	Resource Domain: Resource 1	Resource 2	Date of start
A_1	X	X		4	4	1	3	1/1/2017
B_1		X	X	2	1	4	1	
C_1			X	1	3	4	1	

PDM	Logic Domain: Project 2: A_2	D_2	Time Domain	Cost Domain	Resource Domain: Resource 1	Resource 2	Resource 3	Date of start
A_2	X		4	4	1	3		8/1/17
D_2		X	1	3		1	1	

optimal multi-project plans can be selected with Kosztyán (2020)'s algorithm. In addition, project plans for multi-projects can also be submitted to project managers. Project managers then follow the project plan and register the progress and compliance (i.e., backlogs) of the project. Despite the decision to include or exclude all flexible tasks and dependencies, a deep understanding of the flexibility of the remaining tasks and dependencies helps to replan the remaining part of the multi-project effort as well as any remaining projects.

4.3. Fleshing out and testing before implementing the selected design solution

In January 2015, based on our estimations, the 12 projects were replanned using M4 to demonstrate the reduction in resource demands relative to those given by the former templates. First, each project was restructured, and resources were balanced at the same time (see the solid line emanating from the simulation results in Fig. 1). The project structures were reorganized to specify sprints (of 2–6 weeks); see, for example, the changes in Project A's Phase 2's plan in Table 6 and the changes in the entire project plan in Appendix A (cf. Ta 11 and 12).

The unequally sized components in terms of the number and duration of tasks (see Table 12 in Appendix A) suggested that the firm should follow the Kanban methodology, which allows for sprints longer than 5 weeks. Second, based on expert estimations, the duration of the projects and the entire multi-project effort were recalculated. Hence, the two types of resource balancing (i.e., template-based and matrix-based plans) could be compared. Fig. 1 shows the reduction in resource demands for Project A when M4 is used. After running 1000 simulations, the results were compared with the results of the previous template-based simulations. The mean resource demands decreased by more than 28% (from 21 to 15 resource groups). As highlighted in lines 2 and 3 of Table 7, implementation of M4 would have successfully decreased resource costs by 16%, its project duration (TPT) by almost 10% from 471 to 425 days, and would have practically eliminated the occurrence of bursts (from 27 to 1).

Starting in May 2015, Telemat intended to launch 13 new (interdependent) NPD projects, utilizing the proposed M4 tool (as indicated by line 5 in Table 7). This initiative prompted us to conduct simulations in April 2015 to compare the old and new planning techniques. Because the estimations of experienced project managers (for the task durations and the cost of human resources) proved to be accurate, the simulations indicated the real multi-project durations and cost of human resources for both the template-based and matrix-based planning techniques (see lines 6 and 7 of Table 7). As in the first phase of the DSR cycle (section 4.1), the simulations served to detect bursts (28/1) and overbudgets. As a result, the M4 tool accomplished reductions in real costs (from more than 3, 1M to 2,6M EUR) and total project time (from 547 to 517 days), which helped Telemat's management meet its KPIs.

Thus, the deployment of the M4 template, as a pre-implementation effort toward modeling with real company data, demonstrated its

Table 7
Summary of planned/simulated multi-projects (TPT: Total Project Time).

Multiproject	Planning Technique	TPT (days)	Costs♣ (EUR)	Bursts (occurrences)
1 Plan (01/14-04/15)	Template-based	464	2, 122,277	0♠
2 Simulation	Template-based	471	2, 214, 163	27
3 Simulation	Matrix-based	425	1, 851, 199	1
4 Actual (01/14-04/15)	Template-based	475	2, 220, 568	27
5 Plan (05/15-10/16)	Matrix-based	511	2, 613, 262	0♠
6 Simulation	Template-based	547	3, 114, 435	28
7 Simulation	Matrix-based	517	2, 620, 002	1
8 Actual (05/15-10/16)	Matrix-based	520	2, 710, 451	1

Notes: ♣ In this case, the costs equal the total cost of human resources. ♠ Zero is not a realistic value due to problems with project extrusions.

Table 6
Original and revised development processes of Telemat.

(a) Original process in PDM (logic domain) matrix

		H	I	J	K	L	M	N	O	P	Q	
Phase 2	Mechanical Engineering	X	X	X								H
	Hardware Development		X									I
	Software Development			X								J
	Suppliers Nomination				X	X						K
	DV/PV test list					X						L
	DV tests						X		X			M
	DV2 tests							X				N
	Drafting								X			O
	Production Planning									X	X	P
	Tool Series Start										X	Q

Dependency

(b) Revised process

H	I	J	K	L	M	N	O	P	Q	
1	.9	.9								H
	.8									I
		.8								J
			1	1						K
				1						L
					.6		1			M
						.1				N
							1			O
								.9	.7	P
									1	Q

Sprint

Rel. freq. of dependency

Relative frequency of task occurrence

Notes: DV/PV = Design Verification/Product Validation.

efficacy for both old and new NPD projects by creating substantive performance improvements for Telemat.

These seizing efforts (in DC jargon) also involved fleshing out and testing the designed tool before implementation. In this respect, Telemat's management acknowledged that the M4 design solution has the potential to catalyze the structural rearrangement of Telemat's operating routines (Magistretti et al., 2021; Zollo and Winter 2002) in the area of decision-making and planning protocols for NPD projects, thereby enhancing the company's KPIs.

4.4. Implementing and evaluating the outcomes of the design solution

Following the previous step, Telemat implemented the M4 tool as of May 2015, thereby reconfiguring its NPD project management processes, in terms of its core structures, procedures, and decision-making protocols (Subramanian et al., 2011; Teece, 2007). Line 8 in Table 7 displays the results for the second period. Compared to the earlier simulation results (line 7 in this table), the project duration and resource demands remained almost identical, with only 0.6% and 3.5% increases. Looking at the results of the simulated template-based option, reported in line 6, the application of M4 appears to decrease both TPT and total costs – by 5% and 13% respectively.

Hence, the M4 tool performed well in terms of the KPIs used within Telemat, thereby demonstrating its effectiveness (Romme and Holmström, 2023; Schulze and Brusoni, 2022), as also emphasized in the DC literature (Drnevich and Kriauciunas, 2011; Pezeshkan et al., 2016; Zott, 2003). Nonetheless, further validation checks were deemed necessary to comprehensively evaluate the effectiveness of the design solution (Lager and Simms, 2023).

4.4.1. Additional validity checks

We conducted additional validity checks by assessing the durability of the M4 tool implemented as well as performing a cost-benefit analysis. Amit and Schoemaker (1993) observed that the durability of capabilities is a desirable characteristic that contributes to their rent-producing capacity. We therefore sought to assess the durability of the implemented solution in terms of its process- and performance-related effects. During the period between January 1st' 2018 and December 31st' 2019, Telemat completed 10 projects simultaneously, supported by the M4 method. Table 8 shows the planned and real durations and total cost of human resources as well as the number of bursts. Both the realized timeframes and the costs are very similar to the estimations, and most importantly, the bursts are negligible in terms of both frequency and size, which further underpins the efficacy of the M4 tool. M4 thus appears to have boosted the company's performance in the area of NPD resource management. A Telemat manager observed: "This new method made our lives much easier; now, we are capable of better controlling costs, time, and human resources, and the work environment is less tense, which also reduces the chance that discontented engineers leave our firm".

We also conducted a cost-benefit analysis, because "changing routines is costly" (Teece, 2007, p. 1335; see also Arend and Bromiley, 2009; Danneels, 2012). A cost-benefit analysis of the entire effort toward M4 was therefore needed. Because the interdependencies between projects did not pertain to (the cost of) materials, only the real wage costs of the involved researchers and Telemat managers were included here. As such, Table 9 shows the hours per activity and the related wage costs for developing and implementing the M4 solution, accumulating to a total of almost 21K Euro. Telemat's cost savings arising from the solution, over nearly two years, amounted to more than 403K EUR. This implies a rapid payback time for the capability investment in the M4 tool and associated practices.

4.5. Key learnings for Telemat's managers

Finally, we collected data on the major learning points for Telemat in this DC deployment process. The achievement of effective learning and knowledge sharing is of paramount importance from both the DC perspective (Barreto, 2010; Zollo and Winter 2002) and the DSR lens (Hevner et al., 2004; Romme and Holmström, 2023). The following quotes from interviewees illustrate the key learnings for Telemat's managers:

> "Since we implemented the M4 method, our operational routines have changed significantly. We can now plan and schedule our projects more efficiently and effectively, and avoid unnecessary delays and costs." (*NPD engineer*)

> "The M4 method helped us to learn how to estimate and simulate our projects more accurately and realistically, based on the data from previous projects and the input from our experts. We can now better manage the risks and uncertainties that may arise during the project execution." (*project manager*)

> "The M4 method has enabled us to achieve higher performance and quality in our multi-project management. We can now coordinate and allocate our resources more optimally, and reduce the bursts and overbudgets that used to undermine our productivity and profitability." (*multi-project manager*)

Additional learnings and benefits involve improved communication practices arising from how the tool was developed:

> "The M4 method taught us how to collaborate and communicate more effectively with our stakeholders, such as academic researchers, technology providers and customers. We now involve them more actively in the project planning, scheduling and risk management processes, and more easily obtain their feedback." (*NPD engineer*)

> "The M4 method improves our capability to adapt and innovate in our project management practice. I now use various tools and techniques to solve specific problems or scenarios related to project

Table 9
Calculated duration and costs of the M4 introduction.

Activity	Duration (hours)	Costs (EUR)
Research activity	191.0	9087.78
Literature review	74.0	3520.92
Empirical analyses	117.0	5566.86
Planning	12.0	4800.00
Preparation	4.0	1600.00
Planning	8.0	3200.00
Training	27.5	6458.40
Preparation and completion of study material	23.0	3291.30
M4 training	4.5	3167.10
Closure	2.0	469.20
Final meeting	2.0	469.20
Total for M4 project introduction	*232.5*	*20,815.38*

Table 8
Post hoc analysis of M4 method over two years.

Company	Number of Projects	Planned			Real		
		TPT (days)	Bursts (occur.)	Cost (EUR)	TPT (days)	Bursts (occur.)	Cost (EUR)
Telemat	10	693	0	2,329,414	711	1	2,332,196

management and generate new ideas for improvement." (*project manager*)

"The M4 method has increased our confidence and satisfaction in running development projects. (…) We can now more effectively control the costs, time, and human resources of these projects and create a less tense and more enjoyable work environment for ourselves and our colleagues." *(multi-project manager)*

Finally, Table 10 provides an overview of key insights arising from the implementation of M4, which sheds light on the evolving capabilities of key employees and the corresponding shifts in Telemat's operational routines in managing projects (at two levels) and their scarce resources.

5. Discussion and conclusions

In this section, we first discuss the contribution this study makes to the literature and subsequently explore various methodological implications.

5.1. Contributions to DC theory

Also inspired by Schön (1984) quote at the beginning of this article, we adopted a DSR approach (Romme and Holmström, 2023) to design, test and implement a tool that would help the focal company's decision makers to more effectively manage a large number of interdependent and simultaneously processed projects. As such, our study also responds to those calling for studies that decouple efforts to build the DC to methodically address and solve organizational problems (Ferreira et al., 2020) from measuring the company's long-term performance and viability—as a key outcome of such efforts (Michaelis et al., 2021; Wang, 2007; Wheeler, 2002). That is, the study reported in this paper applies a DSR approach to deliberately create and implement such a capability.

Our study also demonstrates how DSR enables researchers and practitioners to jointly develop knowledge that is grounded in DC theory but also is practically useful. In other words, it demonstrates how (innovation) management scholars can step out of their comfort zone and become highly relevant to management practitioners (cf., Dimov et al., 2023; Romme and Holmström, 2023). In doing so, this study also responds to calls for investigating how DCs are actually created (Kay et al., 2018), and more specifically how management scholars can help create and shape a DC. We answered the latter question by applying a DSR approach to a major challenge in the area of simultaneously managing a large number of interdependent new product development projects. The DSR cycle employed is as follows (see section 3): (a) diagnosing and defining the key problem; (b) conceiving alternative design solutions and selecting the most promising solution; (c) fleshing out the details of the design solution and testing it before implementation; (d) implementing and evaluating the outcomes of the design solution; and (e) specifying the type of (DC and other) learnings that arise from the implemented solution, particularly for the practitioners involved.

This research cycle resonates well with the well-known three clusters of DC development identified by Teece (2007), described in more detail in section 2: sensing opportunities (step 1 above), seizing these opportunities (steps 2 and 3), and reconfiguring intangible and tangible assets (step 4). As observed in section 2, this typology of DC microfoundations is primarily used in the DC literature to describe and theorize about capabilities, rather than to actively co-create such capabilities. In fact, the DSR cycle outlined above turns this threefold perspective on DCs into a more elaborate methodical approach for scholars and practitioners co-creating solutions for specific organizational problems.

Accordingly, we operationalized the key mechanisms of Teece's three DC clusters into five DSR activities (outlined above) that together inform the design and implementation of a tool that supports a micro-DC. In this respect, practitioner-academic collaboration appears to facilitate the identification and diagnosis of major (e.g., project management) performance issues; but without the engagement of scholars (as outsiders), the company's managers may not *sense* such a performance problem at all, or (without a detailed analysis by external experts) accept it as an inevitable and unsolvable problem and therefore fail to *seize* the opportunity to substantially improve performance in this area. Fig. 2 visualizes the synergy between the DSR cycle and the three DC clusters of sensing opportunities, seizing opportunities, and reconfiguring assets.

Moreover, our study also implies that *seizing* an opportunity for enhancing the company's DCs requires a strong commitment to methodical research. Earlier studies of DCs have also emphasized rationality and analysis, but exclusively did so by using mathematical simulations to study and understand the development of DCs over time

Table 10
Learnings and lessons from M4 implementation at the project and multi-project levels (EN refers to NPD engineer, PM to project manager, and MM to multi-project manager).

Project level	Multiproject level
What key employees have learned and what they are capable of achieving?	
• Archive entire project plan, including logic plan and demands, for later reuse by PMs • Tracking alone is insufficient at the project level; replanning and project reorganization by PMs are necessary if needed • PMs can establish priorities based on the relative frequencies of task completion and flexible dependencies • Through reorganized project plans, PMs are capable of helping to meet deadlines while avoiding bursts	• Merely coordinating at the multiproject level is insufficient; active tracking and, if necessary, reorganization are required by MMs • If necessary, multiproject plans should be reorganized by MMs to meet deadlines while avoiding bursts
How it benefits the individual work by key employees?	
• Increased efficiency in work for PMs and ENs • Assignment of personalized tasks for PMs and ENs • Enhanced project-level decision making and resource management by PMs • Improved coordination between PMs and Ens	• System-level perspective for MMs • Improved multiproject-level decision making and resource management by MMs • Enhanced coordination between MMs and PMs
What has changed in Telemat's operational routines?	
• Plans have transitioned from static to dynamic • Reduction in overworking time • Increased flexibility in project plan reorganization	• Utilization of simulations to analyze plan risks from inception to execution • Continuous improvement of resource allocation

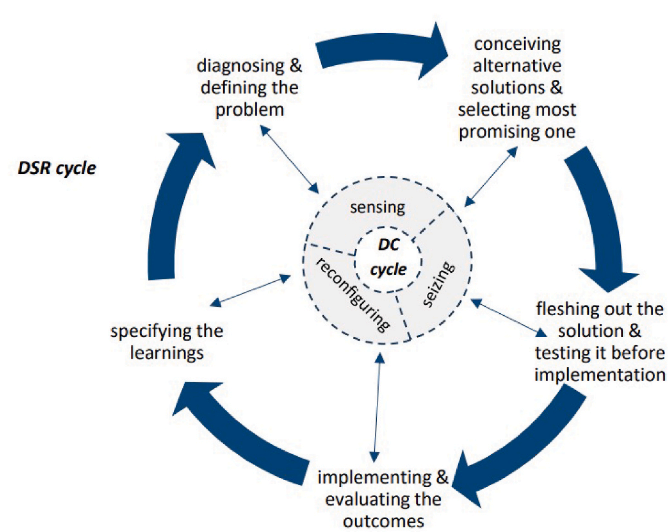

Fig. 2. The synergy between the DSR cycle and the DC cycle.

(Romme et al., 2010; Zott, 2003). In our study, we applied simulation methods to analyze a company's (project management) performance issues and subsequently develop a solution that helps solve these issues (cf., Hutton et al., 2021).

In terms of *reconfiguring* the company's assets, our study suggests that additional micro-foundations of DC involve an ongoing practice of dialogue and coordination among the project managers, engineers (in the various project teams) and researchers involved (Augier and Teece, 2009; Teece, 2007); that is, their distinct thinking dispositions may have to be deliberately aligned (Helfat and Peteraf, 2015) to provide a common language that everyone understands. This resonates with earlier studies that observed that sustained collaboration and dialogue (as a microfoundation) is critical for honing the firm's evolutionary fitness (Helfat et al., 2007; Teece, 2007), especially when it takes a substantial period of time to get from sensing an opportunity to capturing it by reconfiguring core processes.

Finally, as observed in section 2, studies of DC often suffer from tautological issues. Magistretti et al. (2021) therefore called for longitudinal empirical work that is not only informed by design thinking, but also controls for the condition of 'rigorous exogeneity' (Stadler et al., 2013). The latter condition implies that a DC must be distinguishable from the outcomes obtained. The DSR cycle outlined earlier, as a generic DC development methodology, clearly fulfills this condition: as a methodical process and capability, it is completely decoupled from (measurements of) the company's long-term performance. DSR thus appears to systemically connect the high ground of DC theorizing and the swampy lowland of how practitioners attempt to grow their organizations' dynamic capabilities—using Schön's (1984) terminology.

5.2. Managerial implications

Our results have several implications for practitioners. The most important implication is that we translated DC theory into a practical research cycle, informed by the DSR literature (see section 5.1). The latter research cycle enables a systematic process (Ferreira et al., 2020) while adopting a design lens and focusing on problem-solving (Romme and Holmström, 2023), which aligns well with the managerial jargon used in large companies. This DSR cycle provides a practical step-wise approach that translates the activities of sensing, seizing and reconfiguring in ways that resonate well with how practitioners think and operate. Another takeaway for practitioners is that creating and deploying DCs is an arduous process, one that requires stamina and sustained managerial attention. That is, DC development does not fit the kind of short-cycled interventions and changes prevailing in many companies.

More specifically, these two implications can be combined and operationalized in the following guidelines for collaboration between management practitioners and scholars on DC challenges:

- Creating and sustaining DCs require a *dedicated effort* across multiple years, one that the managers and scholars involved have to fully commit to. If the company's top managers prefer a quick (off-the-shelf) solution, they are better off by hiring a consultant.
- Developing a company's DC often is a daunting and extremely complex task. It therefore is important to transform the generic DC construct into *digestible* pieces (e.g. developing a novel multi-project management practice; or redesigning the company's strategy meeting protocol). This enables a focus on specific artifacts, informed by DSR.
- It is also important to *embrace iteration* (see Fig. 2), that is, refine the artifact through repeated feedback loops, ensuring it meets the needs of the practitioners involved and respects practical (e.g. resource) constraints. In this respect, the quality of the final artifact delivered in a DSR project is not determined by the quality of the first prototype, but by the number of careful iterations that serve to adapt and improve the initial artifact into a final one.

5.3. Limitations and future research

This study focused on creating a DC as a collaborative effort by practitioners and scholars, one that complies with the rigorous exogeneity condition (Magistretti et al., 2021; Stadler et al., 2013). As a result of this focus on capability building, we did not study the outcomes in terms of Telemat's long-term viability and performance. While we did evaluate the direct outcomes of the M4 tool (also regarding how it changed the company's operating routines in NPD project management) developed, we have not assessed its contribution to Telemat's evolutionary fitness (Gelhard et al., 2016; Teece, 2007).

Moreover, various conditions and contingencies were not addressed in our study. For example, constraints on management attention as well as internal political games might make a DC development process fail elsewhere. A promising path for future work therefore is to merge research on managerial attentional engagement (Ocasio, 2011; Nicolini and Korica, 2021), dynamic managerial capabilities (Adner and Helfat, 2003; Helfat and Peteraf, 2015; Huy and Zott, 2019), and the employment of DC as explored in this study.

A limitation of the DSR approach adopted is that it is highly sensitive to the availability of data (regarding NPD projects in our case). Both the modeling and optimization processes heavily rely on high-quality data, and the absence of such data significantly affects research outcomes. Therefore, one needs to be cautious and meticulous in collecting data, also by checking the availability and accessibility of the data in initial discussions with various managers in the focal company. If data are not available or accessible (e.g., for confidentiality or privacy reasons), the type of study reported in this paper cannot be done.

Regarding the M4 tool, a more specific constraint arises from the implicit assumption that it does not matter which (group of) engineers are assigned to specific NPD tasks, because the latter are assumed to be highly similar. These engineers are, thus, conceived to be somewhat interchangeable across different projects. However, this assumption may not be valid for a broad range of NPD tasks. A related limitation involves the freedom to restructure tasks. The M4 solution apparently works best if a company can decide freely on how to schedule its tasks. Any interference from the outside, demanding that certain tasks have to be completed at a certain time or need to be outsourced to an external partner, will merely lead to second-best solutions. In other words, if external stakeholders have to approve key intermediate results of a multi-project effort in a go/no go fashion (as in the pharmaceutical industry), the effectiveness of the M4 tool may be reduced.

5.4. Conclusion

DC theories are widely used by innovation scholars, but there are hardly any studies that apply these theories in ways that can be exploited by practitioners. To fill this void, this paper explored how DCs can be created with active support of scholars. We adopted a DSR approach in which scholars and practitioners team up to address and resolve a focal firm's challenges in simultaneously managing a large number of product development projects that all depend on the same resource pool. To address this challenge, we designed and implemented the M4 tool. Our study therefore draws on DSR to develop an artifact that is practically relevant *and* avoids the widespread tautological problem in DC research.

CRediT authorship contribution statement

Szabolcs S. Sebrek: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **A. Georges L. Romme:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Zsolt T. Kosztyán:** Writing – original draft, Validation, Supervision, Resources, Investigation, Formal analysis, Data curation, Conceptualization.

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Appendix A. Original and revised process at Telemat

Table 11
Matrix-based project template for the original project plan for Telemat's new product development project A.

Phase	Activity		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Phase 0	NPA	A	X																							
	Developing the Concept	B		X	X	X																				
	Quotation from suppliers	C			X																					
	Production Cocept	D				X																				
	Offering Price	E					X																			
Phase 1	Developing Specification	F						X	X																	
	BOM-making	G							X																	
Phase 2	Mechanical Engineering	H								X	X	X														
	Hardware Development	I									X															
	Software Development	J										X														
	Suppliers Nomination	K											X	X												
	DV/PV test list	L												X												
	DV tests	M													X		X									
	DV2 tests	N														X										
	Drafting	O															X									
	Production Planning	P																X	X							
	Tool Series Start	Q																	X							
Phase 3	Production Installation	R																		X	X					
	PV tests	S																			X	X				
	PV2 tests	T																				X	X			
	PV3 tests	U																					X	X		
	FDPR	V																						X		
Phase 4a	SOP	W																							X	
Phase 4b	Archive Cycle Time	X																								X

Notes: BOM: Bill of Materiatls, DV: Design Verification, FDPR: Full Day Production Run, NPA: New Product Architecture, PV: Product Validation, SOP: Standard Operating Procedure.

Table 12
Matrix-based project template for the modified project plan (following the Kanban model) for Telemat's NPD project.

Phase	Activity		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Phase 0	NPA	A	1																							
	Developing the Concept	B		.8	.9	.8																				
	Quotation from suppliers	C			.9																					
	Production Cocept	D				.8																				
	Offering Price	E					.9																			
Phase 1	Developing Specification	F						1	1																	
	BOM-making	G							1																	
Phase 2	Mechanical Engineering	H								1	.9	.9														
	Hardware Development	I									.8															
	Software Development	J										.8														
	Suppliers Nomination	K											1	1												
	DV/PV test list	L												1												
	DV tests	M													.6		1									
	DV2 tests	N														.1										
	Drafting	O															1									
	Production Planning	P																.9	.7							
	Tool Series Start	Q																	1							
Phase 3	Production Installation	R																		.9	1					
	PV tests	S																			1	1				
	PV2 tests	T																				.3	1			
	PV3 tests	U																					.1	1		
	FDPR	V																						1		
Phase 4a	SOP	W																							1	
Phase 4b	Archive Cycle Time	X																								1

Notes: BOM: Bill of Materials, DV: Design Verification, FDPR: Full Day Production Run, NPA: New Product Architecture, PV: Product Validation, SOP: Standard Operating Procedure.

Data availability

Data will be made available on request.

References

Adner, R., Helfat, C.E., 2003. Corporate effects and dynamic managerial capabilities. Strateg. Manag. J. 24, 1011–1025.

Amit, R., Schoemaker, P.J., 1993. Strategic assets and organizational rent. Strateg. Manag. J. 14, 33–46.

Arend, R.J., Bromiley, P., 2009. Assessing the dynamic capabilities view: spare change, everyone? Strateg. Organ. 7, 75–90.
Atuahene-Gima, K., 2005. Resolving the capability–rigidity paradox in new product innovation. J. Market. 69, 61–83.
Augier, M., Teece, D.J., 2009. Dynamic capabilities and the role of managers in business strategy and economic performance. Organ. Sci. 20, 410–421.
Barreto, I., 2010. Dynamic capabilities: a review of past research and an agenda for the future. J. Manag. 36, 256–280.
Carlgren, L., Elmquist, M., Rauth, I., 2014. Design thinking: exploring values and effects from an innovation capability perspective. Des. J. 17 (3), 403–423.
Cautela, C., Simoni, M., Moran, P., 2022. Microfoundations of dynamic design capabilities: an empirical analysis of "excellent" Italian design firms. J. Prod. Innovat. Manag. 39 (1), 3–23.
Chen, C.W., Lien, N.H., 2013. Technological opportunism and firm performance: moderating contexts. J. Bus. Res. 66, 2218–2225.
Chirumalla, K., 2021. Building digitally-enabled process innovation in the process industries: a dynamic capabilities approach. Technovation 105, 102256.
Conboy, K., Mikalef, P., Dennehy, D., Krogstie, J., 2020. Using business analytics to enhance dynamic capabilities in operations research: a case analysis and research agenda. J. Operat. Res. 281, 656–672.
Conforto, E.C., Salum, F., Amaral, D.C., da Silva, S.L., de Almeida, L.F.M., 2014. Can agile project management be adopted by industries other than software development? Proj. Manag. J. 45, 21–34.
Dai, Y., Cai, X., Zhong, J., MacKenzie, A.R., 2021. Modelling chemistry and transport in urban street canyons: comparing offline multi-box models with large-eddy simulation. Atmos. Environ. 264, 118709.
Danneels, E., 2008. Organizational antecedents of second-order competences. Strateg. Manag. J. 29, 519–543.
Danneels, E., 2011. Trying to become a different type of company: dynamic capability at smith corona. Strateg. Manag. J. 32, 1–31.
Danneels, E., 2012. Second-order competences and schumpeterian rents. Strateg. Entrep. J. 6, 42–58.
Danneels, E., 2016. Survey measures of first- and second-order competences. Strateg. Manag. J. 37, 2174–2188.
Demeter, K., Losonci, D., Nagy, J., 2021. Road to digital manufacturing–a longitudinal case-based analysis. J. Manuf. Technol. Manag. 32 (3), 820–839.
Dimov, D., 2016. Toward a design science of entrepreneurship. In: Katz, J.A., Corbett, A. C. (Eds.), Models of Start-Up Thinking and Action: Theoretical, Empirical and Pedagogical Approaches. Emerald, Bingley, UK, pp. 1–31.
Dimov, D., Maula, M., Romme, A.G.L., 2023. Crafting and assessing design science research for entrepreneurship. Entrep. Theory Pract. 47 (5), 1543–1567.
Dingsøyr, T., Nerur, S., Balijepally, V., Moe, N.B., 2012. A decade of agile methodologies: towards explaining agile software development. J. Syst. Software 85, 1213–1221. Special Issue: Agile Development.
Drnevich, P.L., Kriauciunas, A.P., 2011. Clarifying the conditions and limits of the contributions of ordinary and dynamic capabilities to relative firm performance. Strateg. Manag. J. 32, 254–279.
Dykes, B.J., Hughes-Morgan, M., Kolev, K.D., Ferrier, W.J., 2019. Organizational speed as a dynamic capability: toward a holistic perspective. Strateg. Organ. 17, 266–278.
Eisenhardt, K.M., Martin, J.A., 2000. Dynamic capabilities: what are they? Strateg. Manag. J. 21, 1105–1121.
Ellonen, H.K., Wikstrom, P., Jantunen, A., 2009. Linking dynamic-capability portfolios and innovation outcomes. Technovation 29, 753–762.
Enkel, E., Sagmeister, V., 2020. External corporate venturing modes as new way to develop dynamic capabilities. Technovation 96–97, 102128.
Fan, S.L., Sun, K.S., Wang, Y.R., 2012. GA optimization model for repetitive projects with soft logic. Autom. ConStruct. 21, 253–261.
Fekri, R., Aliahmadi, A., Fathian, M., 2008. Identifying the cause and effect factors of agile NPD process with fuzzy dematel method: the case of iranian companies. J. Intell. Manuf. 20, 637.
Ferreira, J., Coelho, A., Moutinho, L., 2020. Dynamic capabilities, creativity and innovation capability and their impact on competitive advantage and firm performance: the moderating role of entrepreneurial orientation. Technovation 92–93, 102061.
Gilsing, V.A., van Burg, E., Romme, A.G.L., 2010. Policy principles for the creation and success of corporate and academic spin-offs. Technovation 30 (1), 12–23.
Gelhard, C., von Delft, S., Gudergan, S.P., 2016. Heterogeneity in dynamic capability configurations: equifinality and strategic performance. J. Bus. Res. 69, 5272–5279.
Helfat, C.E., Finkelstein, S., Mitchell, W., Peteraf, M., Singh, H., Teece, D., Winter, S.G., 2007. Dynamic Capabilities: Understanding Strategic Change in Organizations. Blackwell, Malden, MA.
Helfat, C.E., Peteraf, M.A., 2015. Managerial cognitive capabilities and the microfoundations of dynamic capabilities. Strateg. Manag. J. 36, 831–850.
Helfat, C.E., Winter, S.G., 2011. Untangling dynamic and operational capabilities: strategy for the (n) ever-changing world. Strateg. Manag. J. 32, 1243–1250.
Hermano, V., Martin-Cruz, N., Pajares, J., 2022. The effect of project management dynamic capabilities on firm performance. Baltic J. Manag. 17 (2), 266–284.
Hevner, A.R., March, S.T., Park, J., Ram, S., 2004. Design science in information systems research. MIS Q. 28, 75–105.
Hiranabe, K., 2012. Kanban applied to software development: from agile to lean. InfoQ 2008. Retrieved on 4 May 2012, from. http://www.infoq.com/articles/hiranabe-lean-agile-Kanban.
Hodgkinson, G.P., Healey, M.P., 2011. Psychological foundations of dynamic capabilities: reflexion and reflection in strategic management. Strateg. Manag. J. 32, 1500–1516.
Holmström, J., Ketokivi, M., Hameri, A.-P., 2009. Bridging practice and theory: a design science approach. Decis. Sci. J. 40 (1), 65–87.
Hullova, D., Simms, C.D., Trott, P., Laczko, P., 2019. Critical capabilities for effective management of complementarity between product and process innovation: cases from the food and drink industry. Res. Pol. 48 (1), 339–354.
Hutton, S., Demir, R., Eldridge, S., 2021. How does open innovation contribute to the firm's dynamic capabilities? Technovation 106, 102288.
Huy, Q., Zott, C., 2019. Exploring the affective underpinnings of dynamic managerial capabilities: how managers' emotion regulation behaviors mobilize resources for their firms. Strateg. Manag. J. 40, 28–54.
Katkalo, V.S., Pitelis, C.N., Teece, D.J., 2010. Introduction: on the nature and scope of dynamic capabilities. Ind. Corp. Change 19, 1175–1186.
Kay, N.M., Leih, S., Teece, D.J., 2018. The role of emergence in dynamic capabilities: a restatement of the framework and some possibilities for future research. Ind. Corp. Change 27, 623–638.
Kettunen, P., 2009. Adopting key lessons from agile manufacturing to agile software product development—a comparative study. Technovation 29, 408–422.
Khan, M.U., 1999. Dynamic techno-management capability of indian computer firms in comparison with korea. Technovation 19, 243–259.
Kosztyán, Z.T., 2015. Exact algorithm for matrix-based project planning problems. Expert Syst. Appl. 42, 4460–4473.
Kosztyán, Z.T., 2020. An exact algorithm for the flexible multilevel project scheduling problem. Expert Syst. Appl. 158, 113485.
Kosztyán, Z.T., Novák, G., Jakab, R., Szalkai, I., Hegedűs, C., 2023. A matrix-based flexible project-planning library and indicators. Expert Syst. Appl. 216, 119472.
Ladas, C., 2009. Scrumban-essays on Kanban Systems for Lean Software Development. Modus Cooperandi Press.
Lager, T., Simms, C.D., 2023. From customer understanding to design for processability: reconceptualizing the formal product innovation work process for non-assembled products. Technovation 125, 102750.
Lin, H., Zeng, S., Liu, H., Li, C., 2020. Bridging the gaps or fecklessness? a moderated mediating examination of intermediaries' effects on corporate innovation. Technovation 94–95, 102018.
MacLean, D., MacIntosh, R., Seidl, D., 2015. Rethinking dynamic capabilities from a creative action perspective. Strateg. Organ. 13 (4), 340–352.
Magistretti, S., Ardito, L., Messeni Petruzzelli, A., 2021. Framing the microfoundations of design thinking as a dynamic capability for innovation: reconciling theory and practice. J. Prod. Innovat. Manag. 38 (6), 645–667.
March, S.T., Smith, G.F., 1995. Design and natural science research on information technology. Decis. Support Syst. 15 (4), 251–266.
Michaelis, B., Rogbeer, S., Schweizer, L., Özleblebici, Z., 2021. Clarifying the boundary conditions of value creation within dynamic capabilities framework: a grafting approach. Rev. Manag. Sci. 15, 1797–1820.
Micheli, P., Jaina, J., Goffin, K., Lemke, F., Verganti, R., 2012. Perceptions of industrial design: the "means" and the "ends". J. Prod. Innovat. Manag. 29 (5), 687–704.
Mikalef, P., Krogstie, J., Pappas, I.O., Pavlou, P., 2020. Exploring the relationship between big data analytics capability and competitive performance: the mediating roles of dynamic and operational capabilities. Inf. Manag. 57, 103169.
Mikalef, P., Pateli, A., 2017. Information technology-enabled dynamic capabilities and their indirect effect on competitive performance: findings from pls-sem and fsqca. J. Bus. Res. 70, 1–16.
Miller, G.J., 2013. Agile Problems, Challenges, & Failures. Project Management Institute.
Mortati, M., Magistretti, S., Cautela, C., Dell'Era, C., 2023. Data in design: how big data and thick data inform design thinking projects. Technovation 122, 102688.
Mulders, D.E., Romme, A.G.L., 2009. Unpacking dynamic capability: a design perspective. In: Bøllingtoft, A., Håkonsson, D., Nielsen, J., Snow, C., Ulhøi, J. (Eds.), New Approaches to Organization Design (Information and Organization Design Series, vol. 8. Springer, Boston, MA, pp. 61–78, 61-78.
Nicolini, D., Korica, M., 2021. Attentional engagement as practice: a study of the attentional infrastructure of healthcare chief executive officers. Organ. Sci. 32, 1273–1299.
Ocasio, W., 2011. Attention to attention. Organ. Sci. 22, 1286–1296.
Oliveira, M., Zancul, E., Salerno, M.S., 2024. Capability building for digital transformation through design thinking. Technol. Forecast. Soc. Change 198, 122947.
Pascal, A., Thomas, C., Romme, A.G.L., 2013. Developing a human-centred and science-based approach to design: the knowledge management platform project. Br. J. Manag. 24 (2), 264–280.
Patel, P.C., 2011. Role of manufacturing flexibility in managing duality of formalization and environmental uncertainty in emerging firms. J. Oper. Manag. 29, 143–162.
Peffers, K., Tuunanen, T., Rothenberger, M.A., Chatterjee, S., 2007. A design science research methodology for information systems research. J. Manag. Inf. Syst. 24 (3), 45–77.
Peffers, K., Tuunanen, T., Niehaves, B., 2018. Design science research genres: introduction to the special issue on exemplars and criteria for applicable design science research. Eur. J. Inf. Syst. 27, 129–139.
Pezeshkan, A., Fainshmidt, S., Nair, A., Frazier, M.L., Markowski, E., 2016. An empirical assessment of the dynamic capabilities–performance relationship. J. Bus. Res. 69, 2950–2956.
Pillai, A., Joshi, A., Rao, K., 2002. Performance measurement of r&d projects in a multi-project, concurrent engineering environment. Int. J. Proj. Manag. 20, 165–177.
Ragland, K.W., 1973. Multiple box model for dispersion of air pollutants from area sources. Atmos. Environ. 7 (11), 1017–1032.
Rahimian, V., Ramsin, R., 2008. Designing an agile methodology for mobile software development: a hybrid method engineering approach. In: 2008 Second International Conference on Research Challenges in Information Science, pp. 337–342.

Romme, A.G.L., Holmström, J., 2023. From theories to tools: calling for research on technological innovation informed by design science. Technovation 121, 102692.
Romme, A.G.L., Reymen, I.M.M.J., 2018. Entrepreneurship at the interface of design and science: toward an inclusive framework. J. Bus. Ventur. Insights 10, e00094.
Romme, A.G.L., Zollo, M., Berends, P., 2010. Dynamic capabilities, deliberate learning and environmental dynamism: a simulation model. Ind. Corp. Change 19, 1271–1299.
Sánchez, M.G., Lalla-Ruiz, E., Gil, A.F., Castro, C., Voß, S., 2023. Resource-constrained multi-project scheduling problem: a survey. Eur. J. Oper. Res. 309 (3), 958–976.
Schoemaker, P.J., Heaton, S., Teece, D., 2018. Innovation, dynamic capabilities, and leadership. Calif. Manag. Rev. 61, 15–42.
Schön, D., 1984. The Reflective Practitioner: How Professionals Think in Action. Basic Books, New York.
Schulze, A., Brusoni, S., 2022. How dynamic capabilities change ordinary capabilities: reconnecting attention control and problem-solving. Strateg. Manag. J. 43 (12), 2447–2477.
Schwaber, K., 1997. Business Object Design and Implementation: OOPSLA '95 Workshop Proceedings 16 October 1995. Springer, Austin, Texas, pp. 117–134. London. chapter SCRUM Development Process.
Serrador, P., Pinto, J.K., 2015. Does Agile work? A quantitative analysis of agile project success. Int. J. Proj. Manag. 33, 1040–1051.
Shamim, S., Zeng, J., Shariq, S.M., Khan, Z., 2019. Role of big data management in enhancing big data decision-making capability and quality among Chinese firms: a dynamic capabilities view. Inf. Manag. 56, 103135.
Shepard, H.A., 1956. Nine dilemmas in industrial research. Adm. Sci. Q. 1, 295–309.
Sher, P.J., Lee, V.C., 2004. Information technology as a facilitator for enhancing dynamic capabilities through knowledge management. Inf. Manag. 41, 933–945.
Shuen, A., Feiler, P.F., Teece, D.J., 2014. Dynamic capabilities in the upstream oil and gas sector: managing next generation competition. Energy Strategy Rev. 3, 5–13.
Simon, H.A., 2019. The Sciences of the Artificial (Third Edition with a New Introduction by John Laird). MIT Press, Boston.
Stadler, C., Helfat, C.E., Verona, G., 2013. The impact of dynamic capabilities on resource access and development. Organ. Sci. 24, 1782–1804.
Subramanian, A.M., Chai, K.H., Mu, S., 2011. Capability reconfiguration of incumbent firms: nintendo in the video game industry. Technovation 31, 228–239.
Sun, H., Tianchao, Ma, T., 2005. A packing-multiple-boxes model for R&D project selection and scheduling. Technovation 25 (11), 1355–1361.
Teece, D., Pisano, G., 1994. The dynamic capabilities of firms: an introduction. Ind. Corp. Change 3, 537–556.
Teece, D.J., 2007. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. Strateg. Manag. J. 28, 1319–1350.
Teece, D.J., 2014. The foundations of enterprise performance: dynamic and ordinary capabilities in an (economic) theory of firms. Acad. Manag. Perspect. 28, 328–352.
Teece, D.J., 2018. Business models and dynamic capabilities. Long. Range Plan. 51, 40–49.
Teece, D.J., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Strateg. Manag. J. 18, 509–533.
Thakur-Weigold, B., 2021. Capability mapping to improve manufacturing network performance: how a factory can target growth. J. Manuf. Technol. Manag. 32 (6), 1335–1356.
Torres, R., Sidorova, A., Jones, M.C., 2018. Enabling firm performance through business intelligence and analytics: a dynamic capabilities perspective. Inf. Manag. 55, 822–839.
Van Aken, J., Chandrasekaran, A., Halman, J., 2016. Conducting and publishing design science research: inaugural essay of the design science department of the journal of operations management. J. Oper. Manag. 47–48, 1–8.
Walls, J.G., Widmeyer, G.R., Sawy, O.A.E., 1992. Building an information system design theory for vigilant EIS. Inf. Syst. Res. 3, 36–59.
Wang, C., 2007. Dynamic capabilities: a review and research agenda. Int. J. Manag. Rev. 9 (1), 31–51.
Wheeler, B.C., 2002. NEBIC: a dynamic capabilities theory for assessing net-enablement. Inf. Syst. Res. 13 (2), 125–146.
Wilden, R., Gudergan, S.P., Nielsen, B.B., Lings, I., 2013. Dynamic capabilities and performance: strategy, structure and environment. Long. Range Plan. 46 (1–2), 72–96.
Willink, R., 2009. Representing Monte Carlo output distributions for transferability in uncertainty analysis: modelling with quantile functions. Metrologia 46 (3), 154–166.
Winter, R., 2008. Design science research in Europe. Eur. J. Inf. Syst. 17, 470–475.
Winter, S.G., 2003. Understanding dynamic capabilities. Strateg. Manag. J. 24, 991–995.
Wollersheim, J., Heimeriks, K.H., 2016. Dynamic capabilities and their characteristic qualities: insights from a lab experiment. Organ. Sci. 27 (2), 233–248.
Wysocki, R.K., 2009. Effective Project Management: Traditional, Agile, Extreme, fifth ed. John Wiley & Sons.
Yang, S., Fu, L., 2014. Critical chain and evidence reasoning applied to multi-project resource schedule in automobile R&D process. Int. J. Proj. Manag. 32, 166–177.
Yi, Y., He, X., Ndofor, H., Wei, Z., 2015. Dynamic capabilities and the speed of strategic change: evidence from China. IEEE Trans. Eng. Manag. 62, 18–28.
Zahra, S.A., Sapienza, H.J., Davidsson, P., 2006. Entrepreneurship and dynamic capabilities: a review, model and research agenda. J. Manag. Stud. 43 (4), 917–955.
Zahra, S.A., Kaul, A., Bolívar-Ramos, M.T., 2018. Why corporate science commercialization fails: integrating diverse perspectives. Acad. Manag. Perspect. 32 (1), 156–176.
Zmud, R.W., 1982. Diffusion of modern software practices: influence of centralization and formalization. Manag. Sci. 28, 1421–1431.
Zollo, M., Winter, S.G., 2002. Deliberate learning and the evolution of dynamic capabilities. Organ. Sci. 13, 339–351.
Zott, C., 2003. Dynamic capabilities and the emergence of intraindustry differential firm performance: insights from a simulation study. Strateg. Manag. J. 24, 97–125.