Kabelitz-Bock, Robin; Hoberg, Kai; Meuer, Johannes

Adopting Additive Manufacturing in After-Sales: Developing a Typology of Corrective, Preventive, and Anticipatory Approaches

Journal of Business Logistics

Provided in Cooperation with:
John Wiley & Sons

Suggested Citation: Kabelitz-Bock, Robin; Hoberg, Kai; Meuer, Johannes (2024) : Adopting Additive Manufacturing in After-Sales: Developing a Typology of Corrective, Preventive, and Anticipatory Approaches, Journal of Business Logistics, ISSN 2158-1592, Wiley Periodicals, Inc., Hoboken, NJ, Vol. 46, Iss. 1,
https://doi.org/10.1111/jbl.70000

Journal of Business Logistics

WILEY

ORIGINAL ARTICLE OPEN ACCESS

Adopting Additive Manufacturing in After-Sales: Developing a Typology of Corrective, Preventive, and Anticipatory Approaches

Robin Kabelitz-Bock | Kai Hoberg | Johannes Meuer

Kühne Logistics University – KLU, Hamburg, Germany

Correspondence: Kai Hoberg (kai.hoberg@the-klu.org)

Received: 13 June 2023 | **Revised:** 13 September 2024 | **Accepted:** 15 October 2024

Funding: This research project is funded by dtec.bw—Digitalization and Technology Research Center of the Bundeswehr. dtec.bw is funded by the European Union—NextGenerationEU.

Keywords: additive manufacturing | after-sales | *awareness-motivation-capability* perspective | case study | spare part shortages

ABSTRACT

Manufacturing firms face complex after-sales challenges, including spare part shortages. While additive manufacturing (AM) offers a solution by minimizing costs and complexity, not all firms adopt AM equally, and research on differences in AM adoption in the context of spare part shortages is surprisingly scarce. To close this knowledge gap, we apply the *awareness-motivation-capability* (AMC) perspective. Our comparative case study of AM applications in 17 firms identifies three approaches how firms adopt AM—the corrective, preventive, and anticipatory approach. We find that the specific configuration of contextual factors related to a spare part shortage determines the approach firms follow. Using the AMC perspective, we discover and explain why firms differ in adopting AM despite suitable spare part characteristics and similar contexts. Through uniquely analyzing spare part shortages, our study contributes to AM research by challenging the assumption that economic justification is the sole driver of AM adoption and instead revealing that it is a context-dependent process, with *awareness* and *motivation* serving as critical yet underexplored antecedents.

1 | Introduction

Manufacturing firms are experiencing growing complexity and risks of disruption in managing after-sales services, increasing their supply chain costs and challenges (Ferdows 2018; Young 2022). Spare part shortages are a major challenge and therefore firms must determine whether to make spare parts available and assess the associated cost (Westerweel et al. 2021; Xu, Rodgers, and Guo 2021). Moreover, unexpected events, such as supplier disappearances, delays in transportation, and volatile demand, complicate after-sales services even further (Tangel and Katz 2022). Although infrequent, these situations present significant risks to firms' economic success.

While there are various ways to maintain spare part availability, additive manufacturing (AM) (also known as 3D printing) represents a promising alternative (Fawcett and Waller 2014; Knofius et al. 2021), enabling firms to minimize shipments, logistics costs, and warehousing complexity and entirely change their supply chain configuration (Friedrich, Lange, and Elbert 2022; Westerweel et al. 2021). Therefore, many firms are screening their portfolios for spare parts suitable for AM and adopting it to produce spare parts (Deutsche Bahn 2022).

To date, researchers have primarily studied AM replacing traditional manufacturing (Knofius, van der Heijden, and Zijm 2019; Westerweel, Basten, and van Houtum 2018) and ways to identify

spare parts suited for AM (Heinen and Hoberg 2019; Lindemann et al. 2015) while limited research has analyzed AM adoption to provide normative implementation frameworks (Mellor, Hao, and Zhang 2014). However, two notable research gaps remain: first, little research has examined AM's role in spare part shortages (Westerweel et al. 2021). Second, existing studies do not explain why so many firms refrain from adopting AM in spare part management despite suitable spare part characteristics (Akmal et al. 2022; Lindemann et al. 2015). In other words, why AM adoption differs across firms when experiencing spare part shortages remains unresolved.

To address these research gaps, we leverage the theoretical lens of the *awareness-motivation-capability* (AMC) perspective to better explain the differences in AM adoption in after-sales. Chen (1996) originally developed this perspective to analyze drivers of firm behavior. To respond to an external change, firms must be *aware* of it, *motivated* to react, and *capable* of responding (Chen, Su, and Tsai 2007). Our study transfers the AMC perspective to the context of adopting AM in after-sales situations when products break and no spare parts are readily available, that is, spare part shortages.[1] In our context, *awareness* relates to spare part shortages and benefits of using AM, *motivation* to solving spare part shortages using AM, and *capability* to adopting AM. The three constructs of the AMC perspective offer a theory-based conceptual foundation for this study's findings and discussion.

We analyze AM applications in the context of spare part shortages and identify the conditions under which firms adopt AM. Specifically, we ask *how firms adopt AM when experiencing spare part shortages and why AM adoption differs across firms in similar contexts*. We use a unique, extensive primary data set collected through a comparative case study (Eisenhardt and Graebner 2007; Yin 2018) to compare original equipment manufacturers (OEMs) in business-to-business (B2B) and business-to-consumer (B2C) settings and B2B customers (considered as manufacturing firms). Our diverse firm selection spans various industries and supply chain tiers, allowing us to analyze and discuss the findings from multiple perspectives.

Our findings demonstrate firms' diverse approaches in how they adopt AM: the corrective approach to serve short-term needs and address spare part shortages ad hoc; the preventive approach to offer spare parts in situations of low spare part demand; the anticipatory approach to meet future customer requirements and regulations and prevent spare part shortages upfront. Our findings reveal that the suitable approach depends on the context of spare part shortages. Specifically, the contextual factors of *problem urgency*, *response strategy*, *original product production status*, *spare part production readiness*, and *AM production implementation* collectively determine which approach firms follow. Our research reveals that the complex interplay of contextual factors influences AM adoption. Refuting common assumptions, we find that successful adoption requires not only AM-specific *capabilities* but also *awareness* and *motivation* of spare part shortages and AM adoption. Due to our unique and in-depth analysis of spare part shortages, we find that AM adoption is a nonlinear, context-dependent process and advance existing knowledge on AM adoption through developing three adoption approaches and conceptualizing contextual factors that impact AM adoption.

The paper is structured as follows: the Background section presents the theoretical basis and relevant literature on AM adoption in after-sales, followed by the Methodology section describing our comparative case study. The Findings section contains our results while we present our contributions, managerial implications, limitations and future research in the Discussion section. The paper ends with the Conclusions section.

2 | Background

2.1 | After-Sales Services

After-sales services (hereafter, after-sales) are in many ways central to firms' economic success (Durugbo 2020). First, they enable firms to develop competitive advantages and differentiate from competitors (Cohen and Lee 1990). Second, they are a highly profitable income source, with generally higher margins than original product sales (Kurata and Nam 2010; Saccani, Songini, and Gaiardelli 2006). Third, they build strong relationships with customers and positively impact customer satisfaction (Rigopoulou et al. 2008; Shokouhyar, Shokoohyar, and Safari 2020).

However, firms must balance conflicting goals, which makes after-sales challenging. The main goals associated with after-sales are optimizing customer service and satisfaction, ensuring spare part availability, preventing disruptions, and minimizing cost (Boone et al. 2018; Durugbo 2020). Because these goals conflict, firms cannot achieve them all simultaneously and must find optimal tradeoffs (Boone et al. 2018). For example, models show the difficulty of optimizing customer satisfaction and profits simultaneously, forcing firms to prioritize one goal over the other (Kurata and Nam 2010). Since customer requirements constantly evolve, implementing after-sales services, finding their optimal level, and ensuring spare part availability is an ongoing struggle (Hu et al. 2018; Shokouhyar, Shokoohyar, and Safari 2020).

Spare part management is complex (Cohen, Agrawal, and Agrawal 2006), as demand is generally volatile and hard to forecast (Dekker et al. 2013; Syntetos, Keyes, and Babai 2009). It changes over the product lifecycle and is subject to fluctuations very different from original parts demand (Hur, Keskin, and Schmidt 2018; Wagner, Jönke, and Eisingerich 2012). Firms must plan the all-time demand for spare parts (known as final order or last call), with the safety stock, length of remaining service period, shortage risk, and obsolescence risk as critical influences (Hu et al. 2018; Syntetos, Keyes, and Babai 2009). Financial constraints and extensive logistics and warehousing demands further increase the complexity of spare part management (Persson and Saccani 2009; Westerweel et al. 2021).

Inventory management is a key focus for firms striving to manage spare part complexity and prevent spare part shortages (Blair et al. 2020). To avoid disruptions and their impact on customer service, firms tend to overstock (Wagner, Jönke, and Eisingerich 2012), cannibalize other products (Hu et al. 2018), or adapt their supply chain design to reduce the risk of disruptions (Boone et al. 2018; Durugbo 2020). On a broader scale, firms align their spare part strategy with their

overall after-sales goals by weighing the costs and benefits of holding spare parts and by setting target rates of spare part availability (Boone et al. 2018; Pourakbar, Frenk, and Dekker 2012). To develop optimal solutions, researchers have worked extensively on optimal inventory levels and reorder policies (Hu et al. 2018) and assessed new technologies' (e.g., AM) potential to lower inventories while preserving customer satisfaction (Christopher and Ryals 2014). For example, Xu, Rodgers, and Guo (2021) demonstrate how integrating AM into maintenance operations can enhance inventory management by improving efficiency and responsiveness. These research efforts underscore the critical role of inventory management in aligning spare parts strategies with after-sales goals, ultimately ensuring that firms meet customer needs while maintaining operational efficiency.

In practice, however, firms often lack a coherent strategy for spare part availability leading to spare part shortages (Blair et al. 2020) and firms must decide whether a spare part should be offered and at what cost (Cohen, Agrawal, and Agrawal 2006). Current research has greatly emphasized prevention strategies, but a significant gap remains regarding spare part shortages (Westerweel et al. 2021). Although infrequent, these pose a great financial and customer satisfaction risk (Cohen, Agrawal, and Agrawal 2006) and demand a better understanding of how firms mitigate them.

2.2 | Additive Manufacturing for Spare Parts

AM has been identified as a promising technology in spare part management (Fawcett and Waller 2014; Xu, Rodgers, and Guo 2021). Table 1 provides an overview of studies at the interface of AM and spare parts that are relevant to this study's research topics. For example, Westerweel et al. (2021) analyze the advantages of on-site printing at remote locations considering spare part shortages and constraints in replenishment. Bonnín Roca et al. (2019) assess optimal locations for AM use, and Knofius et al. (2021) examine the benefits of spare part production by AM to various supply chains' responsiveness, efficiency, and sustainability. Friedrich, Lange, and Elbert (2022) consider AM's impact on manufacturing firms' make-or-buy decision, and others discuss the facilitation of outsourcing AM through blockchain technology (Kurpjuweit et al. 2021). Researchers agree that AM is a key technology for future spare part production (Khajavi, Partanen, and Holmström 2014; Li et al. 2017; Waller and Fawcett 2014).

For firms to adopt AM, it must outperform existing technologies. Its main advantages over traditional manufacturing are lower setup cost, tool-less production, shorter lead times, and improved part design (Akmal et al. 2022; Knofius, van der Heijden, and Zijm 2019; Xu, Rodgers, and Guo 2021). However, given high switching costs and AM's current technical shortcomings, firms often hesitate to change production technologies and thus retain traditional manufacturing technologies for original part and spare part production (Chekurov et al. 2018; Heinen and Hoberg 2019). Various methods have been used to investigate when to choose AM over traditional manufacturing, including lifecycle cost analysis (Westerweel, Basten, and van Houtum 2018), inventory and spare part demand modeling (Heinen and Hoberg 2019; Khajavi, Partanen, and Holmström 2014), and field experiments (Akmal et al. 2022). Overall, researchers concur that AM must economically outperform existing technologies (i.e., injection molding) to be chosen for spare part production (Handfield et al. 2022).

Researchers have developed diverse methods to identify spare parts suitable for AM (Frandsen et al. 2020), for example, analyzing spare part portfolios to rank parts on their economic and technical suitability for AM (Knofius, van der Heijden, and Zijm 2016) and calculating the overall percentage of spare parts suitable for AM (Heinen and Hoberg 2019). Researchers have also collaborated with experts from practice to develop a method to identify spare parts suitable for AM based on technical, economic, and strategic aspects (Lindemann et al. 2015). Finally, researchers have analyzed adoption factors based on market characteristics (Handfield et al. 2022) and developed normative frameworks explaining the AM adoption process (Mellor, Hao, and Zhang 2014).

However, existing knowledge does not explain why AM adoption differs across firms in similar contexts. Why do firms not always adopt AM when a spare part is suitable for AM production and when AM outperforms traditional manufacturing? Existing knowledge overlooks important aspects that explain effective AM adoption, so we argue that the dominant perspective on technical and economic factors must be extended. To further understand AM adoption, we must zoom out with a theoretical lens that encompasses the context in which firms decide whether to adopt AM for spare part production.

2.3 | The Awareness-Motivation-Capability Perspective

For this purpose, we employ the AMC perspective and contextualize it to fit our research setting. The AMC perspective originates in research on organizational change and decision-making and identifies three fundamental drivers of organizational behavior: *awareness* of external changes, *motivation* to act, and *capability* to act effectively (Dutton and Jackson 1987; Kiesler and Sproull 1982; Lant, Milliken, and Batra 1992). Chen (1996) developed the AMC perspective by integrating these three constructs into a framework that he developed in the context of competitor analysis and interfirm rivalry. In this framework, all three constructs are key drivers of competitive behavior, influencing a firm's likelihood to act or respond to competitors. Its value lies in its comprehensive consideration of all three antecedents and their collective ability to explain a firm's behavior as the phenomenon under investigation.

Recently, the AMC perspective has been employed in various research contexts to examine firms' actions. In the original context of inter-firm rivalry, Chen, Su, and Tsai (2007) used the AMC perspective to investigate the impact of a rival's innovation on a firm's product strategy. Other researchers have adapted the AMC perspective to different managerial contexts, for example, to identify the antecedents of inventory agility (i.e., being able to quickly adapt inventories) upon demand shocks (Udenio, Hoberg, and Fransoo 2018), to analyze complementary product

TABLE 1 | Selected literature on the AM adoption–spare parts interface.

	Research topic				
Reference	**Comparison of AM and traditional manufacturing**	**Spare part selection for AM**	**AM adoption and challenges**	**Context of spare part shortages**	**Categorization of references by AMC components**
Akmal et al. (2022)	Switching to AM to improve customer service	Dynamic decision-making for problematic spare parts based on cost and delivery performance	—	—	Awareness: — Motivation: Improved customer service through a switchover to AM Capability: Method for dynamic spare parts selection for AM
Frandsen et al. (2020)	—	Literature review on classification and selection methods; summarizing future research directions	Difficult process to identify spare parts for AM	—	Awareness: — Motivation: — Capability: Methods for spare parts selection for AM, e.g. screening with limited data availability
Friedrich, Lange, and Elbert (2022)	—	—	Assessment of capacities and skills necessary for in-house and outsourcing AM; development of decision profiles	—	Awareness: — Motivation: — Capability: Governance structures and required capabilities for in-house and external AM production
Handfield et al. (2022)	Adoption characteristics explaining AM adoption; archetypes of AM adaptation	—	AM adoption framework based on market attributes	—	Awareness: Framework based on market attributes for which AM will successfully meet a need Motivation: — Capability: —
Heinen and Hoberg (2019)	Switching to AM based on spare part characteristics	Portfolio level analysis assessing the switchover share across an entire spare part portfolio	—	—	Awareness: — Motivation: — Capability: Portfolio level analysis examining the switchover share from traditional manufacturing to AM

(Continues)

TABLE 1 | (Continued)

Reference	Research topic				Categorization of references by AMC components
	Comparison of AM and traditional manufacturing	**Spare part selection for AM**	**AM adoption and challenges**	**Context of spare part shortages**	
Knofius, van der Heijden, and Zijm (2016)	—	Economic and technical assessment and ranking of spare parts suitable for AM based on digital part information	—	—	Awareness: — Motivation: Identifying economically valuable and technically feasible business cases for Am Capability: Prioritization of AM suitability of a spare part assortment
Reference	Research topic				Categorization of references by AMC components
	Comparison of AM and traditional manufacturing	Spare part selection for AM	AM adoption and challenges	Context of spare part shortages	
Knofius, van der Heijden, and Zijm (2019)	Analysis of when and how a transition to AM becomes profitable	—	—	—	Awareness: — Motivation: Profitable transition to AM for the low-volume spare parts Capability: —
Lindemann et al. (2015)	—	Part selection process based on technical, economic, and strategic aspects	—	—	Awareness: — Motivation: — Capability: Method to help end-users identify appropriate parts
Mellor, Hao, and Zhang (2014)	—	—	Analysis of AM implementation resulting in a normative implementation framework	—	Awareness: — Motivation: — Capability: Model of factors related to AM technology, supply chain, organization, operations, and strategy
Westerweel, Basten, and van Houtum (2018)	Lifecycle cost analysis of component design comparing AM and traditional manufacturing	Holistic assessment across part lifecycle	—	—	Awareness: — Motivation: Analyzing component design options through lifecycle cost Capability: —

(Continues)

TABLE 1 | (Continued)

Reference	Research topic				Categorization of references by AMC components
	Comparison of AM and traditional manufacturing	**Spare part selection for AM**	**AM adoption and challenges**	**Context of spare part shortages**	
Westerweel et al. (2021)	—	—	—	AM for spare parts in the context of limited access to spare parts and fixed replenishment cycles	Awareness: — Motivation: Operational cost savings through on-site inventory reductions and increased asset availability Capability: —
Xu, Rodgers, and Guo (2021)	—	—	Hybrid simulation of AM adoption on operational efficiency and effectiveness	—	Awareness: — Motivation: Operational efficiency and effectiveness of AM Capability: —
This study	*AM applications* in after-sales	*Contextual factors* and *spare part shortages* as starting points for the selection of spare parts	Analysis of *awareness*, *motivation*, and *capability* to adopt AM and three *adoption approaches*	*Spare part shortages* as the main research context	Awareness: Spare part shortages and benefits of using AM Motivation: Business case or marketing drivers to solve shortages Capability: Adopt AM and overcome adoption challenges

markets (Bennett and Pierce 2016), and to understand modern slavery in supply chains (Geng, Lam, and Stevenson 2022). The broad application of the AMC perspective demonstrates its ability to explain firms' behavior in diverse research contexts. However, the AMC perspective has not yet been applied in the context of AM adoption in after-sales, and as the categorization of existing research by AMC components in Table 1 shows, most studies in this domain have addressed individual components of the AMC framework only partially, if at all.

3 | Methodology

Although AM is not new, it remains relatively new to many firms, and the adoption of AM to address spare part shortages is still largely unexplored. To explore variability in AM adoption across firms, we employ a comparative case study (Eisenhardt and Graebner 2007; Voss, Tsikriktsis, and Frohlich 2002), which allows us to compare and contrast similarities and differences across various contexts (Ketokivi and Choi 2014; Yin 2018). In our study, the case is a firm's move to adopt AM in the context of spare part shortages.

3.1 | Setting and Case Selection

We conducted this study among manufacturing firms in Germany, thus controlling for country-specific factors (e.g., differences in legislation, customer characteristics, and technology availability) (Yin 2018). Initially, we conducted expert interviews and assessed the AM literature, which led us to expect differences in how firms adopt AM based on their market orientation (B2B vs. B2C) and supply chain tiers (OEMs vs. customers considered as manufacturing firms). We used these two criteria to select firms of three firm types: B2B OEMs (type A), B2B customers (type B), and B2C OEMs (type C). Given our focus on manufacturing firms and the industrial AM context, we excluded B2C customers.[2]

B2B OEMs (type A) are large OEMs in the B2B sector. They produce long-lasting, expensive, and application-specific products like forklifts, turbines, and industrial mixers. These products are heavily used, leading to high wear and tear, high downtime costs, and high customer expectations. B2B OEMs control product development and spare part management. B2B customers (type B) are large firms that purchase and use products from B2B OEMs, such as operators of trains and production machines. They share similar product characteristics with B2B OEMs but rely on OEMs for product development and spare part management. B2C OEMs (type C) operate in the B2C sector, producing relatively inexpensive, short-lived, and low-intensity products like furniture and electronics. These products have a broad installed base, low wear and tear, and low downtime costs.

To ensure a diverse representation of firm types and varying degrees of AM adoption, we selected firms that aligned well with these criteria. Next, to identify and analyze specific cases, we asked our interview partners to discuss the firm's move to adopt AM (our case) for spare part shortages and to describe the development of AM capabilities for managing spare parts (our unit of analysis). By employing an iterative approach, we adapted to the data as it emerged and incorporated additional firms and cases during the data collection process.

3.2 | Data Collection

We selected 17 firms to be included in this study and collected data via semi-structured interviews lasting about an hour each between January and August 2022 (Eisenhardt and Graebner 2007). As summarized in Table 2, we conducted 46 interviews: 34 with firm representatives and 12 with industry experts. We recorded and transcribed all interviews and coded them using MAXQDA.

To structure our data collection, we developed a case study protocol following Yin (2018) and included an overview of our case study, an outline of our data collection procedure, the interview questions (see Appendix S2), and a provisional structure of the case study report in our case study protocol. We asked respondents to focus on their own products and avoid general statements. We interviewed managers with expert knowledge of their firm's after-sales services based on their scope of duties and their prior work experience. They could discuss why spare part shortages emerged, how the firm handled these situations, and how they considered adopting AM. After assessing their responses, we developed interim findings and resumed the discussion by presenting them to the interview partners and discussing their feedback and comments.

We complemented our findings with insights from additional interviews with industry experts who had extensive experience and specialized knowledge in AM adoption for spare parts. Their contributions were critical in providing a deep understanding of technical characteristics and market dynamics related to AM. For example, experts from AM software consulting firms, which assist manufacturing firms in implementing AM for spare parts, provided insights into adoption motivations and capability gaps, while AM consulting experts shared detailed knowledge on the adoption process and technology selection in practice. These insights were essential for contextualizing our research and enhancing our understanding in addition to the interviews with managers. Although we did not include these expert perspectives in the data analysis process, they enriched our interpretation of the data and allowed us to critically assess and better understand the responses from the firms included in our study. Finally, we collected complementary data (e.g., firm documents and reports, industry reports, and interview memos) to further strengthen data triangulation.

3.3 | Data Analysis

We analyzed the data iteratively through within- and cross-case analysis (Eisenhardt 1989). To ensure quality and rigor, we validated interview data with archival data and literature, maintained a transparent research design, and followed the case study protocol. We discussed differing interpretations within the research team to ensure robust data analysis and shared understanding. For any unclear interview statements, we followed up with the interview partners to clarify. Appendix S3 provides an overview of the measures used to ensure construct validity, internal validity, external validity,

TABLE 2 | Overview of the firms and data collection.

Type	Industry/ products		Firm	Size	State of AM		Interview partners (number of interviews and job titles)
A: B2B OEMs	Forklifts	A.1	Forklift and warehousing manufacturer	~20.000 FTE ~4 Bn. EUR	Selected test runs	4	Director Supply Chain for After-sales Product Group Manager Director Logistics Support
	Elevators and escalators	A.2	Escalator and elevator manufacturer	~70.000 FTE ~10 Bn. EUR	Selected test runs	2	Head of Group Repairs & Spare Parts
	Turbine blades	A.3	Turbine manufacturer	< 1.000 FTE ~40 Bn. EUR	Fully included in operations	1	Advisory Expert Repair/ Additive Manufacturing
	Industrial mixers	A.4	Industrial mixer manufacturer	< 1.000 FTE < 1 Bn. EUR	Fully included in operations	1	Head of Mechanical Development
	Building appliances	A.5	Building appliances manufacturer	~30.000 FTE ~6 Bn. EUR	Adopted for selected products	1	Regional Repair Expert
	Production lines	A.6	Packaging and bottling production line manufacturer	~3.000 FTE < 1 Bn. EUR	Selected test runs	1	Manager International Spare Parts
	Buses	A.7	Bus manufacturer	~100.000 FTE ~40 Bn. EUR	Fully included in operations	1	Head of Center of Competence Additive Manufacturing
B: B2B customers	Production lines	B.1	Car manufacturer	> 100.000 FTE > 100 Bn. EUR	Selected test runs	3	Head of Maintenance
	Trains	B.2	Train operator	> 100.000 FTE ~50 Bn. EUR	Fully included in operations	3	Head of Additive Manufacturing Expert Additive Manufacturing
	Production lines	B.3	Forklift and warehousing manufacturer	~10.000 FTE ~2 Bn. EUR	Adopted for selected products	3	Plant Maintenance Manager
	Production lines	B.4	Car parts manufacturer	> 100.000 FTE ~80 Bn. EUR	Selected test runs	2	Head of Maintenance Innovation Manager Maintenance
	Production lines	B.5	White goods manufacturer	~20.000 FTE ~5 Bn. EUR	Adopted for selected products	1	Head of Maintenance
Type	Industry/Products		Firm	Size	State of AM		Interview partners (number of interviews and job titles)

(Continues)

TABLE 2 | (Continued)

Type	Industry/ products		Firm	Size	State of AM		Interview partners (number of interviews and job titles)
C: B2C OEMs	Furniture	C.1	Garden furniture manufacturer	~1.000 FTE <1 Bn. EUR	Fully included in operations	4	CEO Head of Finance and Operations Managing Director
	Electronic goods	C.2	Electronic goods manufacturer	~10.000 FTE ~3 Bn. EUR	Selected test runs	3	Head of Strategic Service Excellence and Innovation Manager Service Quality
	White goods	C.3	White goods manufacturer	~20.000 FTE ~5 Bn. EUR	Fully included in operations	2	Head of Supply Chain Planning Spares, Accessories, Consumables Manager Innovation
	Furniture	C.4	Furniture manufacturer	>100.000 FTE ~40 Bn. EUR	Adopted for selected products	1	Circular Economy Project Leader
	Building appliances	C.5	Building appliances manufacturer	~30.000 FTE ~6 Bn. EUR	Adopted for selected products	1	Regional Repair Expert
Additional expert interviews	Electronic and white goods	I	Electronic goods seller and repair shop			2	Head of After-sales External Consultant
	Electronic goods	II	Electronic goods repair shop			1	CEO
	Diverse	III	AM and spare parts management software and consulting firm			1	CEO and Founder
	Diverse	IV	AM consulting firm			1	CEO and Founder
	Diverse	V	AM consulting firm			1	CEO and Founder
	Diverse	VI	AM and spare parts management software and consulting firm			3	CEO and Founder
	Diverse	VII	Supply chain and after-sales consulting firm			2	Partner Senior Advisor Digital Manufacturing
	Diverse	VIII	Strategy consulting firm			1	Partner and Associate Director Supply Chain
Additional data sources	• Interview notes and memos • Company archival data (e.g., company reports, communications, and website information)—Other archival data (e.g., industry and consulting reports, regulations, political communications, and news articles)—Notes and talks during industry fairs						

and reliability. We based our analysis and findings solely on data gathered in this study.

Initially, we conducted the within-case analysis in four steps. First, we inductively did open coding on every interview transcript and wrote memos. The initial codes emerged directly from the interview data, which we organized into eight overarching categories, such as *firm goals* relating to product availability and after-sales, and *problem-handling* relating to strategies for spare part shortages (see Appendix S4). Second, we identified three main reasons for spare part shortages: *uncertainty* (e.g., uncertain demand), *storage and warehousing* (e.g., long storage periods and incorrect warehouse entries), and *suppliers* (e.g., supplier exiting the market and wrong last calls) (see Appendix S5). From this, we noted the preferred alternatives firms chose when spare parts were unavailable, such as replacing larger units, sourcing second-hand parts, or producing new batches with traditional manufacturing (see Appendix S6). Third, we clustered all AM applications into three distinct approaches to AM adoption: *corrective*, *preventive*, and *anticipatory* (see Appendix S1 for details). Fourth, we summarized each firm's findings and then developed an aggregated overview for the three firm types (A, B, and C). This completed our within-case analysis.

Subsequently, we conducted the cross-case analysis in three steps. First, we compared the aggregated overviews to identify differences between firm types based on market orientation (B2B vs. B2C) and supply chain tiers (OEMs vs. customers), considering product characteristics, frequency of spare part shortages, and AM's role. Second, to assess practical relevance of AM applications for firm types, we analyzed how frequently interview partners mentioned different opportunities for AM adoption. Third, we examined why each application fell into the corrective, preventive, or anticipatory approach, looking for patterns in our code categories that were consistent within one approach but varied between approaches. Recurring mentions of critical timing and differences in firms' responses led us to develop constructs related to *decision dynamics*, while discussions on production capacities and AM implementation informed constructs on the *production context*. Based on iterative analysis and discussions, we identified five contextual factors as key to understanding how firms adopt AM to address spare part shortages.

3.4 | Theoretical Adaptation of the AMC Perspective

Building on the AMC perspective that Chen (1996) originally developed, we theoretically calibrated and contextualized this framework to fit our study. Specifically, we redefined the three constructs as follows: *Awareness* relates to a firm knowing about the spare part shortage and benefits of using AM. *Motivation* refers to the firms' desire to prevent or mitigate spare part shortages using AM. *Capability* refers to the technical and organizational *capabilities* to adopt AM.

Figure 1 shows how we adapted the original framework of the AMC perspective to our study and how contextual factors, the AMC perspective, and AM adoption are linked. The AMC constructs represent the drivers that lead to and explain a firm's behavior. In our study, this behavior is the firm's move to adopt AM and we break it down into the likelihood of AM adoption (*Does a firm adopt AM?*) and the type of AM adoption (*How does a firm adopt AM?*).

4 | Findings

4.1 | Contextual Factors

Building on our data analysis, we categorize the five identified contextual factors that influence how firms adopt AM when experiencing spare part shortages into two main categories: *decision dynamics* and *production context*. *Decision dynamics* concerns the temporal aspects of the spare part shortage containing two contextual factors. First, *problem urgency* represents how quickly firms must respond to a shortage, contingent on the severity of its consequences. This varies from the imperative for immediate action to a forward-looking, low-pressure approach to decision-making. Second, *response strategy* reflects a firm's attitude toward managing shortages—whether it employs a reactive approach, addressing shortages as they emerge, a proactive approach, anticipating and mitigating potential shortages in advance, or a mix of both.

Production context relates to the operational and manufacturing environment including three contextual factors regarding the original product, the spare part, and AM. First, *original product production status* refers to the original product (not spare part) and indicates whether the original product is currently being manufactured, which influences spare part production and demand, for example, as an indicator of readily accessible capacities for part production. Second, *spare part production readiness* refers to the spare part and reflects firms' spare part production capacities and spare part inventory management, spare part designs, data availability, delivery and supplier networks, reverse logistics, and customer services. Third, *AM production implementation* concerns how firms incorporate AM into after-sales

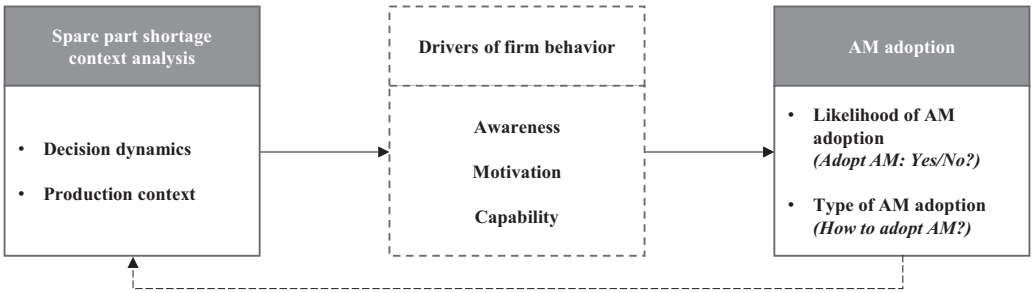

FIGURE 1 | Theoretical adaptation of the AMC perspective to AM adoption in the context of spare part shortages.

TABLE 3 | Contextual factors.

Contextual factor	Definition and operationalization		
Problem urgency	*Problem urgency* relates to how quickly firms react to a spare part shortage depending on the criticality and consequences. Firms apply different strategies to cope and manage situations of varying *problem urgency*, for example, by applying criticality segment policies or extensive stocking of critical spare parts (Boone et al. 2018; Cohen, Agrawal, and Agrawal 2006; Durugbo 2020).		
Description	High *problem urgency* requires immediate action, as it leads to stockouts, rising costs, or dissatisfied customers. Firms must quickly create solutions outside of their usual after-sales processes to maintain reliable spare parts services.	Medium *problem urgency* allows for a moderate timeframe to resolve issues, as firms are aware of the challenges in advance. While costs or other impacts may occur, they are manageable and can be factored into decision-making.	Low *problem urgency* involves long-term problem solving, as the issue affects future products not yet sold. No immediate costs arise, giving firms ample time to assess options and decide on actions.
Example quote	"For example, when a shaft breaks [...]. That happens very abrupt, and you have to react to it instantly." (Firm B.3)	"We currently have a bottleneck with spare parts as far as suppliers are concerned [and] must address endlessly long delivery times." (Firm B.5)	"[The extended producer responsibility] is coming. [...] For furniture, they are discussing the "right to repair" in different forms." (Firm C.4)
Response strategy	*Response strategy* reflects a firm's overall attitude toward managing shortages—whether it adopts a reactive approach, dealing with issues as they arise, a proactive approach, anticipating and preventing problems before they occur, or a mixed strategy that combines both reactive and proactive measures.		
Description	Proactive *response strategy* involves anticipating and preventing spare part shortages before they become critical, ensuring continuous availability.	Mixed *response strategy* combines reactive and proactive measures, addressing current shortages while implementing steps to prevent future issues.	Reactive *response strategy* focuses on resolving shortages after they occur, using immediate solutions like emergency sourcing or temporary fixes, without prior planning for future problems.
Example quote	"We are anticipating potential spare part needs by integrating a 3D printer specifically for maintenance work. We see it as a standard tool in our workshop, much like a lathe." (Firm B.1)	"We use 3D printing for spare parts, moving from occasional use in our training center to making it a regular workshop tool. [...] This helps with short-term maintenance needs, and we build the skills to make AM a key future toolkit." (Firm B.2)	"We had an unexpected shaft breakage [...] and had to react immediately since no spare part was available on the spot. [In other situations], we had to scramble for a quick solution as there was no advance planning for these issues." (Firm B.3)
Original product production status	*Original product production status* relates to the original product (not spare part) lifecycle and describes if the original product is currently produced. Depending on the product's position in its lifecycle, production can either be ongoing, yet to start, or (partially) ceased, indicating to what extent production capacities are available for spare parts production (Dekker et al. 2013; Hu et al. 2018; Hur, Keskin, and Schmidt 2018; Persson and Saccani 2009).		
Description	High *original product production status* means original products are actively produced and used, with high market demand, active production lines, and significant resources allocated to maintain production and to source parts.	Medium *original product production status* means original products are still produced but on a reduced scale, with moderate demand, fewer production lines, or selective resource allocation. Production may have recently ceased, but products are still in use.	Low *original product production status* means original product production has ceased or has yet to start. There is minimal or no market demand, no active production lines, little to no resources allocated, and no suppliers existent.

(Continues)

TABLE 3 | (Continued)

Contextual factor	Definition and operationalization		
Contextual factor	Definition and operationalization		
Example quote	"We use the same supply sources [and production lines] for the original parts and for spare parts. [...] The supplier who supplied the original part production also supplies after-sales." (Firm A.1)	"We face the challenge that [...] as demand for spare parts increases, original part production has already been reduced or ceased and spare parts are no longer being produced." (Firm C.1)	"The design of [production and] supply chains is defined by us. We decide [for our future products] whether to purchase parts from our factories or from external suppliers or [...] produce them ourselves." (Firm C.2)
Spare part production readiness	*Spare part production readiness* relates to the extent to which after-sales services and spare part production capacities are in place at firms. After-sales services go beyond the mere spare parts production and include for example spare parts inventory management, spare part designs, delivery and supplier networks, reverse logistics, and customer services (Boone et al. 2018; Cohen, Agrawal, and Agrawal 2006; Saccani, Songini, and Gaiardelli 2006).		
Description	High *spare part production readiness* indicates that firms have well-developed after-sales services, including spare parts production, product data, tooling, warehousing, logistics, suppliers, and customer services.	Medium *spare part production readiness* means that after-sales services are only partially in place (e.g., missing tools or suppliers), requiring action to restore or improve production capacities.	Low *spare part production readiness* indicates that after-sales services are entirely absent, either because production has not started or has ceased and the firm discontinued these services.
Example quote	"We provide [spare parts] to extend the product life and we provide offers like repair service, assembly, or refurbishment service." (Firm C.4)	"We [struggle with] spare part shortages [because] tools are worn out [...] or must be reworked or refurbished or manufactured from scratch. And then the question comes up: Is it still economic [to produce spare parts] considering the low quantities?" (Firm C.3)	"We work together with the customer [to decide] which value-added services we can offer in the future. As a result, [we ask ourselves] what does our supply chain have to look like?" (Firm A.6)
AM production implementation	*AM production implementation* refers to the after-sales service setup of firms and the extent to which AM has been integrated into the firm's production processes for creating spare parts. Firms include AM in their after-sales services at different stages and in varying extent ranging from substituting traditional manufacturing with AM (while keeping all other processes identical) to designing after-sales services around the AM value chain (Akmal et al. 2022; Knofius, van der Heijden, and Zijm 2019).		
Description	Extensive *AM production implementation* means AM is central to after-sales and spare parts production, with services fully designed to leverage AM's value chain benefits (e.g., digital warehousing, on-demand production).	Selective *AM production implementation* means AM is used for some spare parts, but firms do not fully integrate its value chain benefits into their after-sales services.	No *AM production implementation* means that AM is not used for spare parts production when designing after-sales services.
Example quote	"3D printing is not just an alternative production process, but it is a supply chain management tool for us. It enables extending the product lifecycle indefinitely. You don't have to compare inventory and manufacturing costs, calculate obsolescence or last calls." (Firm C.1)	"[First], the costs are significantly cheaper if we produce [certain plastic parts] ourselves than if we procure it externally. Second, is speed [...]. From a maintenance perspective, that is the essential benefit of a 3D printer." (Firm B.1)	"If a product [...] is not designed for 3D printing, then it is incredibly difficult to make it 3D printable [in hindsight...] and we don't do it." (Firm C.3)

services for spare part supply. This ranges from selectively replacing traditional manufacturing with AM to extensively redesigning after-sales services around the entire AM value chain. Table 3 provides a detailed overview of the five contextual factors including the general definitions used in this study, a description of levels of each contextual factor, and exemplary quotes that serve as the basis for developing these contextual factors.

4.2 | Three Approaches to Adopt AM in After-Sales

Based on the contextual factors, we introduce a typology of three approaches—corrective, preventive, or anticipatory. The configuration of contextual factors determines which approach firms follow. Figure 2 shows the typology of the three approaches, the related configuration of contextual factors, and the relevance for each firm type.

4.2.1 | Corrective Approach

In the corrective approach, firms adopt AM to address short-term issues in after-sales services, such as unexpected supplier disappearances or incorrect last calls (see Appendix S1 for a detailed overview of AM applications). Almost all the study's firms experience severe, short-term challenges, often resulting in costly warehousing or spare part shortages: "At some point, you stock up on spare parts and you don't know if you will ever need them. [But because we have] the 3D files, we can produce this spare part within x hours ... and put significantly fewer spare parts in stock" (Firm B.4). Firms following this approach react to external change and develop short-term solutions. Their main *motivation* is lowering costs (e.g., warehousing) and time (e.g., transportation and customs), resulting in reduced after-sales service complexity while preserving customer satisfaction.

The corrective approach is strongly associated with a high *problem urgency* as firms need to fix time- and cost-critical problems quickly. Firms demonstrate a reactive *response strategy* as they are confronted with ad hoc shortages that they must address immediately. The corrective approach occurs when original products are currently being produced, which correlates with a high *original product production status*. Additionally, firms usually have spare part production and after-sales services in place, correlating with a high *spare part production readiness* and allowing firms to make spare parts available quickly. Firms in these situations adopt AM only to the extent necessary to produce specific spare parts, categorizing them as selective *AM production implementation*.

For the corrective approach, firms create *awareness* by, for example, establishing close communications with their customers so that they quickly learn about spare part shortages (Figure 3, 1a). Additionally, firms increase their *awareness* through transparency within their own processes (e.g., connecting digital warehouse management software) and establishing an AM knowledge base (e.g., pilot projects). A business case for AM strongly drives *motivation* to execute the corrective approach (Figure 3, 2a). Specifically, firms balance costs and benefits in case of shortages to decide on AM adoption. However, from the B2B customers' perspective for example, *motivation* to solve spare part shortages is intense because machine downtime is costly and must be avoided at (nearly) all costs: "If the machine in a production line breaks down and a customer is losing €1.5 million an hour, we set heaven and hell in motion so that the problem gets fixed quickly" (Firm A.6). In many situations relating to the corrective approach, an absent business case for AM results in firms lacking *motivation* and thus not adopting AM. To follow the corrective approach, firms need substantial technical *capabilities* (Figure 3, 3a) encompassing the acquisition and utilization of AM infrastructure (e.g., printers, software, and materials), operational expertise and training, access to or creation of 3D files, testing and certification of printed parts, and comprehension of AM applications.

4.2.2 | Preventive Approach

The preventive approach includes applications in which firms adopt AM to tackle medium-term problems in after-sales

Approach	Corrective approach *Improve after-sales operations*	Preventive approach *Use for low spare part demand*	Anticipatory approach *Meet future customer requirements and regulations*
Contextual factors			
Decision dynamics	*Ad hoc / short-term*	*Medium-term*	*Future / long-term*
Problem urgency	High	Medium	Low
Response strategy	Reactive	Mixed	Proactive
Production context			
Original product production status	High	Medium	Low
Spare part production readiness	High	Medium	Low
AM production implementation	Selective	Selective	Extensive
Assessment			
Relevance for groups			
Type A: B2B OEMs	High	High	Medium
Type B: B2B customers	High	Low	Low
Type C: B2C OEMs	High	Medium	High

FIGURE 2 | Summary of the approaches how to adopt AM in after-sales.

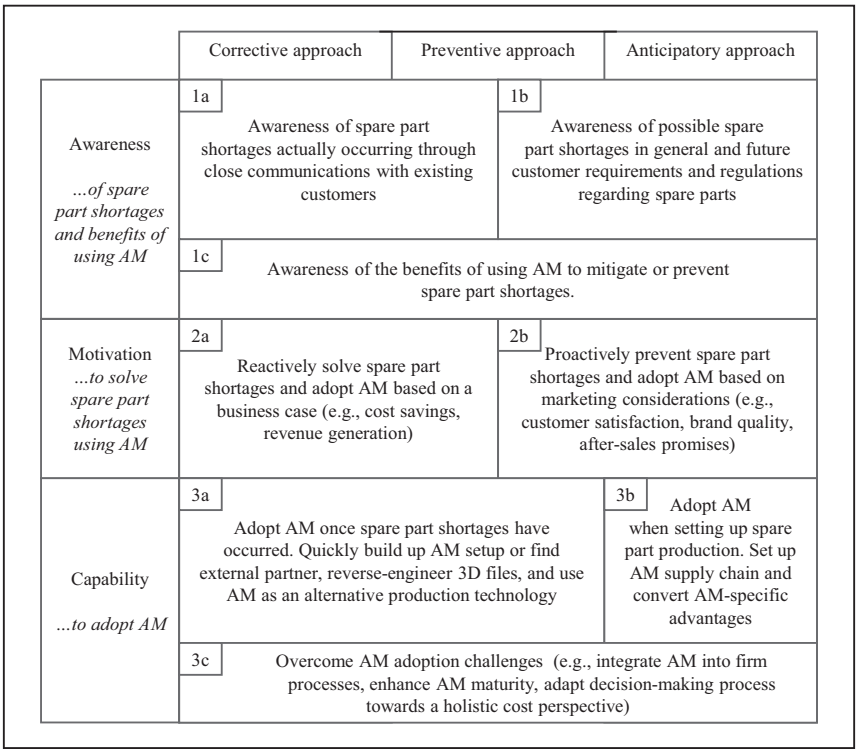

FIGURE 3 | The AMC perspective with respect to the corrective, preventive, and anticipatory approaches.

services. Most firms encounter challenges when spare part demand is low (see Appendix S1 for a detailed overview of AM applications), either because the parts are specialized and the installed base of the original product is low, or the original product is at the end of its lifecycle and production technologies for spare parts have ceased (e.g., tools no longer exist or have worn out): "We [struggle with] spare part shortages [because] tools are worn out [...] or must be reworked or refurbished or manufactured from scratch. And then the question comes up: Is it still economic [to produce spare parts] considering the low quantities?" (Firm C.3).

The preventive approach is associated with a medium *problem urgency* as firms face spare part shortages that are less urgent, costly, or demanding of immediate action compared to the corrective approach. Firms display mixed *response strategies* including both reactive and proactive aspects. The applications in the preventive approach involve original products with a medium *original product production status*. Since forecasting future spare part demand is difficult and production capacities for spare parts are often no longer available, firms have limited after-sales services in place corresponding with a medium *spare part production readiness*: "Only in a few cases, serial production of spare parts is possible once the production [of the original product] has ceased. ... That is why 3D printing is used" (Firm C.1). Like in the corrective approach, in the preventive approach firms may not plan for AM before shortages occur, but instead adopt it when needed and to the extent necessary, corresponding with selective *AM production implementation*.

The preventive approach blends key aspects of both the corrective and anticipatory approaches, emphasizing a balanced focus on current operational needs and potential future risks. *Awareness* in this approach involves a heightened sensitivity to immediate supply chain vulnerabilities while simultaneously anticipating future challenges (Figure 3, 1a,b). *Motivation* in the preventive approach is similarly multifaceted, combining the economic drive to avoid operational disruptions with strategic considerations that focus on long-term brand reputation and customer satisfaction (Figure 3, 2a,b). Immediate financial benefits of avoiding downtime costs or shortages and the desire to maintain a strong market position through reliable after-sales support motivate firms to adopt AM. In addition, the broader goal of sustaining customer trust and loyalty drives firms to follow this approach to adopt AM even in cases where the immediate business case is not compelling. The *capabilities* required for the preventive approach align closely with the ones necessary for the corrective approach, focusing on technical infrastructure, operational expertise, and certification processes (Figure 3, 3a). However, it is crucial to note that while these *capabilities* are essential for the preventive approach, they also support the successful implementation of the corrective and anticipatory approaches. Thus, firms following the preventive approach cultivate a versatile AM *capability* set that not only addresses immediate operational needs but also equips them to handle future uncertainties in the supply chain.

4.2.3 | Anticipatory Approach

The anticipatory approach involves firms planning to address future challenges such as upcoming regulations and customer requirements by adopting AM (see Appendix S1 for a detailed overview of AM applications). Specifically, we find that customers increasingly expect spare part availability long after the sale, inspiring legislation to strengthen product repairability and

sustainability requirements. This, in turn, facilitates AM adoption and compels firms to extend spare part provision periods: "We offer this eternal spare part, which makes AM interesting. Even after 10 or 12 years. If [our customer] no longer has the original spare parts, you can still offer them with AM anyway" (Firm C.1). Additionally, firms are motivated to include AM spare part production in future contract negotiations: "When we order the [machine], it would be smart to order the 3D data at the same time so that we are more independent [from our OEM]. The procurement of spare parts of the future is not to make a last call, but to offer it forever over the product lifecycle" (Firm B.2). Firms taking the anticipatory approach strongly believe that having committed to AM, they will find further applications to deepen the firm's AM expertise, become profitable with AM in the long-term, and position themselves as technology leaders regarding AM.

The anticipatory approach is associated with a low *problem urgency* and a proactive *response strategy* as firms act with no immediate need or no business case being present (yet). Since this approach involves future products, no (or very limited) original product production and spare part after-sales capacities are in place representing low levels of *original product production status* and *spare part production readiness*. Firms have the time and resources to set up after-sales services in line with AM requirements and exploit its benefits along the whole value chain (e.g., digital warehousing, reduced transportation and warehousing, and optimally designed spare parts for AM production), which aligns with extensive *AM production implementation*.

The anticipatory approach involves a proactive stance and firms' knowledge of upcoming legislation, customer expectations, and supplier challenges characterize their *awareness* (Figure 3, 1b). A high level of *awareness* drives firms to actively plan for potential spare part shortages and develop mitigation strategies that include AM adoption. For example, firms discuss future supply risks and assess how AM can support long-term spare parts availability, recognizing that some suppliers may not sustain production over extended periods: "We are currently assessing our future AM in-house production [for spare parts]. To supply spare parts over the product lifecycle, our supplier must stay in business for more than 40 years. Realistically, that means there will be suppliers that will not provide spare parts that long" (Firm B.2).

Primarily marketing considerations such as maintaining customer satisfaction, upholding brand quality, and fulfilling after-sales promises drives *motivation* in the anticipatory approach. Even when a direct business case for AM is missing, firms may still adopt AM to preserve their reputation as reliable, quality-focused providers. This approach is particularly important for OEMs seeking to retain customer loyalty and secure future sales through continuous support and availability of spare parts: "[Adopting AM] is a marketing decision. We want to avoid [telling] the customer that we no longer have the spare parts. Five years ago, the customer might have accepted such a statement ..., but this sort of conversation with a customer is not possible today" (Firm C.1).

The *capabilities* required for the anticipatory approach extend beyond technical skills required for the corrective or preventive approach and include significant organizational *capabilities*. These involve designing AM-specific supply chains, certifying AM suppliers, and adapting internal processes to accommodate AM (Figure 3, 3b): "Supply chain design, that is basically [a] major pillar for [AM adoption]. That includes analyzing production plants or suppliers and initiating processes to adjust to AM" (Firm C.3). Organizational *capabilities* are essential for aligning the firm's supply chain with AM requirements and for ensuring that AM adoption supports long-term strategic goals, making the anticipatory approach a comprehensive and forward-looking strategy.

4.3 | Relevance of AM Adoption Approaches for Different Firm Types

The relevance of the three AM adoption approaches varies across the three firm types in our study (see Figure 2). Our findings show that the market orientation (B2B vs. B2C) and supply chain tiers (OEMs vs. customers) significantly influence the relevance of each AM adoption approach for firms, explaining variations in AM adoption.

First, whether a firm operates in a B2B or B2C setting comes with differences in production and demand, control over spare parts, regulatory and customer pressures, and cost efficiency considerations, which in turn lead to varying relevance for each approach. For example, B2B OEMs adopt preventive and anticipatory approaches because of their need for stringent control over spare parts and brand image, while B2C OEMs focus on customer-centric and regulatory aspects. These differences arise because B2B OEMs deal with long-term parts supply and brand integrity, while B2C OEMs face high-volume production and evolving customer requirements. B2B OEMs find AM particularly advantageous, as it enables them to cater to customized and low-volume spare part demands over extensive periods.

In contrast, B2C OEMs face limitations in reaping AM's benefits given their products' typically standardized, high-volume nature. However, high customer influence, evolving requirements, and addressing sustainability concerns drive AM adoption for B2C OEMs. Additionally, meeting impending regulation becomes crucial for B2C OEMs that anticipate increased regulatory requirements. This positions B2C OEMs to extend products' lifespans in line with future maintenance regulations, whereas the existing stringent regulations in the B2B setting make this consideration less pressing for B2B OEMs: "The 'right to repair,' which is now coming from the European Union, is based on people's awareness about moving away from the throwaway society and [increasing] the pressure to repair. In the B2C sector, it's all about the customers. [The pressure to repair] has always been there in the B2B sector" (Firm VI).

Second, in the realm of B2B supply chains, supply chain tiers impact AM adoption because OEMs leverage AM to maintain brand control and manage spare parts in response to warranty requirements and supply chain challenges, while B2B customers, with established in-house maintenance practices, often see less need for AM despite its benefits in streamlining internal processes. Specifically, B2B OEMs wield influence in the spare

part domain, for example, by requiring customers to adhere to warranty guidelines: "Inside of warranty you must use the original spare parts and, if you don't, you lose your warranty. ... For the OEM, it's crucial to control [brand image] as much as possible" (Firm I). Controlling brand image is pivotal for OEMs, prompting their adoption of AM to address supply chain challenges and bolster resilience.

This allows OEMs to navigate supplier-related issues and elevate customer satisfaction. In contrast, B2B customers, with their established in-house maintenance practices and alternative spare part methods such as stocking and just-in-time delivery, experience fewer disruptions and often find cost-effective solutions that reduce the perceived need for AM in their supply chain dynamics. However, B2B customers recognize the value of AM in streamlining internal processes and generating components with reduced qualification and testing prerequisites compared to OEMs. While mainly B2B OEMs capitalize on the preventive approach during periods of low spare part demand, B2B customers, driven by cost considerations, already extensively employ alternative methods to uphold product functionality. As a result, the widespread maintenance practices observed in B2B customers limit the broader potential for leveraging AM to enhance maintenance activities.

4.4 | Differences in AM Adoption Leveraging the AMC Perspective

With some firms having integrated AM into routine after-sales services and others only initiating test runs to explore its potential (see Table 2), applying the AMC perspective leads to three key insights that explain differences in AM adoption: (1) lack of *awareness*, *motivation*, and/or *capability*, (2) differences in AM *capabilities*, and (3) differences in overcoming AM adoption challenges. First, our study shows that firms do not adopt AM if they lack either *awareness*, *motivation*, or *capability*. For AM adoption to occur, all three constructs must be present: *awareness* of spare part shortages and the benefits of AM, *motivation* to address shortages using AM, and *capability* to adopt AM. In some situations, firms have access to AM *capabilities* but still do not adopt due to a lack of *awareness* or *motivation*. The lack of *awareness* often results from poor inventory management, data analytics gaps, or communication breakdowns within the organization (e.g., firms A.6 and B.4). Similarly, some firms that are aware of AM's benefits lack *motivation* to adopt it, as they are not convinced by the business case or marketing considerations and instead focus on selling new products or maintaining operational simplicity (e.g., firms A.1 and C.1).

Second, the alignment between a firm's existing and required AM *capabilities* varies across the adoption approaches identified in the study. The most important *capabilities* for AM adoption in our study include AM-specific technical *capabilities* (e.g., acquiring and utilizing AM infrastructure, providing training, creating 3D files, certifying printed parts, designing parts for AM, and investing in R&D for advanced materials and digital twins) and non-technical *capabilities* (e.g., fostering cross-functional collaboration, strategically planning supply chains, integrating AM evaluation early in the design phase, and developing streamlined approval processes). While all *capabilities* are important, their relevance differs depending on the specific approach firms follow, leading to potential mismatches that explain why AM adoption differs across firms in similar contexts. The required *capabilities* also vary depending on whether firms choose to develop AM in-house or outsource it. Firms with more in-house AM expertise or infrastructure tend to adopt AM more easily, while those lacking these elements rely on external partners.

Third, our study identifies four major AM adoption challenges and firms differ in their ability to overcome those challenges. First, integrating AM for spare part production into existing processes proves complex and costly, particularly as product development departments often prioritize original part production over spare parts. A lack of communication between departments further complicates this integration (e.g., firms A.1 and B.4). Second, firms face difficulties with the qualification and certification processes for AM, which are time-consuming and expensive. Acceptance of AM by employees and customers, along with alignment to the firm's business model, also present challenges (e.g., firms A.5 and C.2). Third, the overall maturity of AM remains a hurdle, with concerns about quality, data acquisition, and intellectual property hindering widespread adoption (e.g., firms A.2 and B.1). Fourth, decision-making in after-sales often relies on simplistic unit-cost analyses, which can deter firms from adopting AM, despite its potential for overall savings across different business areas (e.g., firms A.1 and C.1).

5 | Discussion

5.1 | Contributions to Theory

Our study explains why AM adoption differs across firms, especially in the context of spare part shortages. We conducted a comparative case study, ensuring our findings are both theoretically grounded and practically insightful, identifying three distinct adoption approaches and using the AMC perspective to explain these differences. In line with Craighead, Ketchen, and Darby's (2019) call for actionable, insightful, and measurable research, and building on Stank et al.'s (2017) emphasis on middle-range theorizing to explain research phenomena, we present our contributions to theory below.

5.1.1 | Expanding Research on AM Adoption

First, our findings challenge the assumption that economic justification is the sole driver of AM adoption. Existing research often posits that firms switch to AM only when it offers immediate cost savings or operational efficiencies (Heinen and Hoberg 2019; Knofius, van der Heijden, and Zijm 2016; Westerweel et al. 2021). In contrast to this, our study reveals that firms can adopt AM even without a clear business case, particularly through the anticipatory approach. These firms prioritize long-term strategic benefits—such as building AM expertise and maintaining after-sales service commitments—over short-term economic considerations. Our findings also stress the importance of focusing on the criticality, related costs of disruptions, and situational context of spare part shortages. Based on our findings, we propose to shift the research perspective on AM adoption beyond economic feasibility

and to acknowledge and explore the strategic motivations involved in AM adoption. Our study's insights open new avenues for understanding AM adoption in the context of customer satisfaction, competitive pressures, and regulatory anticipation, allowing us to challenge the existing focus on economic justification.

Second, our findings reveal that AM adoption is not a straightforward, linear process but a dynamic, context-dependent journey. Existing research often presents AM adoption as a singular decision—such as whether to make-or-buy, when to replace traditional manufacturing, or which parts to produce with AM (Frandsen et al. 2020; Friedrich, Lange, and Elbert 2022; Handfield et al. 2022). However, our study shows that the specific context in which these decisions are made deeply influences AM adoption, as the impact of contextual factors, the firm's B2B or B2C setting, and its supply chain tiers demonstrates. Our study highlights instances where firms are reluctant to adopt AM despite technical and economic feasibility, and including contextual factors into the assessment helps to explain this discrepancy.

The interplay of contextual factors creates a dynamic environment, where firms tailor their AM approach based on their specific context. For instance, a spare part shortage may prompt firms to follow the corrective approach to immediately tackle short-term shortages while simultaneously (or subsequently) implement the anticipatory approach to mitigate future shortages. By analyzing contextual factors, we add a new dimension to identifying spare parts suitable for AM, thus complementing the top-down portfolio analysis and bottom-up single spare part assessment (Heinen and Hoberg 2019; Knofius, van der Heijden, and Zijm 2016; Westerweel, Basten, and van Houtum 2018). Based on our findings, we emphasize the significant role of contextual factors in facilitating AM adoption, which allows new pathways for understanding AM adoption within the broader context of decision-making in after-sales.

Third, focusing on spare part shortages as our specific research context offers unique insights that expand existing knowledge on AM adoption. While most research tends to focus on parts for original production or occasionally spare parts, it rarely addresses spare part shortages (Akmal et al. 2022; Knofius, van der Heijden, and Zijm 2019; Lindemann et al. 2015), despite the critical challenges they pose (Westerweel et al. 2021). Our study fills this gap by highlighting how terminal spare part shortages represent decisions that significantly impact AM adoption. Through an in-depth analysis of this unique context—characterized by low and volatile part demand, high customer expectations, and the need for swift action—, we identify three distinct AM adoption approaches and demonstrate how organizational motivations influence AM adoption decisions. Based on our methodological choice and focus on a specific research context, we highlight the value of employing diverse methods and researching underexplored contexts in AM adoption research to close knowledge gaps.

5.1.2 | Leveraging the AMC Perspective

Applying the AMC perspective has been crucial in explaining why firms in similar contexts (e.g., industry, products, and after-sales challenges) vary in their AM adoption, offering insights missed by previous research. Although existing research mainly focuses on AM-specific *capabilities*, the limited attention to all three constructs of the AMC perspective in the literature (see Table 1) shows that research overlooks the critical roles of *awareness*, *motivation*, and non-technical *capabilities*.

First, critical *capabilities* in AM adoption extend beyond AM-specific skills to include the ability to develop and adapt these *capabilities* within the firm. Existing research highlights that AM adoption depends on firms having the necessary infrastructure and technology skills (Handfield et al. 2022; Mellor, Hao, and Zhang 2014; Xu, Rodgers, and Guo 2021) and making strategic make-or-buy decisions based on their *capabilities* or to safeguard their digital assets and foster internal learning (Friedrich, Lange, and Elbert 2022). However, our findings show that successful AM adoption also requires developing non-technical *capabilities*. Firms' ability to overcome the identified AM adoption challenges varies based on their *capabilities*, ultimately adding to the explanation of differences in AM adoption despite similar spare part shortages. Additionally, the make-or-buy decision reflects power dynamics in the AM supply chain, where firms without internal resources rely on external providers who leverage their expertise for favorable terms and long-term contracts. In line with Friedrich, Lange, and Elbert (2022), our findings support the importance of AM governance and transaction costs in explaining AM in-house or external AM adoption. Based on our findings, shifting the perspective on AM adoption beyond assessing required AM technology *capabilities* to understanding AM adoption in the context of overcoming organizational barriers, fostering internal collaboration, and leveraging partnerships is essential and provides opportunities to link AM adoption to research on strategic decision-making and organizational processes.

Second, both *awareness* and *motivation* play critical roles in AM adoption, acting as significant antecedents for AM adoption. Existing research on AM adoption tends to neglect the importance of *awareness* and *motivation* in the decision-making process (Frandsen et al. 2020; Lindemann et al. 2015; Mellor, Hao, and Zhang 2014). In contrast, our study reveals that these two constructs are not inherent, and a lack of either one significantly hinders AM adoption. Even when firms have the necessary technical *capabilities* and *motivation*, a lack of *awareness* about AM's benefits to mitigate a shortage can prevent adoption. In several situations, firms were unaware that AM could resolve issues they were facing, resulting in missed opportunities and reluctance to adopt AM. Similarly, *motivation* is a critical factor for AM adoption, as even firms with *awareness* and *capabilities* avoid AM adoption if they lack *motivation* to adopt AM or to solve the spare part shortage in general, particularly in situations of planned obsolescence. These insights demonstrate that research profits from viewing AM adoption through a broader lens that includes both *awareness* and *motivation* as pivotal antecedents. Understanding how firms develop *awareness* of AM's benefits, what drives their *motivation*, and how these elements influence AM adoption decisions is essential to overcoming the barriers that limit the widespread use of AM.

5.2 | Policy Recommendations and Managerial Implications

Our findings offer practical recommendations for managers and policymakers to facilitate AM adoption. Based on the insights from applying the AMC perspective, managers should start by developing *awareness* in two key areas (see Figure 3). First, create *awareness* of spare part shortages by analyzing the frequency, predictability, reasons, and financial and operational impacts of shortages. Second, create *awareness* of AM benefits, including technical capabilities and costs, for example by introducing AM pilot projects for non-critical parts, team leads to explore AM, or consulting from external service providers.

Once managers establish *awareness*, they should critically assess the firm's *motivation* to tackle spare part shortages. If shortages are not acceptable to the firm's after-sales strategy and should be mitigated, managers should define the most suitable adoption approach based on the AM applications in Appendix S1 and evaluate if the required *motivation* and *capability* to follow this approach are met (see Figure 3). While the corrective approach requires selective AM implementation only, the anticipatory approach requires an extensive AM implementation across the value chain (see Figure 2). Depending on the approach, managers should evaluate their *motivation* to adopt AM by developing a business case that includes costs and savings along the value chain and by analyzing non-monetary, after-sales related benefits of AM, for example, regarding customer satisfaction and AM expertise leadership.

Furthermore, managers should build the required *capabilities* depending on the selected approach. To follow the corrective approach, firms need *capabilities* that allow them to quickly produce spare parts. This includes the necessary printers, 3D files, expertise, and certification processes. To follow the preventive approach, firms require the same *capabilities* but have a more moderate timeframe to resolve the shortage (see Figure 2). To follow the anticipatory approach, firms also need the same *capabilities* as above but must additionally foster collaboration across departments to integrate AM into product design processes and to realize cost savings along the value chain (e.g., in warehousing or transportation). Based on our findings, managers should decide whether to build these *capabilities* in-house or source them externally based on the problem urgency, the availability of internal knowledge, resources, and technology, and the strategic importance of AM expertise. If AM is expected to become a core part of the after-sales business, building internal *capabilities* is essential, but if the focus is on finding an efficient and reliable solution to spare part shortages, outsourcing to a specialized service provider may be the better option.

Following these steps, managers can tailor their AM adoption strategy to effectively meet their business needs and leverage AM adoption to help reduce disruptions and enhance customer satisfaction. AM's advantages over traditional manufacturing—such as lower setup costs, tool-less production, shorter lead times, and improved part design—and its ability to improve supply chain responsiveness make it an attractive option for firms looking to mitigate spare part shortages.

Finally, recognizing AM's advantages are not only crucial for managers but also for policymakers who seek to promote AM adoption. By addressing all three elements of the AMC perspective, they can develop a business environment that facilitates AM adoption. Specifically, policymakers can raise *awareness* through public campaigns and communication strategies that emphasize the benefits of solving spare part shortages and using AM, increase *motivation* through subsidies and regulations that encourage firms to prioritize spare part availability and repair activities (e.g., the "right to repair"), and simplify investments in necessary AM *capabilities* and collaborations across firms. By doing so, they can help shape an environment that fosters greater AM adoption in spare part management, ultimately benefiting both businesses and the broader drive for sustainability.

5.3 | Limitations and Future Research

While our study provides novel insights into AM adoption, theoretical and methodological limitations remain. First, given our theoretical lens and research design, our study captures the complexity of AM adoption at a single point in time, while our findings reveal that AM adoption is a dynamic process rather than a singular decision. Ongoing technical advancements and shifting market conditions influence firms continuously and require them to adapt their strategies over time. Although our study provides valuable insights on this complexity at a specific moment, future studies could offer deeper understanding by tracking firms longitudinally through various stages of AM decision-making. For example, by applying innovation assimilation theory (Meyer and Goes 1988), researchers could gain more nuanced insights into the AM adoption process, complementing the context-dependent findings highlighted in our study and moving beyond the static view of the AMC perspective.

Second, there are methodological limitations linked to our comparative case study that affect the generalizability of our findings. Focusing on manufacturing firms in Germany may not fully represent firms in different regions or industries, the number of cases could limit the results, and firm selection may skew our findings toward firms more supportive of AM, as they were likely more willing to participate in this study. Since we find that regulations and customer requirements can significantly impact AM adoption, our findings are likely limited to countries with regulatory and cultural proximity to Germany. To address these limitations, future research could expand to diverse countries, industries, and cultures to assess the broader applicability of our findings and the role of contextual factors and AM approaches in these different settings.

6 | Conclusions

Our study conducts a comparative case study exploring AM adoption in the unique context of spare part shortages. We find that AM adoption varies, with firms employing corrective, preventive, or anticipatory approaches depending on the specific nature and context of the shortage. By applying the AMC perspective, we address this notable knowledge gap and can better explain differences in AM adoption that had not been fully understood before. Our study contributes to AM adoption research by challenging the assumption that economic justification primarily drives AM adoption, highlighting the contextual factors that influence the

dynamic, context-dependent process of AM adoption, and emphasizing the importance of non-technical *capabilities*, *awareness*, and *motivation* as critical antecedents for successful AM adoption. Further research on AM adoption in underexplored settings like spare part shortages will not only deepen theoretical understanding but also provide practical guidance for firms navigating the complexities of AM adoption.

Acknowledgments

This research project is funded by dtec.bw—Digitalization and Technology Research Center of the Bundeswehr.dtec.bw is funded by the European Union—NextGenerationEU. The authors thank the editorial team and the anonymous reviewers for their valuable support and guidance during the review process.

Conflicts of Interest

The authors declare no conflicts of interest.

Endnotes

[1] This study defines spare part shortages as prolonged unavailability of spare parts given manufacturing constraints or permanent cessation.

[2] We excluded B2C customers as they are individuals rather than manufacturing firms and usually do not manage spare part stocks, have no strong relationships with spare part suppliers, and differ from manufacturing firms in their decision-making process.

References

Akmal, J. S., M. Salmi, R. Björkstrand, J. Partanen, and J. Holmström. 2022. "Switchover to Industrial Additive Manufacturing: Dynamic Decision-Making for Problematic Spare Parts." *International Journal of Operations & Production Management* 42, no. 13: 358–384. https://doi.org/10.1108/IJOPM-01-2022-0054.

Bennett, V. M., and L. Pierce. 2016. "Motivation Matters: Corporate Scope and Competition in Complementary Product Markets." *Strategic Management Journal* 37, no. 7: 1304–1315. https://doi.org/10.1002/smj.2398.

Blair, C. W., M. Rungtusanatham, E. Rabinovich, Y. Hwang, and R. B. Money. 2020. "Managing Critical Spare Parts Within a Buyer-Supplier Dyad: Buyer Preferences for Ownership and Placement." *Journal of Business Logistics* 41, no. 2: 111–128. https://doi.org/10.1111/jbl.12243.

Bonnín Roca, J., P. Vaishnav, R. E. Laureijs, J. Mendonça, and E. R. H. Fuchs. 2019. "Technology Cost Drivers for a Potential Transition to Decentralized Manufacturing." *Additive Manufacturing* 28: 136–151. https://doi.org/10.1016/j.addma.2019.04.010.

Boone, C. A., B. T. Hazen, J. B. Skipper, and R. E. Overstreet. 2018. "A Framework for Investigating Optimization of Service Parts Performance With Big Data." *Annals of Operations Research* 270, no. 1: 65–74. https://doi.org/10.1007/s10479-016-2314-1.

Chekurov, S., S. Metsä-Kortelainen, M. Salmi, I. Roda, and A. Jussila. 2018. "The Perceived Value of Additively Manufactured Digital Spare Parts in Industry: An Empirical Investigation." *International Journal of Production Economics* 205, no. September: 87–97. https://doi.org/10.1016/j.ijpe.2018.09.008.

Chen, M. 1996. "Competitor Analysis and Interfirm Rivalry: Toward a Theoretical Integration." *Academy of Management Review* 21, no. 1: 100–134. https://doi.org/10.5465/amr.1996.9602161567.

Chen, M., K. Su, and W. Tsai. 2007. "Competitive Tension: The Awareness-Motivation-Capability Perspective." *Academy of Management Journal* 50, no. 1: 101–118. https://doi.org/10.5465/amj.2007.24162081.

Christopher, M., and L. J. Ryals. 2014. "The Supply Chain Becomes the Demand Chain." *Journal of Business Logistics* 35, no. 1: 29–35. https://doi.org/10.1111/jbl.12037.

Cohen, M. A., N. Agrawal, and V. Agrawal. 2006. "Winning in the Aftermarket." *Harvard Business Review* 84, no. 5: 129–138.

Cohen, M. A., and H. L. Lee. 1990. "Out of Touch With Customer Needs? Spare Parts and After Sales Service." *Sloan Management Review* 31, no. 2: 55–66.

Craighead, C. W., D. J. Ketchen, and J. L. Darby. 2019. "Taking AIM at Theoretical and Pragmatic Impact: A Call for Actionable, Insightful, and Measurable Rresearch." *Journal of Business Logistics* 40, no. 4: 289–298. https://doi.org/10.1111/jbl.12214.

Dekker, R., Ç. Pinçe, R. Zuidwijk, and M. N. Jalil. 2013. "On the Use of Installed Base Information for Spare Parts Logistics: A Review of Ideas and Industry Practice." *International Journal of Production Economics* 143, no. 2: 536–545. https://doi.org/10.1016/j.ijpe.2011.11.025.

Deutsche Bahn. 2022. "Die DB am Drucker." https://www.deutschebahn.com/de/3d_druck-6898636.

Durugbo, C. M. 2020. "After-Sales Services and Aftermarket Support: A Systematic Review, Theory and Future Research Directions." *International Journal of Production Research* 58, no. 6: 1857–1892. https://doi.org/10.1080/00207543.2019.1693655.

Dutton, J. E., and S. E. Jackson. 1987. "Categorizing Strategic Issues: Links to Organizational Action." *Academy of Management Review* 12, no. 1: 76–90. https://doi.org/10.5465/amr.1987.4306483.

Eisenhardt, K. M. 1989. "Building Theories From Case Study Research." *Academy of Management Review* 14, no. 4: 532–550. https://doi.org/10.5465/amr.1989.4308385.

Eisenhardt, K. M., and M. E. Graebner. 2007. "Theory Building From Cases: Opportunities and Challenges." *Academy of Management Journal* 50, no. 1: 25–32. https://doi.org/10.5465/amj.2007.24160888.

Fawcett, S. E., and M. A. Waller. 2014. "Supply Chain Game Changers—Mega, Nano, and Virtual Trends—And Forces That Impede Supply Chain Design (i.e., Building a Winning Team)." *Journal of Business Logistics* 35, no. 3: 157–164. https://doi.org/10.1111/jbl.12058.

Ferdows, K. 2018. "Keeping Up With Growing Complexity of Managing Global Operations." *International Journal of Operations & Production Management* 38, no. 2: 390–402. https://doi.org/10.1108/IJOPM-01-2017-0019.

Frandsen, C. S., M. M. Nielsen, A. Chaudhuri, J. Jayaram, and K. Govindan. 2020. "In Search for Classification and Selection of Spare Parts Suitable for Additive Manufacturing: A Literature Review." *International Journal of Production Research* 58, no. 4: 970–996. https://doi.org/10.1080/00207543.2019.1605226.

Friedrich, A., A. Lange, and R. Elbert. 2022. "Make-Or-Buy Decisions for Industrial Additive Manufacturing." *Journal of Business Logistics* 43, no. 4: 623–653. https://doi.org/10.1111/jbl.12302.

Geng, R., H. K. S. Lam, and M. Stevenson. 2022. "Addressing Modern Slavery in Supply Chains: An Awareness-Motivation-Capability Perspective." *International Journal of Operations & Production Management* 42, no. 3: 331–356. https://doi.org/10.1108/IJOPM-07-2021-0425.

Handfield, R. B., J. Aitken, N. Turner, T. Boehme, and C. Bozarth. 2022. "Assessing Adoption Factors for Additive Manufacturing: Insights From Case Studies." *Logistics* 6, no. 2: 36. https://doi.org/10.3390/logistics6020036.

Heinen, J. J., and K. Hoberg. 2019. "Assessing the Potential of Additive Manufacturing for the Provision of Spare Parts." *Journal of Operations Management* 65, no. 8: 810–826. https://doi.org/10.1002/joom.1054.

Hu, Q., J. E. Boylan, H. Chen, and A. Labib. 2018. "OR in Spare Parts Management: A Review." *European Journal of Operational Research* 266, no. 2: 395–414. https://doi.org/10.1016/j.ejor.2017.07.058.

Hur, M., B. B. Keskin, and C. P. Schmidt. 2018. "End-Of-Life Inventory Control of Aircraft Spare Parts Under Performance Based Logistics." *International Journal of Production Economics* 204: 186–203. https://doi.org/10.1016/j.ijpe.2018.07.028.

Ketokivi, M., and T. Choi. 2014. "Renaissance of Case Research as a Scientific Method." *Journal of Operations Management* 32, no. 5: 232–240. https://doi.org/10.1016/j.jom.2014.03.004.

Khajavi, S. H., J. Partanen, and J. Holmström. 2014. "Additive Manufacturing in the Spare Parts Supply Chain." *Computers in Industry* 65, no. 1: 50–63. https://doi.org/10.1016/j.compind.2013.07.008.

Kiesler, S., and L. Sproull. 1982. "Managerial Response to Changing Environments: Perspectives on Problem Sensing From Social Cognition." *Administrative Science Quarterly* 27, no. 4: 548–570. https://doi.org/10.2307/2392530.

Knofius, N., M. C. van der Heijden, A. Sleptchenko, and W. H. M. Zijm. 2021. "Improving Effectiveness of Spare Parts Supply by Additive Manufacturing as Dual Sourcing Option." *OR Spectrum* 43, no. 1: 189–221. https://doi.org/10.1007/s00291-020-00608-7.

Knofius, N., M. C. van der Heijden, and W. H. M. Zijm. 2016. "Selecting Parts for Additive Manufacturing in Service Logistics." *Journal of Manufacturing Technology Management* 27, no. 7: 915–931. https://doi.org/10.1108/JMTM-02-2016-0025.

Knofius, N., M. C. van der Heijden, and W. H. M. Zijm. 2019. "Moving to Additive Manufacturing for Spare Parts Supply." *Computers in Industry* 113: 103–134. https://doi.org/10.1016/j.compind.2019.103134.

Kurata, H., and S. H. Nam. 2010. "After-Sales Service Competition in a Supply Chain: Optimization of Customer Satisfaction Level or Profit or Both?" *International Journal of Production Economics* 127, no. 1: 136–146. https://doi.org/10.1016/j.ijpe.2010.05.005.

Kurpjuweit, S., C. G. Schmidt, M. Klöckner, and S. M. Wagner. 2021. "Blockchain in Additive Manufacturing and Its Impact on Supply Chains." *Journal of Business Logistics* 42, no. 1: 46–70. https://doi.org/10.1111/jbl.12231.

Lant, T. K., F. J. Milliken, and B. Batra. 1992. "The Role of Managerial Learning and Interpretation in Strategic Persistence and Reorientation: An Empirical Exploration." *Strategic Management Journal* 13, no. 8: 585–608. https://doi.org/10.1002/smj.4250130803.

Li, Y., G. Jia, Y. Cheng, and Y. Hu. 2017. "Additive Manufacturing Technology in Spare Parts Supply Chain: A Comparative Study." *International Journal of Production Research* 55, no. 5: 1498–1515. https://doi.org/10.1080/00207543.2016.1231433.

Lindemann, C., T. Reiher, U. Jahnke, and R. Koch. 2015. "Towards a Sustainable and Economic Selection of Part Candidates for Additive Manufacturing." *Rapid Prototyping Journal* 21, no. 2: 216–227. https://doi.org/10.1108/RPJ-12-2014-0179.

Mellor, S., L. Hao, and D. Zhang. 2014. "Additive Manufacturing: A Framework for Implementation." *International Journal of Production Economics* 149: 194–201. https://doi.org/10.1016/j.ijpe.2013.07.008.

Meyer, A. D., and J. B. Goes. 1988. "Organizational Assimilation of Innovations: A Multilevel Contextual Analysis." *Academy of Management Journal* 31, no. 4: 897–923. https://doi.org/10.2307/256344.

Persson, F., and N. Saccani. 2009. "Managing the After-Sales Logistic Network—A Simulation Study." *Production Planning and Control* 20, no. 2: 125–134. https://doi.org/10.1080/09537280802707530.

Pourakbar, M., J. B. G. Frenk, and R. Dekker. 2012. "End-Of-Life Inventory Decisions for Consumer Electronics Service Parts." *Production and Operations Management* 21, no. 5: 889–906. https://doi.org/10.1111/j.1937-5956.2012.01340.x.

Rigopoulou, I. D., I. E. Chaniotakis, C. Lymperopoulos, and G. I. Siomkos. 2008. "After-Sales Service Quality as an Antecedent of Customer Satisfaction: The Case of Electronic Appliances." *Managing Service Quality: An International Journal* 18, no. 5: 512–527. https://doi.org/10.1108/09604520810898866.

Saccani, N., L. Songini, and P. Gaiardelli. 2006. "The Role and Performance Measurement of After-Sales in the Durable Consumer Goods Industries: An Empirical Study." *International Journal of Productivity and Performance Management* 55, no. 3: 259–283. https://doi.org/10.1108/17410400610653228.

Shokouhyar, S., S. Shokoohyar, and S. Safari. 2020. "Research on the Influence of After-Sales Service Quality Factors on Customer Satisfaction." *Journal of Retailing and Consumer Services* 56: 102139. https://doi.org/10.1016/j.jretconser.2020.102139.

Stank, T. P., D. A. Pellathy, J. In, D. A. Mollenkopf, and J. E. Bell. 2017. "New Frontiers in Logistics Research: Theorizing at the Middle Range." *Journal of Business Logistics* 38, no. 1: 6–17. https://doi.org/10.1111/jbl.12151.

Syntetos, A. A., M. Keyes, and M. Z. Babai. 2009. "Demand Categorisation in a European Spare Parts Logistics Network." *International Journal of Operations & Production Management* 29, no. 3: 292–316. https://doi.org/10.1108/01443570910939005.

Tangel, A., and B. Katz. 2022. "Airplane-Parts Shortage Threatens More Disruptions to Air Travel." *Wall Street Journal*. https://www.wsj.com/articles/airplane-parts-shortage-threatens-more-disruptions-to-air-travel-11659087181.

Udenio, M., K. Hoberg, and J. C. Fransoo. 2018. "Inventory Agility Upon Demand Shocks: Empirical Evidence From the Financial Crisis." *Journal of Operations Management* 62: 16–43. https://doi.org/10.1016/j.jom.2018.08.001.

Voss, C., N. Tsikriktsis, and M. Frohlich. 2002. "Case Research in Operations Management." *International Journal of Operations & Production Management* 22, no. 2: 195–219. https://doi.org/10.1108/01443570210414329.

Wagner, S. M., R. Jönke, and A. B. Eisingerich. 2012. "A Strategic Framework for Spare Parts Logistics." *California Management Review* 54, no. 4: 69–92. https://doi.org/10.1525/cmr.2012.54.4.69.

Waller, M. A., and S. E. Fawcett. 2014. "Click Here to Print a Maker Movement Supply Chain: How Invention and Entrepreneurship Will Disrupt Supply Chain Design." *Journal of Business Logistics* 35, no. 2: 99–102. https://doi.org/10.1111/jbl.12045.

Westerweel, B., R. Basten, J. den Boer, and G. J. van Houtum. 2021. "Printing Spare Parts at Remote Locations: Fulfilling the Promise of Additive Manufacturing." *Production and Operations Management* 30, no. 6: 1615–1632. https://doi.org/10.1111/poms.13298.

Westerweel, B., R. J. I. Basten, and G. J. van Houtum. 2018. "Traditional or Additive Manufacturing? Assessing Component Design Options Through Lifecycle Cost Analysis." *European Journal of Operational Research* 270, no. 2: 570–585. https://doi.org/10.1016/j.ejor.2018.04.015.

Xu, X., M. D. Rodgers, and W. Guo. 2021. "Hybrid Simulation Models for Spare Parts Supply Chain Considering 3D Printing Capabilities." *Journal of Manufacturing Systems* 59: 272–282. https://doi.org/10.1016/j.jmsy.2021.02.018.

Yin, R. K. 2018. *Case Study Research and Applications: Design and Methods*. Thousand Oaks, CA: Sage Publications.

Young, L. 2022. "Companies Face Rising Supply-Chain Costs Amid Inventory." *Wall Street Journal*. https://www.wsj.com/articles/companies-face-rising-supply-chain-costs-amid-inventory-challenges-11655829235?page=1.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.