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Orchestrating resources for Big data analytics implementation in manufacturing SMEs: insights into managerial role and engagement

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ABSTRACT

Big Data Analytics (BDA) offers transformative potential for Small and Medium Enterprises (SMEs), enabling enhanced performance, improved decision-making, innovation and business growth. Yet, manufacturing SMEs often face considerable constraints that hinder effective BDA implementation. This study adopts Resource Orchestration Theory (ROT) to explore how managers in manufacturing SMEs structure, bundle, and leverage resources to overcome these challenges and deploy BDA effectively. Using semi-structured interviews with 17 SMEs managers, we examine BDA deployment across supply chain operations guided by the SCOR model. The findings reveal key managerial roles and strategies, including approaches to selecting, configuring, and operationalising BDA solutions. This study contributes to theory by applying ROT to the underexplored context of BDA implementation in SMEs, highlighting the dynamic capabilities managers must develop to succeed. Practically, it provides actionable insights for SMEs managers navigating digital transformation in resource-constrained settings. The study proposes a roadmap to guide BDA adoption in manufacturing SMEs.

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Big data analytics; SMEs; resource orchestration theory; managers' role

1. Introduction

The digital transformation has accelerated technological advancements, particularly with the rise of Industry 4.0 technologies such as Big Data Analytics (BDA), the Internet of Things (IoT), and Artificial Intelligence (AI) (Bibby and Dehe 2018; Papadopoulos et al. 2022; Winkelhaus and Grosse 2020). Among these, BDA has gained prominence for its potential to optimise decision-making processes and enhance operational efficiencies (Wang et al. 2016; Hasan et al. 2024;; Kgakatsi, Galeboe, and Molelekwa 2024; Zhang et al. 2021). BDA refers to the application of advanced techniques to large datasets, enabling organisations to uncover patterns and correlations that drive actionable insights (Asiri, Al-Somali, and Maghrabi 2024; LaValle et al. 2011; Tsai et al. 2015). By leveraging BDA, firms and their supply chains can become more responsive, demand-driven, and customer-focused (Schoenherr and Speier-Pero 2015; Willetts and Atkins 2024). With the widespread adoption of Industry 4.0 technologies, BDA capabilities have become a critical enabler of competitiveness (Olabode et al. 2022; Olaniyan et al. 2024;; Potluri and Vajjhala 2021). Its application in manufacturing operations has particularly gained attention in recent years (Babu et al. 2021; Chen, Preston, and Swink 2021; Zhang et al. 2021), with BDA capabilities emerging as a key differentiator (Cadden et al. 2023; Dahiya et al. 2022;; Wamba et al. 2017).

Despite these advancements, many SMEs have yet to fully harness the opportunities offered by BDA and can benefit from learning from peers (Tao et al. 2018; Waqas et al. 2021). According to Willetts and Atkins (2024) only 10% to 15% of SMEs have adopted BDA technologies, highlighting significant barriers to their implementation. SMEs are proved to be slow in adopting BDA due to various challenges such as lack of technological maturity, cultural barriers, and shortage of in-house analytics expertise (Coleman et al. 2016).

SMEs represent approximately 99% of all firms in Organisation for Economic Co-operation and Development (OECD) countries. They account for around 60% of total employment, and contribute between 50% and 60% of business sector value added (OECD 2023). Yet in 2022, it was estimated that only about 14% of SMEs had adopted BDA, compared to 35% of large enterprises (250+ employees), revealing a persistent 2.5-fold gap despite the digital acceleration following the COVID-19 pandemic (OECD 2022a; 2025). While firms deploying BDA report 5–10% higher productivity, the adoption shortfall limits SMEs' ability to capture productivity gains and exacerbates competitive and income disparities across the economy (OECD 2022a). Government evaluations underscore the implementation gap: in the UK,

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the flagship £296 million 'Help to Grow: Digital' subsidy programme, intended to support 100 000 SMEs, was terminated in February 2023 after lower-than-expected uptake, with fewer than one thousand vouchers actually redeemed (Department for Business & Trade 2023; techUK 2022). Echoing this picture, an Italian cross-sector study of 300 firms reported that 55% of Big Data projects never reached completion and overall failure rates can range between 50% and 85% (Gervasi et al. 2023). SMEs face specific constraints, such as lack of financial resources, shortage of data-skilled talent, and technological capabilities, that impact their approach to BDA implementation compared to larger firms (Asiri, Al-Somali, and Maghrabi 2024; Kgakatsi, Galeboe, and Molelekwa 2024). Limited financial resources restrict their ability to invest in advanced technologies and hire specialised talent, and, they often struggle to develop and integrate the requisite skills. Additionally, the rapid pace of technological change can overwhelm SMEs lacking robust infrastructure to support large-scale data initiatives. However, SMEs possess inherent flexibility and agility that enable them to reallocate resources swiftly, experiment with new approaches, and adapt their strategies to navigate the complexities (Minshull, Dehe, and Kotcharin 2022) such of BDA implementation. These capabilities are generally developed by managers. These tensions, between constraints and capabilities, create a relevant context for exploring how SMEs managers orchestrate resources to successfully adopt BDA. This exploration is important for advancing academic research and offering practical insights into digital transformation in smaller firms (Brinch et al. 2018; Hasnan et al. 2023; Lamba and Singh 2017; Matthias et al. 2017).

While the adoption of BDA is widely pursued for its potential to drive innovation and growth, many initiatives fall short of expectations due to their complexity, the substantial investments involved, and the need for specialised skills (Côrte-Real et al. 2019; Vidgen, Shaw, and Grant 2017). Moreover, there remains a limited understanding of the managerial role in the implementation of BDA (Tabesh, Mousavidin, and Hasani 2019), coupled with a shortage of empirical research on how BDA is utilised within SMEs (Kgakatsi, Galeboe, and Molelekwa 2024). Additionally, the mechanisms through which BDA initiatives contribute to innovation and business growth are still not well understood (Hasan et al. 2024). This led us to design this empirical and qualitative research to shed light on the relationship between BDA capabilities, resource orchestration, and implementation outcomes (Côrte-Real et al. 2019; Hasan et al. 2024;; Kgakatsi, Galeboe, and Molelekwa 2024; Mikalef et al. 2020). This study brings novelty and contributes to the literature by focusing on the role of SMEs managers in BDA implementation, answering the following research question: *How do manufacturing SMEs managers orchestrate resources to implement BDA successfully to drive innovation and growth?*

Studies indicated that the widespread hesitation or failure among manufacturing SMEs to adopt BDA is less about technological limitations and more rooted in managerial and organisational shortcomings. A consistent challenge for SME managers is the strategic allocation of resources necessary for BDA adoption. For instance, data from New Zealand show that 50% of businesses struggle to identify suitable technologies or dedicate time to learn them, symptoms of deeper issues in strategic planning and time-constrained owner-managers operating with minimal strategic guidance (Ministry of Business, Innovation & Employment [MBIE], 2025). On the factory floor, industry surveys highlighted the lack of clear strategic direction as a key issue (Callaghan Innovation 2025). Similarly, a UK government-commissioned study found that the adoption of digital technologies, like BDA, is impeded by limited buy-in and risk appetite, low managerial awareness and skills, and absence of supportive decision structures (Busby, Warby, Walsh, Coulter, Nelles, and Vorley 2025). OECD (2022b) further emphasised that managerial capabilities, alongside workforce skills and investment in intangibles, are crucial for adopting and deriving value from advanced digital technologies. Using semi-structured interviews with 17 manufacturing SME managers in Italy, the UK and New Zealand, this study applies thematic analysis (Clarke, Braun, and Hayfield 2015) to examine the strategies and resource orchestration processes underpinning successful BDA implementation. The findings, compiled into an ROT model and a BDA roadmap, provide actionable insights for SMEs' managers on leveraging BDA to overcome resource constraints and enhance their companies' decision-making, innovation and growth. With a certain guidance, we argue that managers can overcome challenges in structuring, bundling, and leveraging resources in a way that supports successful BDA implementation. The model and roadmap proposed in this study contribute to address this issue by offering a coherent approach for effective resource orchestration.

2. Literature review

2.1. Big data analytics (BDA)

In recent years, BDA has emerged as a transformative technology, impacting various business functions from sales and marketing to logistics and production (Shi 2022; Wang et al. 2022; Xu and Pero 2023). Big data is commonly encapsulated in the 'five Vs' framework: variety (diverse nature of data sources), volume (magnitude of data being generated), value (potential benefits of data), velocity (speed at which data is generated, processed, and analysed), and veracity (accuracy and reliability of data) (Lamba and Singh 2017). These characteristics underline the complexity and potential of big data for modern organisations.

According to Gandomi and Haider (2015), to obtain meaningful insights from BDA and leverage the decision-making process, a five-stage process should be followed: i) acquisition and recording, ii) extraction, cleaning and annotation, iii) integration, aggregation and representation, iv) modelling and analysis, and v) interpretation. The first three stages fall under data management, while the latter two constitute analytics. This systematic approach ensures that data is not only managed effectively but also analysed to generate insights that support strategic and operational decisions. BDA involves examining and analysing data to identify potential

patterns and correlations generating valuable insights for optimising decision-making, and fostering value creation and growth (LaValle et al. 2011; Tsai et al. 2015). Raffoni et al. (2018) highlighted the importance of integrating BDA with different management control systems to enhance the quality and ability of the decision-making. BDA capabilities are typically classified into three categories: descriptive, predictive, and prescriptive (Delen and Zolbanin 2018). Descriptive analytics provides a retrospective view of business performance by identifying trends and patterns using basic statistical methods (Sedkaoui 2018). Predictive analytics leverages historical and current data to forecast future events through advanced algorithms and statistical models (Wang et al. 2016; Jeble et al. 2018). Prescriptive analytics focuses on recommending optimal actions by utilising mathematical techniques to enhance business performance and decision-making (Lustig et al. 2010). Prescriptive analytics represents the peak of analytics maturity by not only forecasting future outcomes ('what will happen?') but also by systematically evaluating possible courses of action and recommending the optimal decision ('what should be done?'). Unlike descriptive and predictive analytics, which inform and anticipate, prescriptive analytics guides decision-making by bridging the gap between insight and action (Lepenioti et al. 2020). This enables SMEs to make data-driven choices that optimise outcomes in real-time.

2.2. Managers' use, role and engagement in BDA implementations in SMEs

While employees should be capable of using BDA tools in their day-to-day activities, managers are responsible to orchestrate resources supporting the implementation. Managers play a pivotal role in the successful utilisation and implementation of BDA as they serve as the leaders for technology transfers and adoptions. Lower-level managers are usually responsible for acquisition, recording, extraction, cleaning and annotation of data; middle-level managers might be more regularly involved in the integration, aggregation, visualisation and modelling aspects, and finally, executives and senior managers are focused on the analysis and interpretation, and often responsible for overseeing the implementation of the BDA solution (Choi et al. 2022). It is accepted that BDA implementations would require involvement of all managerial levels of the company. Managers are tasked with orchestrating efforts and resources to ensure BDA initiatives align with organisational goals and supply chain requirements (Tabesh, Mousavidin, and Hasani 2019). Their decisions are influenced by factors such as the cost of BDA, the expertise required for their use, and the degree of employee support (Moraes et al. 2022). Misunderstandings about BDA capabilities or an inability to effectively translate analytical insights into actionable strategies can lead to implementation failures.

While BDA technologies generate valuable insights such as insights on internal operations performance and supply chain efficiency (Bertello et al. 2021), managers must carefully evaluate these outputs to ensure their applicability and coherence within specific contexts (Papadopoulos et al. 2022). This is particularly critical for SMEs, which face significant financial and resource constraints. For SMEs to harness BDA effectively, managers must recognise its value and develop capabilities to support innovation, and growth (Maheshwari, Gautam, and Jaggi 2021). In this context, innovation refers to the development or significant improvement of products, processes, or business models enabled by insights derived from BDA. It involves leveraging data to introduce new offerings, enhance production efficiency, or create new ways of delivering products and services to customers. Growth refers to the expansion of the business in terms of revenue, market share, customer base, or operational scale, facilitated by big data-driven decision-making. Through BDA, firms can identify new opportunities, optimise operations, and respond more effectively to market demand, ultimately supporting sustainable business scaling.

Moreover, to realise the full potential of BDA, managers must be proactive in addressing barriers to implementation and learn from peer organisations that have successfully integrated BDA into their operations. Understanding these barriers enables the formulation of effective policies and strategies for optimising BDA adoption (Sharma et al. 2021).

Research has shown that BDA can add substantial value to organisations (Mikalef et al. 2020; Wamba et al. 2018) by supporting managers day-to-day tasks (Dehbi et al. 2022; Wang et al. 2016). For instance, it enhances the abilities for management to plan and control by providing insights through the analysis of large volumes of data (Dehbi et al. 2022). It also provides managers with the visibility and actionable insights that enable them to mitigate risks associated with delays, disruptions, and optimise trade-offs among cost, quality, and time (Wang et al. 2016; Lai, Sun, and Ren 2018; Stevens and Johnson 2016). However, to gain positive outcomes from BDA implementations, the organisations must focus not only on enhancing technological capabilities, but also on developing organisational capabilities and establishing a data-driven culture (Gao and Sarwar 2022; Falahat et al. 2022). Managers play a crucial role in driving such initiatives, they should have roadmaps and models to organise and utilise internal and external resources and capabilities to drive innovation through BDA implementations (Xie et al. 2024).

2.3. BDA domains of manufacturing application – a SCOR perspective

The widespread application of BDA across the value chain underscores its versatility. BDA supports procurement, demand management, planning, sales and marketing, design, manufacturing, production, warehouse and logistics, transportation, customer service, product recovery, reverse logistics, refurbishment, and other circular operations (Chehbi-Gamoura et al. 2020). Wang et al. 2016; Li et al. 2015; Sanders 2016; Therefore, guided by the SCOR model (Planning, Sourcing, Making, Delivering and Returning), which provide a standardised way to understand, analyse, and improve supply chain operations (Chehbi-Gamoura et al.

2020;; Georgise, Wuest, and Thoben 2017; Wall, Jagdev, and Browne 2007), we investigate the use and deployment of BDA within manufacturing SMEs.

For example, in Planning, BDA facilitates the development of flexible and resilient forecasting systems, which are critical for controlling supply chain operations and addressing volatile market demands (Wang et al. 2016; Hofmann and Rutschmann 2018). By leveraging customer data, BDA enables companies to identify distinct customer segments and tailor strategies to meet their needs. Importantly, it also helps uncover customer preferences, providing insights into purchasing behaviours, online searches, and future requirements (Li et al. 2015; Richey et al. 2016). Tools like customer relationship management (CRM) systems are instrumental in capturing and organising this data, thereby enhancing demand planning accuracy. Such capabilities allow firms to optimise push/pull strategies, shape market demand, and reduce time-to-market, ultimately supporting innovation and competitiveness.

In Sourcing, BDA can play a strategic role by helping organisations identify optimal procurement channels and evaluate suppliers based on key performance metrics, such as service levels, product quality, and pricing (Gu et al. 2021; Li et al. 2015). By analysing historical performance and supplier reputations, firms can make informed decisions that balance cost and risk while conducting targeted negotiations (Hasan et al. 2024; Sanders 2016). Additionally, BDA enables the prediction of supply disruptions through the identification of uncertainties, allowing businesses to respond proactively (Wang et al. 2016). A comprehensive view of procurement trends provided by BDA allow firms to be in a strong negotiation position, improving delivery schedules and material quality while achieving significant cost savings (Richey et al. 2016).

In Making, BDA empowers organisations to monitor productivity and quality in real-time, enabling managers to identify bottlenecks and make data-driven decisions promptly (Sanders 2016). Predictive maintenance is a key application and enables shifting the focus from reactive to preventative approaches by identifying potential equipment failures before they occur (Lade, Rumi, and Soundar 2017). This proactive strategy minimises downtime, reduces maintenance costs, and enhances overall supply chain performance (Lee et al. 2017). BDA also supports efficient resource allocation, optimises machine operations, and ensures energy consumption is minimised. These capabilities collectively contribute to higher product quality, reduced defect rates, and enhanced operational efficiency (Lee et al. 2017; Li et al. 2015). Additionally, inventory management benefits from BDA by allowing companies to maintain safety stock levels while minimising excess inventory (Tao et al. 2018; Waqas et al. 2021).

Finally, advanced BDA applications are critical in Delivering and Returning, leveraging technologies such as smart sensors, augmented reality, IoT, and GPS data. These tools improve picking and packing efficiency, enhance transit visibility, and enable real-time monitoring of warehouse and transport networks to mitigate potential disruptions (Hopkins and Hawking 2018; Wang et al. 2016). By identifying optimal distribution centre locations and supply routes, BDA helps organisations reduce transportation costs. Applications extend to monitoring driver behaviour, vehicle maintenance, and fuel efficiency, all of which enhance operational sustainability (Sanders 2016). Additionally, BDA supports tracking truck capacities, analysing shipping cost fluctuations, and monitoring traffic volumes and carbon emissions, further optimising logistics and reverse processes (Tiwari, Wee, and Daryanto 2018; Villegas et al. 2013).

2.4. Success factors and challenges in BDA implementations

The successful implementation of BDA relies on a firm's culture, leadership, and ability to orchestrate resources, including a commitment to learning and innovation. Moreover, developing the required skills and competencies through training is also essential (Dutta and Bose 2015). Sanders (2016) emphasises the importance of optimising the entire supply chain via a globally coordinated BDA strategy. A survey of 175 European firms identified dynamic capabilities, strategic alignment between business and IT, and the strategic role of BDA as key drivers of successful implementation (Côrte-Real et al. 2019). Other critical success factors include technical capacity, competitive dynamics, and intra-firm power structures, alongside fostering collaboration with external partners (Jha, Agi, and Ngai 2020). Successful BDA implementations require technology skills (e.g.: programming and statistical analysis), domain knowledge, analytical skills (e.g.: machine learning, data extraction and analysis) as well as soft skills (e.g. communication and collaboration) (Umamaheswaran et al. 2023). Thus, it is important that SMEs focus on developing those skills inhouse or identify the ways in which this expertise can be brought in. To support the BDA implementations, SMEs might have to recruit data scientists and business analysts (Verma, Singh, and Bhattacharyya 2021). The cost of the solution deployment is important to consider (Baig, Yadegaridehkordi, and Nizam Bin Md Nasir 2023). SMEs can rarely afford making significant technology investments at once (Willetts, Atkins, and Stanier 2020). So, the cost of adoption including hardware and software, training and hiring are a significant barrier (Babalghaith and Aljarallah 2024; Sun et al. 2018).

Raut et al. (2021) found that there are twelve significant barriers to BDA implementation in manufacturing supply chains, including the absence of top management support, required skills and funds, as well as appropriate techniques and procedures. Companies may also have time constraints, lack of skills and competencies (Schoenherr and Speier-Pero 2015) data storage and accessibility (Richey et al. 2016; Zhong et al. 2016), data ownership and privileges (Richey et al. 2016). Data security and cybersecurity concerns may deter companies from fully utilising BDA or sharing data across the supply chain (Chen, Chiang, and Storey 2012; Richey et al. 2016; Zhong et al. 2016). Falahat et al. (2022) also explained that the main barriers to BDA implementations are financial and technical issues, lack of awareness and data literacy. Khan (2019) categorised these barriers into eight domains: technical, cultural, ethical,

operational, tactical, procedural, functional, and organisational, highlighting the multifaceted nature of challenges in BDA adoption.

2.5. Research gap

Despite the recognised importance of managers in BDA implementation, the specific ways in which they engage with and shape these processes remain insufficiently explored (Tabesh, Mousavidin, and Hasani 2019). In particular, there is limited understanding of how managerial actions support innovation and growth through BDA initiatives. This gap is intensified by persistent mismatches between organisational needs and available BDA capabilities (Chehbi-Gamoura et al. 2020;; Olabode et al. 2022; Wamba et al. 2017), underscoring the need to examine how managers can bridge these divides. Furthermore, scholars have called for greater contextual depth in studies of BDA adoption to better understand the nuanced, industry-specific challenges and opportunities it presents (Nguyen et al. 2018; Tiwari, Wee, and Daryanto 2018; Zhang et al. 2021). In the case of manufacturing SMEs, empirical research on BDA implementation remains relatively nascent (Asiri, Al-Somali, and Maghrabi 2024; Hasan et al. 2024). While the benefits of BDA are increasingly recognised, adoption complexities in resource-constrained environments require further attention (Raut et al. 2021). For instance, Anwar et al. (2024) highlighted BDA's potential to drive performance but stressed the need for more applied research to contextualise its impact. Similarly, Al-Khatib (2023) emphasised the importance of organisational capabilities in enabling innovation through BDA but noted that SMEs often struggle to mobilise these effectively due to a lack of empirical guidance. Even the few existing empirical studies on BDA implementation within the context of SMEs have only utilised data collected from a single country, thus offer country specific findings, for example, Falahat et al. (2022) in Malaysia, Zheng et al. (2025) in China, Persaud and Zare (2024) in Canada and Bertello et al. (2021) in Italy. Most of the research conducted on the use of BDA in the context of SMEs (Maroufkhani, Iranmanesh, and Ghobakhloo 2023; Zheng et al. 2025), ; does not specifically focus on the role of managers in these implementations. Table 1 summarises chronologically the main findings, methods, theories, and limitations of relevant studies. This research responds to these calls by investigating how managers in manufacturing SMEs orchestrate resources to implement BDA by using the data collected from three different countries: Italy, the UK and New Zealand. By doing so, it contributes to a deeper theoretical understanding of managerial roles in digital transformation and offers practical insights into how SMEs can overcome barriers to innovation and growth through BDA capabilities.

2.6. Theoretical framework – a resource orchestration perspective

To capture and evidence-based successful BDA implementations patterns and trends within SMEs, we use the resource orchestration theory (ROT). ROT is an extension of the Resource-based view (RBV) (Sirmon et al. 2011). RBV, is rooted in management literature, and highlights that organisations compete based on the resources and capabilities which are valuable, rare, difficult to imitate and non-substitutable (Barney 1991; Bharadwaj 2000). However, ROT explicitly focuses on explaining the managers' role in handling resources and capabilities to achieve competitive advantage. ROT considers resource management as a process which consists of three levels: structuring, bundling, and leveraging resources. Structuring resources focuses on acquiring, accumulating and divesting resources to create a portfolio. Bundling resources explains how resources can be integrated to form capabilities. Three subcomponents of bundling include stabilising (i.e. minor improvements to existing resources), enriching (i.e. extending existing capabilities), and pioneering (i.e. creating new capabilities). Leveraging focuses on exploiting the firm capabilities. Three subcomponents of leveraging include mobilising (i.e. plan for generating required capability configurations), coordinating (i.e. integrating capability configurations) and deploying (i.e. exploiting capability configurations) for value creation (Sirmon, Hitt, and Ireland 2007, Sirmon et al. 2011).

ROT also explains three areas in which managers should focus on; i) breath of the operations (i.e. orchestrating the resources across the organisation), ii) life cycle (i.e. orchestrating the resources at various stages of organisation maturity), and iii) depth (i.e. orchestrating the resources at different levels of the organisation) (Ketchen, Wowak, and Craighead 2014).

Previous research has used ROT to explain how the resources can be used to enhance sustainability (Wong, Wong, and Boon-itt 2018), profitability (Wong, Wong, and Boon-itt 2018), supply chain transparency (Gligor et al. 2022, Malik, Ghaderi, and Andargoli 2021), innovation (Sirmon et al. 2011, Wong, Wong, and Boon-itt 2018) and achieve competitive advantages (Gong et al. 2018, Ketchen, Wowak, and Craighead 2014, Sirmon et al. 2011). Xu and Pero (2023) applied ROT to explain the BDA adoption process in the context of SC planning.

Managers play a pivotal role in determining when and how to mobilise individual, organisational, and technological resources to enhance performance and drive business growth (Xu and Pero 2023). A central aspect of this role involves the effective orchestration of BDA resources and capabilities to foster an organisational culture that supports innovation. In SMEs' volatile environments, managers may employ strategic tactics, such as resource unlocking, refocusing, and shortcutting, to mitigate disruptions and maintain growth trajectories (Skipworth et al. 2023). BDA can also be leveraged to enhance supply chain operations, in planning, sourcing, production, delivery and returning activities, by improving both proactive and reactive decision-making. Figure 1 presents the conceptual frame developed in this study, which provides a high-level view of how BDA can be integrated across key operational areas. Building on this model, the remainder of the article explores how SMEs managers orchestrate resources to implement BDA effectively,

Table 1. Overview of existing related research.

Study	Method	Theory	Main Findings	Limitations	How does each article relate to our study?
Chehbi-Gamoura et al. (2020)	SLR	N/A	Highlights the need of all SC partners to collaborate in BDA implementations.	Based on a SLR, no empirical findings.	Discusses the importance of managers focusing on obtaining data from all the partners of the SC to ensure that BDA is providing accurate and valid insights.
Bertello et al. (2021)	Quantitative method – Survey	Resource-based view (RBV)	Simply having BDA governance is not sufficient for enhancing SME internationalisation. It is important to couple BDA governance with BDA capabilities to enhance SME internationalisation.	Data (103 survey responses) were collected only from Italy. Have a specific focus on SME internationalisation. Do not have a specific focus on the managers role	Highlights the importance of BDA governance and BDA capabilities.
Gao and Sarwar (2022)	Quantitative method – Survey	Dynamic capabilities and social capital theory	Discusses that big data analytics management capabilities (i.e. the ability to manage BDA) significantly enhances innovation performance.	Data (103 survey responses) were collected. Do not have a specific focus on the managers role	Highlights the importance of developing management capabilities such as planning, investment, coordination and control for BDA to enhance innovation performance.
Zheng et al. (2025)	Quantitative method – Survey	Resource-based and dynamic capabilities theory	Highlights that BDA capabilities are positively associated with firm market agility. Also discusses firm market agility is positively associated with innovation generation and innovation adoption.	Data (186 survey responses) is collected only from entrepreneurial and micro, small, and medium enterprises in China. Do not have a specific focus on the managers role	Highlights the importance of managers role in developing BDA capabilities, which ultimately supports innovation.
Falahat et al. (2022)	Qualitative method – focus groups	Grounded theory	Discusses the challenges of adopting big data analytics capabilities and suggest a BDA capability eco system model. This model captures BDA enabling factors, barriers to BDA adoption and value creation factors.	Only focuses on Malaysian SMEs	Highlights the importance of top management vision and commitment to BDA implementations.
Xu and Pero (2023)	Qualitative method – case studies	Resource orchestration theory and technology innovation diffusion literature	Develops a framework for BDA adoption process. The main stages of this framework include 1) Structuring – Sense business need and accumulate BDA intellectual resources, 2) Bundling – catalyse BDA learning and engage in DBA system development, and 3) leveraging – continuous refinement and internalise BDA competencies	Only focuses on European manufacturing industry Do not have a specific focus on SMEs	Discusses the importance of considering resource orchestration theory in understanding BDA implementations.
Xie et al. (2024)	Quantitative method – Survey	Resource orchestration theory	Highlight the importance of 'big data resources acquisition capability' in BDA integration and utilisation. Also highlight the importance of government support and data governance in BDA implementations.	Data (179 survey responses) is collected only from one province (i.e. Guangdong Province) in China.	Highlights the importance of developing big data resources acquisition capabilities.
Persaud and Zare (2024)	Quantitative method – Survey	BDA capabilities and absorptive capacity	Discusses that BDA capabilities including technological, staff and management capabilities enhance strategic business value. It also highlights that an analytics-driven culture and BDA-specific	Data (447 survey responses) is collected only from Canadian SMEs Does not explicitly discuss how the managers can orchestrate	Highlights the importance of enhancing management BDA capabilities and management involvement in supporting analytics culture

(*continued*)

Table 1. Continued.

Study	Method	Theory	Main Findings	Limitations	How does each article relate to our study?
			absorptive capacity enhance the influence of technological and human capabilities in generating strategic business value.	resources to implement BDA successfully	
Maroufkhani, Iranmanesh, and Ghobakhloo (2023)	Quantitative method – Survey	Technological, Organisational and Environmental (TOE)	Challenges the assumption that TOE factors are independent of each other and suggests that TOE factors are interrelated and interact with each other.	Data (171 survey responses) were collected only from Iran. Do not have a specific focus on the managers role	Highlights the importance of top management support in BDA implementations.
Hasan et al. (2024)	SLR	Task-Technology-Fit theory and institutional theory	Highlights the importance of conducting empirical studies focusing on BDA implementations. Moreover, discussed the importance of conducting research which explain business value of BDA and required supporting systems for BDA implementations.	Based on a SLR, no empirical findings.	Highlights the lack of empirical studies focusing on BDA implementations.

addressing the research question: *How do manufacturing SMEs managers orchestrate resources to implement BDA successfully to drive innovation and growth?*

3. Methodology

To address the research question, we employed a qualitative research design (Klein and Myers 1999). It enabled us to 'make sense of contemporary, real-world dilemmas' and provide key insight into the complexity of BDA implementations (Fawcett et al. 2014). The primary data was collected through 17 semi-structured interviews with managers of manufacturing SMEs. Similarly to Winkelhaus, Grosse, and Glock (2022) and Minshull, Dehe, and Kotcharin (2022) we chose semi-structured interviews as the most appropriate method to explore causal relationships, gain deep insights into the phenomenon and spot patterns and trends. This method provided the flexibility to probe specific themes while allowing participants to elaborate on their experiences.

We employed a purposive sampling technique to target managers who had been directly involved in BDA projects within their organisations (Patton 2002). Our sample included manufacturing SMEs managers of in three different countries, Italy, the UK and New Zealand. It enables us to capture diverse perspectives on perceived and reported successful BDA implementation across a range of geographical and organisational contexts.

Initially, we compiled a list of 55 potential SMEs in the manufacturing sector from Italy (16), the UK (20), and New Zealand (19) that we believed had implemented BDA within their supply chain operations. This initial list was developed using publicly available information from company websites, LinkedIn posts, and insights from our professional networks. The criteria for inclusion were: i) the company operates in the manufacturing sector; ii) it qualifies as an SME, employing fewer than 250 employees; and iii) there was some indication that the company had implemented BDA in its operations. Our aim in constructing this initial sample was threefold: i) to capture diversity and ensure a heterogeneous range of perspectives on BDA implementation; ii) to enable in-depth exploration of the phenomenon; and iii) to ensure the validity and reliability of our findings, thereby enhancing their credibility and transferability.

We then gathered additional data on the 55 companies using Refinitiv (a global provider of financial market data), company websites and LinkedIn. Specifically, we recorded the number of employees, total revenue, available financial KPIs, business classification, and searched for any other relevant information related to BDA. Based on this information, we reviewed and refined our list to focus on companies that are closely aligned with our criteria. For instance, we excluded some of the companies from the initial sample due to the lack of clear evidence of BDA implementation.

This process resulted in a refined sample of 34 suitable companies, 11 based in Italy, 12 in the UK and 11 in NZ. We believe this refinement enhanced the rigour and quality of our sample selection by increasing our confidence that each

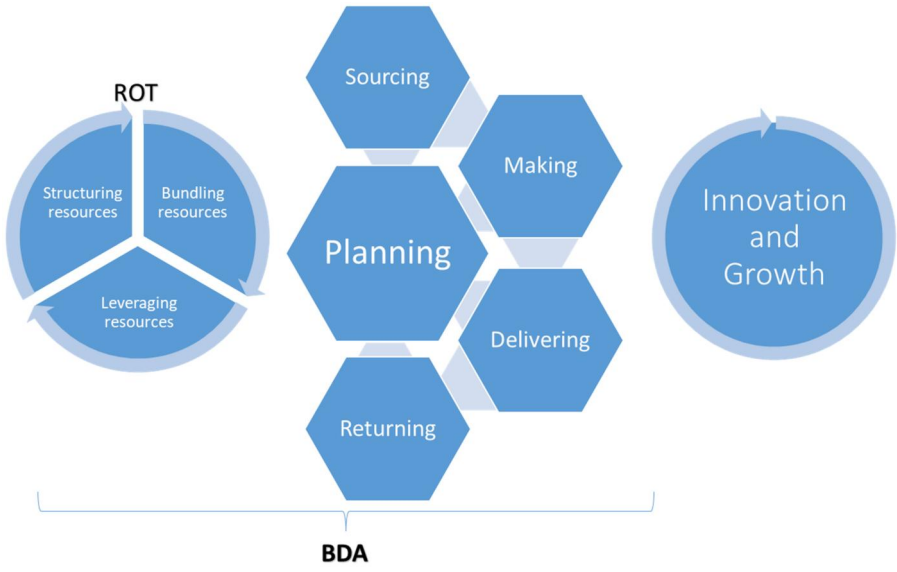

Figure 1. High level concept of BDA deployment within manufacturing operations.

company met our inclusion criteria. We then identified potential participants from these 34 companies and approached them via LinkedIn messages or email, following our university's ethical guidelines and protocols. Out of the 34 individuals contacted, 17 managers agreed to participate in the study, six were in Italy, five in the UK and six in NZ. To ensure relevance, we confirmed that each participant had been involved in BDA implementation within their organisation. Where this was not the case, the participant was asked to recommend a more appropriate colleague. Table 2 provides an overview of the participants' roles, along with details about their companies' sectors, sizes, and turnover. Our inclusion criteria focused on SMEs that had implemented BDA to a certain extent, enabling us to examine the dynamics of resource orchestration in active adoption contexts. As such, companies that had not attempted BDA implementation or failed were excluded from the final sample. This focus allowed for in-depth exploration of enabling factors and managerial practices; however, it inevitably introduced a bias towards relatively more successful or advanced adopters. To mitigate reliance on self-reported claims, we triangulated interview data with secondary sources such as company websites, industry reports, or press releases. This approach provided contextual validation and supported the credibility of reported outcomes. Nonetheless, the exclusion of non-adopters mean that the findings should be interpreted as reflecting strategies and challenges encountered in comparatively more receptive organisations, rather than representing the full spectrum of BDA adoption experiences.

The interviews followed a flexible structure, divided into two main parts. First, we were interested in the general context, asking questions about the participants' roles, organisational characteristics, and general experiences with BDA. Second, we wanted to explore further the participant experience of BDA deployment. We asked questions exploring the implementation process, including, the initial motivations and steps for adopting BDA, the types of BDA solutions implemented, the challenges encountered during implementation, the resources required for successful integration, the use of BDA across different functions, the perceived value generated from BDA implementation. While the interview protocol provided a guiding framework, we adapted questions dynamically to align with respondents' experiences and insights (Patton 2002). This iterative approach allowed us to gather rich and relevant data. Table 3 presents the interview protocol, including sample questions and illustrative quotes from participants.

We have developed the interview protocol based on our understanding and interpretation of the literature review and the topic of interest. We undertook the interviews in English and used a research assistant for interviewing the Italian based participants. The Italian interviews were then translated into English. All interviews were done online via zoom or MSTeams and lasted between 45 and 60 minutes.

To ensure the reliability of this research study, we adopted a series of methodological steps guided by established principles for rigorous qualitative research (Tracy 2010). First, we piloted the interview protocol with two academic staff members and two industry experts. This allowed us to refine the questions and structure, ensuring clarity and relevance for addressing the research objectives. By incorporating feedback from these experts, we enhanced the protocol's alignment with the study's goals and improved its applicability in obtaining meaningful responses from participants.

We also took steps to confirm the suitability of the participants. Respondents were carefully selected based on their direct knowledge and involvement in BDA implementation within their organisations. Ensuring their knowledge and expertise in this domain was critical for gathering insights that were both informed and reflective of real-world practices. Additionally, our sampling approach captured diverse

Table 2. Participants' profile and companies' information.

Participants	Positions	BDA implementation role and experience	Company sector	Turnover 2020–2023 in Million $	Employees number 2020–2023 FTE
P1	Managing director (Italy)	P1 supervised the BDA implementation projects across the business with application in forecasting, procurement, inventory management, production and distribution.	Industrials goods Blind rivets manufacturer	14.8–22	128 – 123
P2	Chief Operating Officer (Italy)	P2 was involved in the development of an advanced monitoring system for monitoring and handling, designed to enhance the efficiency of their machines.	Machinery manufacturer	14.72 – 22.6	70 – 79
P3	Innovation Director (UK)	P3 was involved in implementing digital technologies and BDA into the business.	Printing machinery manufacturer	3.8 – 6	26 – 9
P4	Product manager (Italy)	P4 was involved in the BDA projects that allow demand patterns analysis to optimise inventory levels, forecast accurately.	Bottling systems manufacturer	69 – 71	160–170
P5	Process manager (Italy)	P5 used the BDA solution to anticipate production trends and operational needs.	Technology component manufacturer	22–31	86 – 79
P6	Operation manager (Italy)	P6 used BDA for data-driven analysis to support strategic planning and operational efficiency.	Mining machinery and equipment manufacturer	10–16	35 – 62
P7	Digital manufacturing manager (UK)	P7 was involved in deploying the BDA solution to improve production efficiency and product quality.	Rolled steel shapes manufacturer	4–7	23 – 21
P8	Operations director (Italy)	P8 was actively involved in the roll out of the BDA solution in production, maintenance, and demand management.	Industrial manufacturer	80–87	135
P9	Process improvement manager (UK)	P9 used the company BDA system to collect and analyse asset performance to make informed decisions, optimise operations, improve safety, reduce costs, and enhance sustainability.	Oil and gas equipment manufacturer	N/D	200–250
P10	Head of procurement and supply chain (UK)	P10 was involved in the BDA solution to identify usage patterns and preferences, informing the development of new products and features.	Electric housewares, and consumer electronics manufacturer	18–28	69–93
P11	Procurement manager (NZ)	P11 was involved in the BDA solution developed to implement a comprehensive S&OP process.	Specialty Foods Processing and Packaging manufacturer	N/D	<100
P12	Technology senior consultant (NZ)	P12 offered BDA services and implementation to manufacturers.	Consultant to manufacturer	N/D	5–7
P13	Logistics and warehouse operations manager (NZ)	P13 used BDA integrated software to manage inventory data, and optimising warehouse operations.	Pharmaceutical manufacturer	20–27	200–250
P14	Global Commodity Manager (NZ)	P14 was involved in the implementation of Power BI and work with Salesforce to develop the BDA solution.	Household appliances manufacturer	18–28	69–93
P15	Logistics Manager (NZ)	P15 worked with the Business Analysis and Management team to deploy the BDA solution across the logistics chain.	Paper and Forest Products Manufacturer	N/D	<100
P16	Supply Chain Optimisation lead (NZ)	P16 was involved in deploying the BDA solution within the supply chain team and is a user of the technology.	Chemical Manufacturer	N/D	200–250
P17	Supply chain manager (UK)	P17 was involved in the team deploying BDA across the business.	Food manufacturer	N/D	120–150

Table 3. Sample data and associated coding.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
How is BDA used in your organisation?	'Big data help us to reduce our operational uncertainties and assist our decision-making' (P5) 'With BDA we can reduce our development time by between 20% and 50%. We can also better manage the demand planning across multiple sites and our supply chains' (P9) '[BDA] allows us to synchronise our operations, and to be more accurate in our decisions-making. It helps us to improve our time to market and customers knowledge. It also allows us to have better communication with our suppliers by sharing forecasts and adjusting the demand planning'. (P14) '… We need more transparency … Everyone knows what was used, which order was used for that fulfilment of that particular order. So there's a lot of transparency happening which the customer wants currently' (P15) 'We can reduce the number of touchpoints [using BDA]' (P15) 'Big data is extremely customer-centric and can lead to reducing time-to-market and allowing us to respond quickly to market and customer needs' (P4) 'We are able to determine the root cause of problems with more confidence' (P9)	Insight and decision making Predictive BDA in Demand planning Enhance customer value – time to market Enhance supplier management Transparency in production and logistics efficiency customer centricity process performance problem solving	BDA is used to reduce uncertainty, make better decisions, enhance performance and create more transparency across the supply chain eg: demand management, in procurement, in production and logistics.	Use of descriptive and predictive BDA Objective of BDA is to gain new insight, make better decisions, enhance performance	SMEs' managers use primarily descriptive and predictive BDA to optimise their operations and decision-making
How can you innovate with BDA?	'BDA can lead to valuable improvements and innovation in the internal processes of a business, for example by	Improve and innovate Manage the customer demand better	Descriptive and predictive BDA to innovate and predict new demand	Descriptive and predictive BDA is used to innovate. But there are new opportunities that will	SMEs' managers aspire to use prescriptive BDA to develop new products, services and processes

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
	understanding the customer demand better, improving production, scheduling, inventory management and maintenance'. (P4)	Improve inventory	New strategies are developed thanks to BDA	emerge as firms leverage prescriptive analytics.	
		Monitor product performance			
	'We can now monitor our product performance and behaviour and adjust the next generation of products' (P9)	Fresh solution and pair of eye			
		Innovate with new services			
	'We are bringing in some new people … they are bringing in new minds to actually tell us what kind of a new solution can be achieved'(P15)	New strategies and new models			
	'We have been able to provide new services such as insurances for our customer based on predictive BDA' (P16)				
	'We are able to much more accurately predict our customer demand in the different segments of the company and therefore innovate with new product more effectively' (P17)				
	'[…] for example, we moved from a "made-to-stock" strategy to a "make-to-order" model by predicting the demand better' (P8)				
When and how did your company started to invest in BDA?	'Every company owns data but, at the moment, only a few organisations know BDA potential, we started small based on the data we had at the time from our system'. (P3)	Organically based on our data available	start small based on the legacy data.	Conscious vertical and horizontal technology transfer.	SMEs' managers need to be proactive in employing a mix of horizontal and vertical technology transfer strategies and stratification methods to successfully implement BDA
			BDA was a solution to recover from business downturn	Managers are proactive and used the developed capabilities of the firm and the economic context to start the implementation	
	'After the financial crisis of 2008, we experienced a deep recession. We had to redefine a new business strategy in order not to sink and survive despite the global instability. So, we embraced new technologies which supported us in significantly expanding our business and sustaining our	After a crisis using a vertical technology transfer strategy	Managers tapped in the capabilities of the firm to start the implementation		

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
	revenue. As we invested in new technologies such as BDA, we were able to navigate the Covid-19 pandemic relatively well'. (P1)	Horizontal technology transfer			
	'We are actually right now doing a project with for our client's warehouse in Malaysia. They are interested in condition monitoring of the product inside the warehouse, we are replicating what we did in their NZ warehouse … ' (P12)				
	'… we had a lot of experience within our supply chain, with folks who have worked with a lot of different systems, technologies and SAP previously and this is how we started'. (P13)	Building on the exciting capabilities in process improvement to implement BDA			
	'We created data and databases because we were a manufacturing site and needed numbers. We have created everything, but we're not putting it to full use (P15)	Vision and conscious investment			
	'A couple of years ago, we decided to implement lean principles to streamline processes and develop a continuous improvement culture. This helped us to offer a better service. The great results obtained by this change supported us in embracing the innovation of Industry 4.0 technology and specifically BDA more recently'. (P3)				
	'We have fostered a data-driven culture within the company' …				
	So in terms of time and human capital, it would have been a significant part in the past couple of years (P16)				
	'Since the early days we believed in the analytics opportunities' (P17)				

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
Where does your company BDA come from?	'Our business has built a robust data lake over the years which collects precious historical information, and enable us to make the most of our data … We use Power BI and Tableau' (P8)	Power BI and Tableau	Organising and structuring the available resources and data Considering the internal and external systems and resources to access big data	Managers are being proactive and develop partnerships Managers need to bundle resources for effectively used of BDA	SMEs' managers have to develop and rely on partnerships and investments in technology and people (proactive);
	'BD comes from our R&D database, ERP, MES, customer data, virtual factory modelling and our sensors' (P9)	ERP, MES, CMS in production and demand management Combination of systems			
	'We use Power BI and we use sales force as well, for instance, like an application that'll help us to manage contracts … For drawings, we use wind chill … We use apex as well as a system that help us to extract information in a better way'. (P14)	Open-source solutions			
	'Our website is a key source for capturing our customer data … We use custom-built solution for our specific needs now'. (P17)				
	'The IT and technology market offers different solutions for a variety of companies with different budgets some are open source such as Apache Hadoop'. (P7)	Need partnership with BDA companies and suppliers			
	'Being able to do transactions in real time. So as staff move the product around, they can scan it in real time then and there, rather than having to record it and then go back to a PC'. (P13)	Data scientists for visualisations, descriptive and predictive BDA			
	'The vendor has a cloud platform. And our sensors, and devices talk to the cloud platform in an encrypted and proprietary way … ' (P12)				

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
	We developed our BDA through many partnerships with other companies … Amazon has been a big supporter of us and we've used Amazon to store a lot of our data (P16)				
	We've purchased a lot of data as well, and so we've invested heavily in data scientists to collate and aggregate the data and invested heavily in the tools to be able to extract the data and have visualisation tools to make decisions. (P16)				
	From our web store, our machines, our customers and (…) transactional data through NetSuite and Amazon redshift (P16)				
Why did your company invest in BDA?	'Postponing the process would have led to a risk of being left behind by competitors and by the bigger firms' (P8)	Competition	For gaining insight, modernising and innovating	Managers believe that BDA enable them to stay competitive, innovate and create value	SMEs' managers believe that not investing in BDA would mean being left behind, not innovating not growing the business
	'It is still a new concept not all SMEs have understood its potential' (P5)	Differentiation			
	Other companies are already investing in newer technologies … if we have to compete in the market, we need to start using them. (P15)	Remain competitive			
	'BDA enable us to gain insights from our data to improve customer experience, optimise operations, and make data-driven decisions. This will help sustaining the growth of the company' (P17)	Enhance performance and customer value creation			
	'International companies are often ahead with regard to research and innovation. Accordingly, the competitiveness gap is growing wider. For this reason, using big data was not an option but an absolute need to survive in the global markets'. (P5)				

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
	'BDA hasn't quite been implemented in SC as much as in Sales and Marketing initially because it more cost focused than revenue generating' (P16)				
What type of issues have you experienced with BDA deployment?	'The business culture in SMEs can prevent the implementation of big data and other Industry 4.0 technologies' (P6)	Issues with culture and mindset Reluctance to learn new things	Cultural issues Skills issues Costs issues Resource issues Security and cybersecurity issues Integration issues	Overcoming internal barriers Overcoming external barriers Bundling resources – pioneer capabilities	SMEs' managers have to overcome internal, external barriers and inhibiting factors preventing BDA implementation; (structuring) SMEs' managers have to bundle and align resources for effective and efficient BDA implementation; (Bundling)
	'The first issue is to change the mindset of the people to adapt for new technologies or new systems' (P14)	Issues with organisational structure and processes Internal skills and knowledge shortage			
	'And they are learning some new stuff. They're not completely happy, but they're still learning'. (P15)				
	'Our complex internal bureaucracy slow down the innovation process' (P8)	Concerns with cybersecurity			
	'there's a lot of garbage in or wasting information in the system that we need to clean up before using the data' (P14)	Lack of innovation from suppliers			
	'Knowledge and skills related to big data and other Industry 4.0 technologies are fragmented and barely widespread in Italy' (P8)				
	'We need some new pool of knowledge to come inside to give us new perspectives on how data can be used'(P15)	Cost and investment needed			
	'Cybersecurity violations should be prevented, and this issue should not be underestimated […] the probability of experiencing cyberattacks increases' (P1)	Complexity Integration			

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
	'The data quality and integration has been a big issue for us as well as the cyber security and privacy' (P17)				
	'Having suppliers who do not update their processes negatively affects our business. We have been available to support several businesses in improving their processes by bringing our experience. However, the close-minded attitude of small suppliers forced us to find new vendors' (P2)				
	'BDA has proved to be extremely expensive and required large investments of time and money' (P4)				
	'We basically see that from the vendors as a loaded cost of the device … because there is an ongoing service that they provide, as I said, the first leg of the communication chain is always between the device and the vendor platform'. (P12)				
	'So, we're still almost getting dumb data from a smart device and not appreciating or talking about, what is the problem we're trying to solve?' (P11)				
	'There are large disparity in the use of BDA between the different departments' (P9)				
	'Data extracted from machines and ERP systems still requires a great deal of manual intervention' (P9)				
	'The challenge for us is how monetising big data' (P16)				

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
	'The integration is another issue that we have had challenges with. We run multiple different systems from our transport team uses a different system to our warehouse team, to our procurement team' (P16)				
What are some critical resources and capabilities needed to succeed?	'A change of mentality is needed to conduct the transformation' (P8)	Mindset shift	Culture	Managers need to be proactive	Successful BDA implementation requires SMEs' managers to be proactive to develop a homogenous culture, acquire new skills and capabilities
	'Top management should understand the need of a digital transformation with a long-term perspective' (P8)	Top management support Talent and skills acquisition	Skills Platforms Internal processes	Mangers need to get the buy-in from senior managers and staff	
	'It is crucial to hire competent data scientists but they should also be capable of being flexible with broad and inter-functional knowledge' (P1)	Interoperability between platforms and systems Internal process capabilities			
	'We need experts in IT for sure, people involved in planning in ERP, purchasing people with skills of checking statistics and forecast demand planning as well'. (P14)	Required infrastructure			
	'We've got so much data coming at us. But we don't have really enough skilled people who can make sense of that data' (P11)				
	'We need to create an abstraction layer where the platform will interface with an increasing number of devices … (P12)				
	'Strong assets, software and structured industrial processes are needed to benefit from big data since the lack of solid foundation might threaten the company in quickly responding to the speed of this innovation' (P2)				

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
	'We recognised the obsolescence of our IT architecture; hence, we had to invest a significant amount of money to re-structure' (P6)				
How have you integrated BDA to the rest of the business	'We had to re-align our business strategies and integrate the use of BDA in order not to sink and during the global instability' (P8)	Re-aligning strategies Responsibility Allocation and Organisational Structure	Structuring resources Bundling resources Leveraging resources	Managers need to be proactive to integrate BDA solution to the business	SMEs' managers need to design and integrate different systems for exploiting BDA (proactive);
	'We needed to align the BDA with the overall business goals and objectives and make sure it helps fostering internal collaboration' (P17)	BDA as a business specific tool that can't be replicated or plugged in			
	'We needed our suppliers to also embrace BDA and other industry 4.0 technologies'. (P2)				
	'We are all connected … forcing the people to use a standard platform that allow us to have the same formats, same methodology to track for example, track a price change or track any change'. (P14)				
	'BDA forced us to start from the real requirements of the business and not from the available assets and tools. Some companies […] find themselves with technologies which they are unable to effectively utilise'. (P4)				
How do you use and leverage BDA?	'Our BDA software measures the production performance of our machines in real-time […] data collected are precious to track all the batches produced' (P1)	Real-time performance tracking Staff Engagement Data Insights Value Realisation	Managers use and leverage BDA in production, procurement, demand management and logistics and warehouse operations to create new value and innovate	Managers use and leverage descriptive and predictive BDA but the next level is to tap into prescriptive analytics	SMEs' managers need to leverage different resources to gain unique insights from a prescriptive BDA

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
	'We can innovate from the discussions with the staff … They come back with questions about the analytics as we work through the process'. (P13)	Procurement and sourcing insight			
	'We get seasonality analysis, it's all automatically done and kept in the cloud'. (P11)	Unique, scalable, comprehensive insights			
	'We rely on BDA to obtain insights into suppliers' information and understand if they can provide us with reliable service and excellent raw materials which meet compliance standards'(P1)	Increase speed Reduce cost Demand management			
	'Understand the relationship between a commodity cost and the overall product cost as a basis for targeted cost improvements' (P9)				
	'We can extract interesting information about spare parts or other products our customer might need. Accordingly, we can create a strategy to push the sales of these items' (P2)				
	'For advance demand forecasting and supply planning' (P9)				
	'Our BDA software measures […] and the production status' (P1)				
	'To create process transparency in production and enable to mass customise our products' (P9)				
	'BDA helps in avoiding unnecessary and unplanned maintenance interventions. Potential problems are promptly fixed by quickly identifying the cause of a failure'. (P5)				

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
	'[. . .] obsolete stock since it is hard to sell it and it exponentially increases the cost of inventory. In this regard, BDA supported our business in preventing obsolete inventory' (P7) 'We are using BDA to target new market segments [. . .] understand customer needs' (P1) 'Prescriptive analytics could help us explore alternative solutions and actions to make better decisions in the future' (P1). Supporting farmers on their crop yield, so putting BDA together from other farms and be able to be shared with farmers and support their needs for crop yields. (P16)				
What value do you get from BDA?	'BDA led to valuable improvements and innovation in the internal processes of a business in particular in demand management and production' (P4) 'BDA reduced operational uncertainties by assisting decision-makers in making informed decisions' (P5) 'BDA is allowing the organisation to respond quickly to market and customer needs'. (P4) 'We are using BDA to target new market segments [. . .] understand customer needs'(P1) 'It is paramount for us to offer high-quality products [. . .] with reliable service and excellent raw materials which meet compliance standards' (P1)	Improve internal process Innovation Reduce cost and uncertainty Customer value Supplier insights Demand analysis Reliability Process streamlining Sale strategies	BDA to focus more on the customer BDA for effectiveness and efficiency	BDA for customer centricity, value generation and business growth ultimately	SMEs' managers use predictive BDA to enhance the business customer centricity and focusing on value'.

(*continued*)

Table 3. Continued.

Questions	Sample of interview quotes	Features: type of data, deployments, used of BDA, role of manager	Primary codes	Secondary codes	Themes
	'We use this information to understand the situation that we are facing with this particular supplier and it helps us to negotiate better terms and align with engineering'. (P14)				
	'In performing demand analysis, […] we can create a strategy to push the sales of these items' (P2)				
	'Predictive maintenance reduces waiting times by allowing us to provide faster and more reliable service to our customers' (P5)				
	It should streamline a lot of our process and eliminate a lot of lost time. Having to be disbound to complete all our transactions so'. (P13)				
	'BDA really gave us that competitive advantage to step into the farming sector and from there we're able to build the business further' (P16)				

perspectives by including SMEs from varied sectors and regions, reducing the potential for bias and enhancing the breadth of the findings. To build credibility and transparency, we included illustrative quotes and data points in the results section, as demonstrated in Table 2, which provided evidence to support our conclusions.

Furthermore, to complement the primary qualitative data, we identified and selected a series of manufacturing SMEs cases, specifically, from Italy, the UK, and NZ, based on the availability of secondary data detailing their adoption and use of BDA. Each case was examined through multiple credible secondary sources, including industry reports, academic publications, company websites, and news articles. Relevant information was extracted and analysed in alignment with the structure of the interview protocol. This approach enabled methodological consistency and facilitated the triangulation of findings. It provided us the ability to conduct a more balanced and verifiable analysis by triangulating with our primary data analysis.

The primary data were analysed using thematic analysis for identifying, examining, and interpreting patterns within qualitative data (Clarke, Braun, and Hayfield 2015). This process involved the application of both *a priori* and *a posteriori* approaches. Drawing on *a priori* methods, we utilised concepts derived from the literature to inform the initial coding framework, while *a posteriori* analysis allowed emergent themes to surface directly from participants' responses. Together, these approaches facilitated a comprehensive understanding of BDA implementation and the nuances of participants' experiences.

The thematic analysis was conducted in several stages. Initially, interviews were transcribed and allowed us to familiarise ourselves with the data and identify preliminary insights. Subsequently, specific words, phrases, and sentences were coded to represent recurring ideas or concepts. These codes were then grouped into broader themes that encapsulated the core patterns and relationships in the data. The identified themes were carefully analysed to uncover connections and contrasts, which were further contextualised using insights from the literature review. Finally, the thematic analysis ended in the interpretation of themes, linking them to the broader research objectives and providing actionable insights into BDA implementation in SMEs.

The reliability and legitimacy of the analysis were further reinforced through collaborative coding. All authors participated in the data collection and analysis process, ensuring consistency and minimising potential bias in the interpretation of findings (Belotto 2018). This iterative and collective approach enabled us to refine the thematic framework and ensure that the extracted themes accurately reflected the complexities of BDA implementation. Ultimately, this comprehensive process led to the extraction of 11 key themes structured in three domains that underpin the study's findings. These themes offer valuable insights into how manufacturing SMEs' managers navigate the complexities of BDA implementation, shedding light on the challenges, opportunities, and managerial strategies involved.

4. Findings and results

This study sheds light on the pivotal role SMEs' managers play in navigating BDA implementation. Through the interviews analysis, 11 main themes emerged categorised under three domains of focus, which provide insight about how managers use BDA, their roles and strategies during the implementation and the perceived impact, as presented in Table 4.

4.1. Managers' use of BDA

Organisations and managers are increasingly relying on data-driven solutions to extract and process large amount of data gathered from the firms' digital systems. According to P7, BDA are 'paramount assets for companies to make data-driven decisions and reduce operational uncertainties'. In line with the literature (e.g. Yu et al. 2018), participants also highlighted the importance of having a holistic and strategic use of BDA across their operations to gain efficiencies and achieved some optimisations.

However, SMEs' managers predominantly leverage descriptive and predictive BDA to optimise operations and decision-making. Predictive analytics emerged as a key tool for demand management, with participants describing its ability to forecast trends, anticipate operational disruptions, and reduce uncertainties. One participant explained, 'BDA reduces our operational uncertainties and assists our decision-making' (P5). Another manager highlighted, 'with BDA, we can reduce our development time by 20-50% and manage demand planning across multiple sites and supply chains' (P9). Nonetheless, managers also aspire to integrate prescriptive BDA to develop new products, services, and processes. As one manager noted, 'prescriptive analytics could help us explore alternative solutions and actions to make better decisions in the future' (P1). The transition to prescriptive analytics is seen as the next frontier, requiring investments in advanced capabilities and systems integration (Delen and Zolbanin 2018). For example, Beverston Engineering in the UK began with IoT-fed descriptive dashboards and evolved to predictive maintenance models to anticipate equipment failures (Made Smarter 2024). Likewise, Tecno Mulipast, an Italian SME integrated IoT-enabled laser welding with its ERP to capture real-time, batch-level data. Initially leveraging descriptive dashboards and predictive models for monitoring and anomaly detection, the company intentionally designed the system for scalability, enabling future upgrades to include prescriptive analytics that recommend real-time parameter adjustments for process optimisation (Magaletti et al. 2025). These cases reflect Lepenioti et al. (2020) recommendation that firms extend predictive analytics by incorporating optimisation and simulation models, shifting from 'what will happen' to 'what should be done'. Moreover, our findings suggest that predictive analytics are used to better understand and serve customers, aligning operational decisions with value, '[BDA] helps us to improve our customers knowledge. It also allows us to have better communication by sharing forecasts and adjusting the

Table 4. Main emerging domains, themes and description.

Domain	Theme	Description
Managers' use of BDA	1. Operational optimisation through descriptive and predictive BDA	SMEs' managers primarily use descriptive and predictive analytics to enhance operational efficiency and support better decision-making.
	2. Enhancing customer centricity	Predictive analytics are used to better understand and serve customers, aligning operational decisions with customer value.
Managers' roles and strategies in BDA implementation	3. Strategic use of technology transfer methods	SMEs' managers adopt vertical, horizontal, and stratification strategies to ensure the successful implementation of BDA across the organisation.
	4. Building a data-driven culture	Proactive managerial efforts are needed to foster a cohesive organisational culture and develop new competencies.
	5. System design and integration	SMEs' managers take responsibility for integrating and aligning systems necessary to exploit BDA capabilities.
	6. Developing partnerships and investing in people and technology	Implementation success depends on external collaborations and investments in technological and skills.
	7. Overcoming barriers	SMEs managers must navigate and resolve technical, organisational, and contextual barriers that inhibit BDA implementation.
	8. Bundling and aligning resources	Effective implementation relies on how well SMEs managers coordinate and allocate organisational resources.
	9. Leveraging resources for prescriptive insights	Advanced BDA applications require SMEs managers to combine diverse resources to generate prescriptive and actionable insights.
Managers' perceptions of BDA implementation's impact	10. Perceived necessity of BDA	SMEs' managers view BDA adoption as critical to avoiding obsolescence, sustaining innovation, and achieving business growth.
	11. Prescriptive BDA implementation for innovation and growth	SMEs' managers envision using prescriptive analytics to support the development of new products, services, and processes.

demand planning' (P14). Participants also reported using predictive analytics to improve responsiveness and tailor offerings. 'BDA reduces time-to-market and allows us to respond quickly to market and customer needs' (P4). Predictive analytics emerged as a critical tool for improving customer experiences and value 'potential problems are [now] promptly fixed … allowing us to provide faster and more reliable service to our customers' (P5).

4.2. Managers' roles, and strategies used in BDA implementation

4.2.1. Strategic use of technology transfer

Our findings underscore the importance of proactive strategies and behaviours from the managers, including the use of both horizontal and vertical technology transfers, stratification methods, and cross-functional integration. For instance, one participant shared, that they replicated the solution they implemented in a NZ warehouse for condition monitoring in a Malaysian facility, (P12), exemplifying horizontal technology transfer. Conversely, vertical technology transfer was described as designing the BDA solution in line with the revised strategic goals, as one manager stated, 'we had to redefine a new business strategy in order not to sink and survive despite the global instability. So, we embraced new technologies which supported us in significantly expanding our business and sustaining our revenue' (P1). Another participant concurred stating that 'we created [new] data and databases because we were a manufacturing site and needed [specific] numbers. We have created everything [for a BDA solution], but we're not putting it to full use' (P13).

In manufacturing SMEs, adopting BDA typically unfolds in stages, beginning with isolated departmental pilots, progressing to multiple interconnected departments, and culminating in comprehensive, organisation-wide systems via technology transfer. For example, a New Zealand based manufacturer, Comvita limited, followed 'the 'Think Big – Start Small – Scale Fast' approach' by introducing barcode and load-cell data systems into their decant area (Callaghan Innovation 2021). Encouraged by early success, they then 'used an agile 'plug and play approach' to transfer the technology horizontally and vertically (Callaghan Innovation 2021). Moreover, we noticed the use of a stratification method, such as fostering lean and continuous improvement principles, as foundational for building a data-driven culture and implementing BDA. 'We implemented lean principles, which helped us embrace Industry 4.0 technologies and specifically BDA' (P3). This proactive alignment of processes, technology, strategy and culture enables SMEs to harness BDA more effectively.

4.2.2. Building organisational culture, capabilities, partnerships and investments

Creating a homogenous organisational culture seems critical for BDA success. Participants emphasised the need for cultural shifts and skill acquisition. 'A change of mentality is

needed to conduct the transformation' remarked P8. Additionally, hiring skilled data scientists with cross-functional expertise was deemed essential. 'It is crucial to hire competent data scientists … flexible with broad, inter-functional knowledge' (P1).

Managers also stressed the necessity of modernising infrastructure and integrating systems to exploit BDA capabilities. 'We recognised the obsolescence of our IT architecture and invested significantly to prepare for BDA implementation' (P6). These efforts underscore the proactive measures required to align systems with BDA initiatives.

Partnerships with technology providers and investments in human resources emerged as key enablers. One manager explained, 'we developed our BDA solution through partnerships … Amazon has been a big supporter' (P16). Open-source tools like Apache Hadoop were also highlighted as cost-effective options for SMEs (P7). Investment in training and talent development complements these partnerships. As P15 explained, they are bringing in new people with fresh perspectives to help developing innovative BDA solutions. Such initiatives underscore the importance of combining internal and external resources to drive BDA success.

Across Italy, the UK and NZ, governments invest in pilot and progression initiatives to assist SMEs in adopting digital technologies. They also foster a consortium-based culture, bringing together research institutes, tech firms, and manufacturer SMEs to operationalise BDA and build workforce capability through targeted upskilling programmes. In NZ, the Advanced Manufacturing Industry Transformation Plan promotes firm growth and transformation through partnerships (MBIE, 2023). For example, Callaghan Innovation's Industry 4.0 Demonstration Network 'takes selected companies through a fully funded assessment process to help them accelerate their own journey' (Callaghan Innovation 2024). Italy hosts several national competence centres specialising in Big Data. BI-REX, for example, provides SMEs 'Test-before-Invest' access to a fully sensor-equipped pilot plant, enabling real-time streaming of machine data into cloud-based analytics sandboxes (BI-REX 2025). Similarly, in the UK, UKRI's Made Smarter Innovation challenge funds national hubs to support SMEs with data platforms, funding, and skills development. The Smart Manufacturing Data Hub (SMDH) exemplifies this approach by facilitating collaboration among SMEs, universities, and technology providers. It offers sensor kits, cloud analytics tools, and expert guidance, allowing SMEs to safely experiment with BDA while contributing anonymised data to benefit the broader sector.

4.2.3. Overcoming barriers

SMEs face a spectrum of barriers, including cultural resistance, resource limitations, and technical challenges. One participant noted, 'the business culture in SMEs can prevent the implementation of big data and other Industry 4.0 technologies' (P6), referring to the need for cultural alignment to embrace digital transformation. This is in line with the literature (e.g. Côrte-Real et al. 2019; Khan 2019; Raut et al. 2021). Additionally, skills shortages further hinder progress, 'we don't have enough skilled people who can make sense of the data' suggested P11, meanwhile, P4 reported that 'it is hard finding suitable people'. Moreover, P8 perceived this as a widespread issue and argued 'knowledge and skills related to BDA and other Industry 4.0 technologies are fragmented and barely widespread'. In parallel, inherent barriers include cost and complexity of the implementation, particularly for SMEs. One participant remarked, 'BDA technology has proved to be extremely expensive' (P4), while another highlighted the organisational restructuring required: 'the complexity is not only related to the effort required to extract meaning but also to the required internal reorganisation' (P6). These findings align with existing literature that underscores the financial and technical challenges of BDA adoption.

There are also external challenges which have been mentioned, for example, cybersecurity concerns and resistance from supply chain partners. 'Cybersecurity violations should be prevented … the probability of cyberattacks increases with BDA adoption' (P1). While Khan (2019) refers to privacy and security as an ethical challenge, our findings suggest that participants considered data security, or unwillingness to share data as the problem (Brinch et al. 2018; Wang et al. 2016; Kache and Seuring 2017). These are the challenges that SMEs managers have to overcome to lead successful deployment.

4.3. Managers' perception of BDA implementation's impact

Managers acknowledged that failing to invest in BDA will lead to business stagnation and lack of future competitiveness. For example, P8 discussed: 'Postponing the process would have led to a risk of being left behind by competitors and larger firms'. BDA is seen as indispensable for making better decisions, enhancing operations and processes, meeting market demands, and sustaining growth, 'BDA enables us to gain insights, optimise operations, and make data-driven decisions to sustain the company's growth' (P17).

Managers highlighted the necessity to integrate BDA across all the SCOR model functions (planning, sourcing, making, delivering and returning) to maximise effectiveness. For example, P6 mentioned: 'the implementation in all the supply chain areas is fundamental and having a holistic BDA strategy is crucial to obtain positive results'.

Despite the challenges, managers reported significant benefits from BDA adoption, including process optimisation, innovation, and enhanced customer value (Zhang et al. 2021). BDA's customer-centric capabilities were widely recognised. Overall, it enables firms to streamline operations and make informed decisions, reducing uncertainty and fostering innovation. As one participant noted, 'it should streamline a lot of our process and eliminate a lot of lost time. Having to be disbound to complete all our transactions' (P13). This streamlining enhances operational efficiency, reducing delays in service delivery.

BDA also aids in better supplier management, which can lead to cost savings and improved offerings for customers. For example, P1 shared: 'we rely on BDA to obtain insights into suppliers' information'. Similarly, another participant

stated, 'we use this information to understand the situation that we are facing with this particular supplier and help us to negotiate better terms or better price'. (P14).

Beyond operational efficiency, BDA provides strategic advantages. Participants highlighted BDA's role in supporting competitiveness: 'using big data is not an option but an absolute need to survive in the global markets' (P5). As expressed by a participant, 'BDA really gave us that competitive advantage to step into the farming sector and from there we're able to build the business further' (P16).

Managers in our study confirmed that obtaining unique insights into customer requirements, demand forecasting, production and procurement are key benefits of BDA. These findings align with established literature, which highlights these benefits as central to the effective use of BDA (Blackburn et al. 2015; Hofmann and Rutschmann 2018; Li et al. 2015). Participants also saw BDA's potential to foster innovation, aligning with findings by Babu et al. (2021). BDA supports innovation in customer services. For instance, one manager shared, 'we've been able to provide new services such as insurance for our customers based on predictive BDA' (P16). These innovations underscore the transformative potential of BDA in enhancing customer value and driving business growth.

Participants noted that BDA adoption is accelerating, driven by both internal strategies and external pressures. As one participant observed, 'every company owns big data but… only a few organisations know their potential. It is only a matter of time before this technology will explode' (P3). This sentiment reflects the growing recognition of BDA as a critical asset for business survival and growth, especially in this era of the explosion of generative AI.

The participants suggested that postponing this process would lead to a risk of being left behind by competitors. Participants also highlighted that external market pressure triggers companies to embrace innovation. 'International companies are often ahead with regard to research and innovation. Accordingly, the competitiveness gap is growing wider. For this reason, using big data is not an option but an absolute need to survive in the global markets' (P5).

5. Discussion – *how do manufacturing SMEs managers orchestrate resources to implement BDA successfully to drive innovation and growth?*

5.1. Theoretical findings - resource structuring, bundling, and leveraging

Based on Resource Orchestration Theory (ROT) and the interview data, SMEs' managers structure, bundle, and leverage BDA resources strategically to drive innovation, value creation, and growth. Structuring involves acquiring and accumulating essential resources, such as data, advanced analytics tools and technologies, and skilled personnel, while divesting obsolete systems to build a robust resource portfolio. For instance, one participant explained, 'we recognised the obsolescence of our IT architecture and invested significantly to restructure' (P6), highlighting the importance of foundational infrastructure in enabling BDA initiatives. Secondary evidence underscores that robust digital infrastructure and legacy knowledge are prerequisites for successful BDA. For instance, in Beverston Engineering a 2020 Made Smarter project installed a dedicated machine-data server, upgraded the shop-floor Ethernet and retrofitted IIoT gateways to every CNC, deliberately 'laying the foundations for connectivity' before any dashboards were built (Made Smarter 2024). Managers also draw on existing resources, such as historical data and operational expertise, to establish a strong starting point for BDA adoption. Participants highlighted the deliberate collection of proprietary data, such as sales figures and operational metrics from production, procurement and logistics, as mechanisms to accumulate valuable resources. This exclusive data offers insights into internal processes, demand, sourcing strategies, and market opportunities, enabling informed decision-making to drive innovation. This approach aligns with Dahiya et al. (2022) framework that suggests customised BDA solutions with 'proprietary' data lead to firm-specific knowledge and competitive advantage.

Bundling resources focuses on integrating these elements to develop organisational capabilities through stabilising, enriching, and pioneering strategies. Stabilising involves making incremental improvements to existing systems, such as enhancing demand forecasting accuracy, as described by P9: 'we can reduce development time by up to 50% and better manage demand planning across multiple sites'. Bindatex (UK) provides another illustration, by barcoding every sales order and capturing those scans in the cloud-based MES Total Control Pro, the company gained real-time visibility of work in progress across its narrow-slitting line reducing cycle time from 4.5 h to 3.5 h (≈30% productivity gain) and trimming average lead time by 25% (Made Smarter, n.2022d.a). Enriching builds on these improvements by extending capabilities to new domains, such as predictive maintenance and inventory management, enabling real-time operational insights. Pioneering creates entirely new capabilities, such as transitioning from 'make-to-stock' to 'make-to-order' production models by leveraging predictive analytics to anticipate demand (P8).

Finally, leveraging resources entails exploiting developed capabilities to generate tangible outcomes through mobilising, coordinating, and deploying strategies. Mobilising involves planning resource configurations to address specific goals, such as improving customer responsiveness or enhancing product quality. For instance, Oasis Engineering (NZ) mobilised its resources by implementing smart sensors and tablets on the shop floor as part of a 'Digital Lean' initiative, enabling real-time process data analytics tailored to reduce machine downtime (Callaghan Innovation 2020). Coordinating integrates these configurations across organisational functions to ensure alignment with strategic objectives. For example, Storth Engineering's roadmap spans sales, planning and production; it launched a data-rich robotic-welding cell whose live metrics feed straight into pricing and capacity tools, tying shop-floor efficiency to the strategic aim of maintaining short lead-times (Made Smarter, n.2020d.b). Similarly, our participant shared, 'we

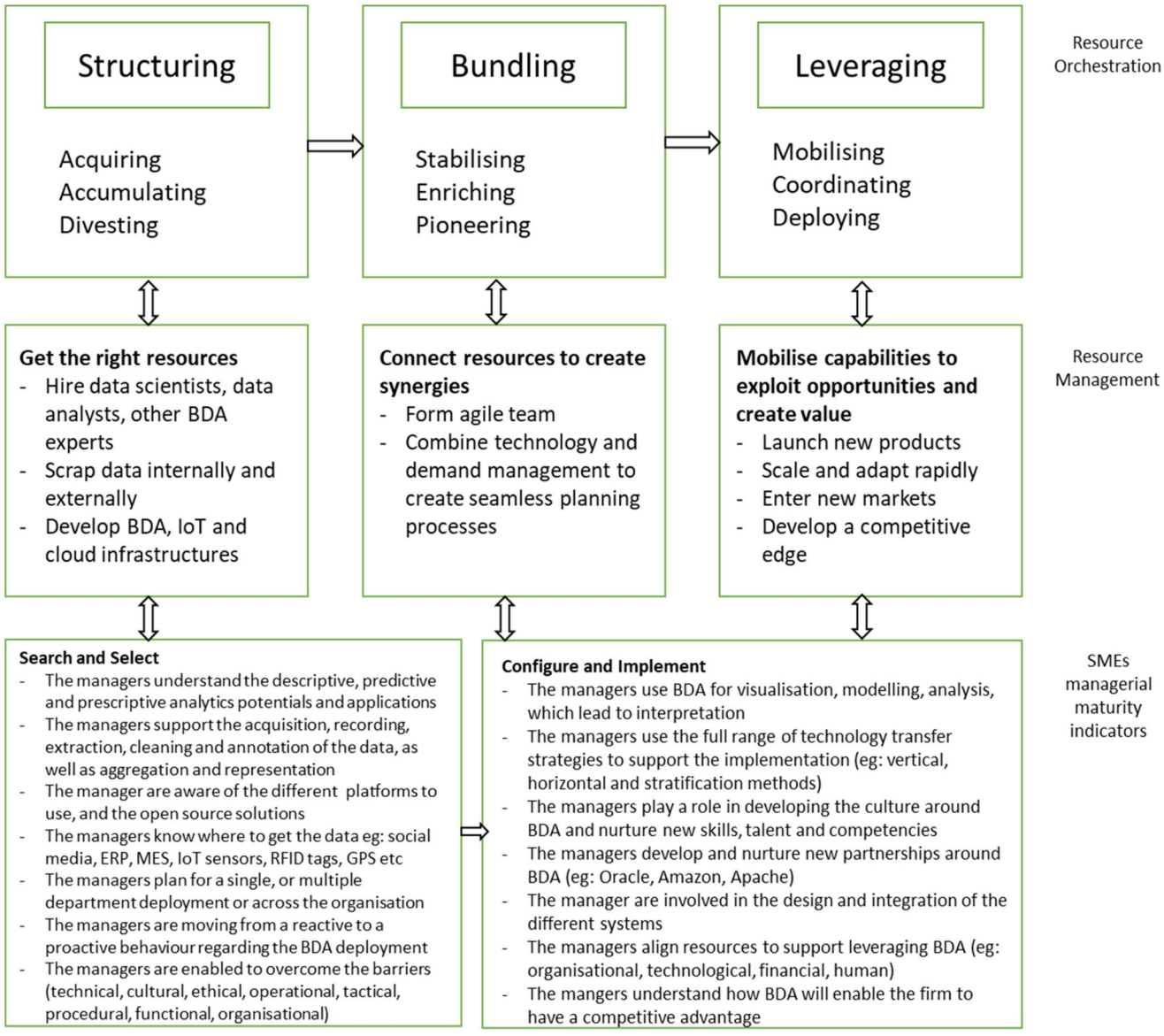

Figure 2. A ROT model for BDA implementation.

rely on BDA to gain insights into suppliers' information and negotiate better terms and align with engineering' (P14), demonstrating the integration of procurement and production and BDA. Deploying these capabilities focuses on exploiting them to create value, as noted by P5: 'predictive maintenance reduces waiting times and allows us to provide faster and more reliable service to our customers'.

The ability to strategically orchestrate BDA is rare due to the complex blend of specialised knowledge and resources needed to transform data into strategic insights. This aligns with LaValle et al. (2011), who emphasise that having large amounts of data without knowing how to use them and what to obtain from them is futile. Participants further argued that while data access is common, the ability to orchestrate and strategically apply BDA remains rare. Most participants believed that BDA adoption is accelerating; however, as P3 remarked, 'every company owns big data but, at the moment, only a few organisations know their potential. It is only a matter of time before this technology will explode by being recognised as a compulsory asset for business survival'. This view is supported by literature that highlights BDA's role in optimising processes and improving efficiency and performance (Tao et al. 2018; Wamba et al. 2017).

Through structuring, bundling, and leveraging BDA resources, SMEs' managers effectively orchestrate resources across the organisation, adapt strategies to different stages and function (SCOR), and align initiatives across various levels, ensuring sustainable innovation and growth.

Our Figure 2 provides a ROT model for BDA implementation. It presents a dynamic, three-stage model illustrating how manufacturing SMEs managers strategically can orchestrate resources to implement BDA within their operations.

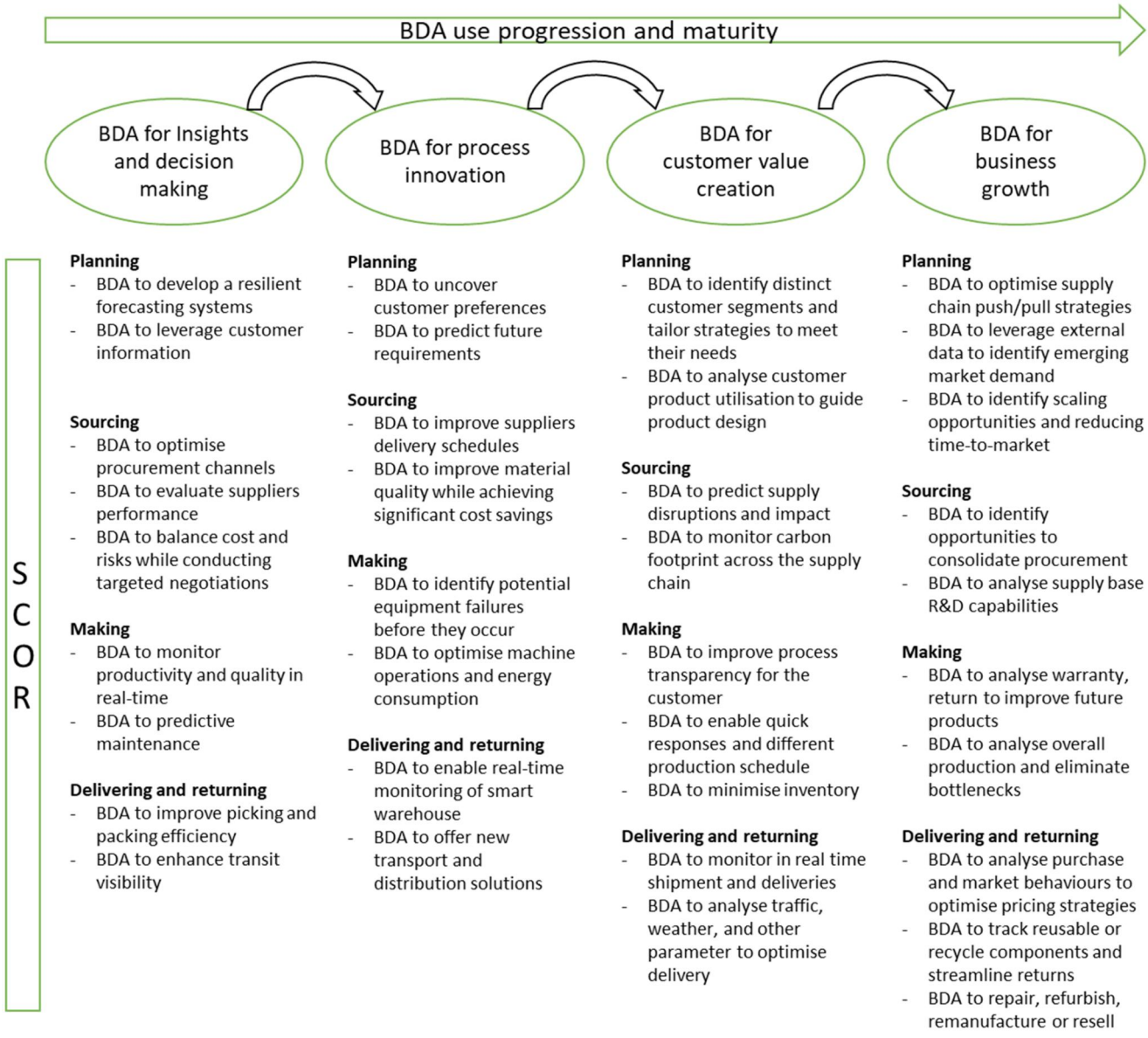

Figure 3. A SCOR BDA roadmap for SMEs.

The model is structured around the resource orchestration framework, comprising the three interrelated processes: structuring, bundling, and leveraging. In the structuring phase, managers focus on acquiring, accumulating, and divesting resources to ensure the foundational capabilities are in place. This involves hiring data specialists, scrapping and aggregating internal and external data, and developing infrastructure such as BDA platforms, IoT systems, and cloud computing. Managers play an active role in searching and selecting appropriate technologies and data sources, while also shifting from a reactive to a proactive stance in BDA adoption.

The bundling phase centres on creating synergies by stabilising, enriching, and pioneering resource combinations. This includes forming agile teams and integrating technologies with demand management to support seamless planning. Here, managers are involved in configuring and implementing BDA systems for visualisation, modelling, and analysis. They also facilitate further technology transfer, develop internal competencies, and build strategic partnerships with key technology providers (e.g. Oracle, Amazon, Apache). This phase is critical in fostering an innovation-oriented culture, underpinned by organisational learning and cross-functional integration.

Finally, in the leveraging phase, firms mobilise, coordinate, and deploy their configured capabilities to create value. Managers use BDA to enable agility, such as launching new products, entering new markets, and scaling operations quickly. This stage reflects the culmination of earlier efforts and showcases how BDA can serve as a strategic enabler of innovation and competitive advantage. Importantly, the model underscores the iterative and interconnected nature of these phases, illustrating that effective BDA implementation is not a linear progression but a continuous, adaptive process shaped by managerial agency, contextual factors, and technological maturity.

5.2. A SCOR BDA roadmap for SMEs

To complement the resource orchestration model in Figure 2, we developed a second framework presented in Figure 3 that serves as a maturity roadmap for BDA integration across supply chain operations. Anchored in the SCOR model, this roadmap delineates the progressive use of BDA within manufacturing SMEs, revealing how firms gradually evolve their BDA capabilities to support increasingly strategic objectives and business growth.

At the initial stage, firms apply BDA for insights and decision-making, primarily within a single function (e.g.: in planning or production activities). Here, BDA is used to enhance forecasting accuracy, monitor performance, and support data-informed decision-making. As SMEs gain confidence and build internal capabilities, they can progress to BDA for process innovation, particularly across two or more functions (e.g.: sourcing and production activities). This would involve managers leveraging BDA to optimise procurement strategies, streamline manufacturing, and reduce operational inefficiencies.

Subsequently, SMEs could shift focus and progress to BDA for customer value creation, by applying the technology to delivery and returns processes to personalise offerings, improve responsiveness, and enhance service recovery. At this stage, the use of BDA transcends internal efficiencies and begins to directly shape customer experience and satisfaction.

The final stage represents BDA for business growth, where SMEs and their managers harness the technology across all SCOR domains to enable scalability, market expansion, and strategic agility. BDA becomes a source of sustained competitive advantage, driving innovation and supporting dynamic capability development.

This framework offers a practical model for understanding the evolutionary trajectory of BDA use and deployment in SMEs. It underscores that value from BDA does not emerge immediately or uniformly across the supply chain operations. Rather, it reflects a journey of gradual adoption, capability building, and strategic alignment, with each phase reinforcing the foundation for the next and where managers are at the centre. The model highlights how BDA maturity is tightly coupled with the capacity to innovate, differentiate, and grow in competitive environments.

6. Implications, limitations and future research

This study examined the critical role that managers of manufacturing SMEs play in the implementation of BDA, focusing on how they orchestrate resources to improve operational performance, foster innovation, and enable business growth. Drawing on a qualitative thematic analysis, we identified eleven interrelated themes across three domains: the use of BDA, managerial roles and strategies in implementation, and managers perceptions of BDA's impact. Collectively, these findings underscore the multifaceted responsibilities that SMEs' managers assume in navigating BDA implementation and maturity.

Our analysis reveals that managers primarily utilise descriptive and predictive BDA to optimise decision-making and operational efficiency. However, many also aspire to harness the potential of prescriptive analytics for product, service, and process innovation. To successfully deploy BDA solutions, managers must adopt proactive implementation strategies, such as integrating vertical and horizontal technology transfer approaches, fostering a data-driven organisational culture, and investing in systems, partnerships, and talent. They must also overcome a range of internal and external challenges, including capability gaps, financial constraints, and concerns about cybersecurity.

Importantly, we demonstrate how managers engage in dynamic resource orchestration, not only by acquiring and bundling resources but also by aligning and leveraging them across organisational and technological domains. This strategic orchestration enables SMEs to progress in their BDA maturity, enhance customer value, and position themselves for sustainable growth.

This study makes contributions to research and practise. From a theoretical perspective, it applies Resource Orchestration Theory (ROT) to the underexplored context of BDA implementation within SMEs. In doing so, it elucidates how managers serve as critical agents in strategically structuring, bundling, and leveraging resources to support BDA adoption and value realisation. The study contributes to emerging literature on digital transformation in SMEs (Asiri, Al-Somali, and Maghrabi 2024; Kgakatsi, Galeboe, and Molelekwa 2024) by offering a nuanced understanding of managerial agency and capability development in BDA-driven initiatives. This study extends BDA research in manufacturing sector (Gu et al. 2021; Waqas et al. 2021) by explaining the complexities associated with DBA implementations and highlighting the role of managers in orchestrating BDA resources to gain innovation and growth. Moreover, the findings of this study are derived through interviews, thus it provides largely missing empirical evidence for BDA implementation studies.

From a practical perspective, the study offers actionable insights for SMEs managers navigating the complexities of BDA implementation. The two complementary frameworks developed, presented in Figures 2 and 3, provide both a conceptual model of resource orchestration and a roadmap for BDA use progression and maturity guided by the SCOR model. These frameworks enable SMEs to assess their current state, reflect on their strategies, and align resource capabilities with technological deployment and business objectives.

While the study offers valuable contributions, it also has limitations. The sample comprises 17 interviews, which may limit generalisability. Future research could extend this work by incorporating a larger, more diverse sample of SMEs, or by conducting cross-sectoral comparisons. Future research could also utilise methodologies such as surveys and experiments to extend and validate our findings. Additionally, the study focuses exclusively on manufacturing SMEs; future research could compare resource orchestration strategies between SMEs and large enterprises to explore how firm size

and structural differences influence BDA adoption. Longitudinal studies may also provide deeper insights into the evolution and long-term impact of BDA implementation, including questions such as: What is the long-term effect of BDA on SMEs performance? What training and investment models best support capability development? And what role might emerging technologies like AI and machine learning play in supporting data-driven innovation and decision-making in SMEs? Another limitation lies in the selection bias towards firms that had, to some extent, successfully implemented BDA. While this allowed for rich insights into managerial roles, resource orchestration, and enabling factors, it excludes the perspectives of firms that have struggled, failed, or never attempted adoption. Including such cases could yield a more complete understanding of barriers, organisational resistance, and contextual constraints that hinder BDA adoption, ensuring findings reflect the full spectrum of SME experiences. Future research could examine both successful and unsuccessful BDA implementations by adopting a comparative case study design that purposefully samples firms across the adoption spectrum, including non-adopters and failed adopters. Such an approach would provide a more balanced and comprehensive understanding of BDA's real-world challenges and opportunities in SMEs.

Finally, while the model and roadmap developed in this study are grounded in empirical data from a range of manufacturing SMEs (e.g.: agricultural machinery, oil and gas equipment, and pharmaceutical manufacturing), they are designed to be adaptable to other industrial contexts. We acknowledge that implementation will vary depending on specific sectoral needs, organisational characteristics, and strategic priorities. Nevertheless, the frameworks offer a flexible foundation for managers, industry bodies, and policy-makers seeking to enable the broader adoption and effective use of BDA across the manufacturing SME sector.

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References

Al-Khatib, A. W. 2023. "How Big Data-Driven Organizational Capabilities Shape Innovation Performance? An Empirical Study from Small and Medium Manufacturing Enterprises." *Kybernetes* 54 (1): 456–482.

Anwar, M. A., Z. Zong, A. Mendiratta, and M. Z. Yaqub. 2024. "Antecedents of Big Data Analytics Adoption and Its Impact on Decision Quality and Environmental Performance of SMEs in Recycling Sector." *Technological Forecasting and Social Change* 205: 123468. https://doi.org/10.1016/j.techfore.2024.123468.

Asiri, A. M., S. A. Al-Somali, and R. O. Maghrabi. 2024. "The Integration of Sustainable Technology and Big Data Analytics in Saudi Arabian SMEs: A Path to Improved Business Performance." *Sustainability* 16 (8): 3209. https://doi.org/10.3390/su16083209.

Babalghaith, R., and A. Aljarallah. 2024. "Factors Affecting Big Data Analytics Adoption in Small and Medium Enterprises." *Information Systems Frontiers* 26 (6): 2165–2187. https://doi.org/10.1007/s10796-024-10538-2.

Babu, M. M., M. Rahman, A. Alam, and B. L. Dey. 2021. "Exploring Big Data-Driven Innovation in the Manufacturing Sector: evidence from UK Firms." *Annals of Operations Research* 333 (2): 689–716. https://doi.org/10.1007/s10479-021-04077-1.

Baig, M. I., E. Yadegaridehkordi, and M. H. Nizam Bin Md Nasir. 2023. "Influence of Big Data Adoption on Sustainable Marketing and Operation of SMEs: A Hybrid Approach of SEM-ANN." *Management Decision* 61 (7): 2231–2253. https://doi.org/10.1108/MD-06-2022-0778.

Barney, J. 1991. "Firm Resources and Sustained Competitive Advantage." *Journal of Management* 17 (1): 99–120. https://doi.org/10.1177/014920639101700108.

Belotto, M. J. 2018. "Data Analysis Methods for Qualitative Research: Managing the Challenges of Coding, Interrater Reliability, and Thematic Analysis." *The Qualitative Report* 23 (11): 2622–2633. https://doi.org/10.46743/2160-3715/2018.3492.

Bertello, A., A. Ferraris, S. Bresciani, and P. De Bernardi. 2021. "Big data analytics (BDA) and degree of internationalization: the interplay between governance of BDA infrastructure and BDA capabilities." *Journal of Management and Governance* 25 (4): 1035–1055.

Bharadwaj, A. S. 2000. "A Resource-Based Perspective on Information Technology Capability and Firm Performance: An Empirical Investigation." *MIS Quarterly* 24 (1): 169–196. https://doi.org/10.2307/3250983.

Bibby, L., and B. Dehe. 2018. "Defining and Assessing Industry 4.0 Maturity Levels–Case of the Defence Sector." *Production Planning & Control* 29 (12): 1030–1043. https://doi.org/10.1080/09537287.2018.1503355.

BI-REX. 2025. "About us." https://bi-rex.it/en/

Blackburn, Robert, Kristina Lurz, Benjamin Priese, Rainer Göb, and Inga-Lena Darkow. 2015. "A Predictive Analytics Approach for Demand Forecasting in the Process Industry." *International Transactions in Operational Research* 22 (3): 407–428. https://doi.org/10.1111/itor.12122.

Brinch, M., J. Stentoft, J. K. Jensen, and C. Rajkumar. 2018. "Practitioners Understanding of Big Data and Its Applications in Supply Chain Management." *The International Journal of Logistics Management* 29 (2): 555–574. https://doi.org/10.1108/IJLM-05-2017-0115.

Busby, A., M. Warby, L. Walsh, A. Coulter, J. Nelles, and T. Vorley. 2025, June 2. "Barriers and Enablers to Advanced Technology Adoption for UK Businesses." Department for ScienceInnovation & Technology Department for Culture, Media & Sport. https://www.gov.uk/government/publications/barriers-and-enablers-to-advanced-technology-adoption-for-uk-businesses/barriers-and-enablers-to-advanced-technology-adoption-for-uk-businesses

Busby, A., M. Warby, L. Walsh, A. Coulter, J. Nelles, and T. Vorley. 2025, June 2. "Barriers and Enablers to Advanced Technology Adoption for UK Businesses." (Research No DSIT 2025/007). GOV.UK. https://www.gov.uk/government/publications/barriers-and-enablers-to-advanced-technology-adoption-for-uk-businesses

Cadden, T., J. Weerawardena, G. Cao, Y. Duan, and R. McIvor. 2023. "Examining the Role of Big Data and Marketing Analytics in SMEs Innovation and Competitive Advantage: A Knowledge Integration Perspective." *Journal of Business Research* 168: 114225. https://doi.org/10.1016/j.jbusres.2023.114225.

Callaghan Innovation. 2020. July 2. "Oasis Engineering: Set up for New Market Success by Setting up Industry 4.0 Solutions." https://www.callaghaninnovation.govt.nz/stories/oasis-embraces-industry-40/

Callaghan Innovation. 2021. "Comvita: Industry 4.0 Case Study." https://www.callaghaninnovation.govt.nz/assets/documents/Industry-4-Case-Studies/comvita-case-study-2021.pdf

Callaghan Innovation. 2024. November. "Aotearoa's Industry 4.0 Journey."

Callaghan Innovation. 2025. "2025 Industry 4.0 Insights Survey [PDF]." Callaghan Innovation. https://www.callaghaninnovation.govt.nz/assets/documents/Industry-4-0/2025_Industry4_Insights_Survey_FINAL.pdf

Chehbi-Gamoura, S., R. Derrouiche, D. Damand, and M. Barth. 2020. "Insights from Big Data Analytics in Supply Chain Management: An All-Inclusive Literature Review Using the SCOR Model." *Production Planning & Control* 31 (5): 355–382. https://doi.org/10.1080/09537287.2019.1639839.

Chen, D. Q., D. S. Preston, and M. Swink. 2021. "How Big Data Analytics Affects Supply Chain Decision-Making: An Empirical Analysis." *Journal of the Association for Information Systems* 22 (5): 1224–1244. https://doi.org/10.17705/1jais.00713.

Chen, H., Chiang, R. H. L., & Storey, V. C. 2012. "Business Intelligence and Analytics: From Big Data to Big Impact." *MIS Quarterly*, 36(4), 1165–1188. https://doi.org/10.2307/41703503.

Choi, H. S., S. Y. Hung, C. Y. Peng, and C. Chen. 2022. "Different Perspectives on BDA Usage by Management Levels." *Journal of Computer Information Systems* 62 (3): 503–515. https://doi.org/10.1080/08874417.2020.1858729.

Clarke, V., V. Braun, and N. Hayfield. 2015. "Thematic Analysis." *Qualitative Psychology: A Practical Guide to Research Methods* 3: 222–248.

Coleman, S., R. Göb, G. Manco, A. Pievatolo, X. Tort-Martorell, and M. S. Reis. 2016. "How Can SMEs Benefit from Big Data? Challenges and a Path Forward." *Quality and Reliability Engineering International* 32 (6): 2151–2164. https://doi.org/10.1002/qre.2008.

Côrte-Real, N., P. Ruivo, T. Oliveira, and A. Popovič. 2019. "Unlocking the Drivers of Big Data Analytics Value in Firms." *Journal of Business Research* 97: 160–173. https://doi.org/10.1016/j.jbusres.2018.12.072.

Dahiya, R., S. Le, J. K. Ring, and K. Watson. 2022. "Big Data Analytics and Competitive Advantage: The Strategic Role of Firm-Specific Knowledge." *Journal of Strategy and Management* 15 (2): 175–193. https://doi.org/10.1108/JSMA-08-2020-0203.

Dehbi, S., H. C. Lamrani, T. Belgnaoui, and T. Lafou. 2022. "Big Data Analytics and Management Control." *Procedia Computer Science* 203: 438–443. https://doi.org/10.1016/j.procs.2022.07.058.

Delen, D., and H. M. Zolbanin. 2018. "The Analytics Paradigm in Business Research." *Journal of Business Research* 90: 186–195. https://doi.org/10.1016/j.jbusres.2018.05.013.

Department for Business & Trade. 2023. *Evaluation of Help to Grow: Digital: Final Evaluation Report*. London, UK: RSM UK Consulting LLP.

Dutta, D., and I. Bose. 2015. "Managing a Big Data Project: The Case of Ramco Cements Limited." *International Journal of Production Economics* 165: 293–306. https://doi.org/10.1016/j.ijpe.2014.12.032.

Falahat, M., P. K. Cheah, J. Jayabalan, C. M. J. Lee, and S. B. Kai. 2022. "Big Data Analytics Capability Ecosystem Model for SMEs." *Sustainability* 15 (1): 360. https://doi.org/10.3390/su15010360.

Fawcett, S. E., M. A. Waller, J. W. Miller, M. A. Schwieterman, B. T. Hazen, and R. E. Overstreet. 2014. "A Trail Guide to Publishing Success: tips on Writing Influential Conceptual, Qualitative, and Survey Research." *Journal of Business Logistics* 35 (1): 1–16. https://doi.org/10.1111/jbl.12039.

Gandomi, A., and M. Haider. 2015. "Beyond the Hype: Big Data Concepts, Methods, and Analytics." *International Journal of Information Management* 35 (2): 137–144. https://doi.org/10.1016/j.ijinfomgt.2014.10.007.

Gao, J., and Z. Sarwar. 2022. "How Do Firms Create Business Value and Dynamic Capabilities by Leveraging Big Data Analytics Management Capability?" *Information Technology & Management* 25 (3): 1–22. https://doi.org/10.1007/s10799-022-00380-w.

Georgise, F. B., T. Wuest, and K. D. Thoben. 2017. "SCOR Model Application in Developing Countries: challenges & Requirements." *Production Planning and Control* 28 (1): 17–32. https://doi.org/10.1080/09537287.2016.1230790.

Gervasi, M., N. G. Totaro, G. Specchia, and M. E. Latino. 2023. "Unveiling the Roots of Big Data Project Failure: A Critical Analysis of the Distinguishing Features and Uncertainties in Evaluating Big Data Potential Value." (CEUR Workshop Proceedings No. 3606). CEUR-WS.

Gligor, D. M., B. Davis-Sramek, A. Tan, A. Vitale, I. Russo, I. Golgeci, and X. Wan. 2022. "Utilizing Blockchain Technology for Supply Chain Transparency: A Resource Orchestration Perspective." *Journal of Business Logistics* 43 (1): 140–159. https://doi.org/10.1111/jbl.12287.

Gong, Y., F. Jia, S. Brown, and L. Koh. 2018. "Supply Chain Learning of Sustainability in Multi-Tier Supply Chains: A Resource Orchestration Perspective." *International Journal of Operations & Production Management* 38 (4): 1061–1090. https://doi.org/10.1108/IJOPM-05-2017-0306.

Gu, V. C., B. Zhou, Q. Cao, and J. Adams. 2021. "Exploring the Relationship between Supplier Development, Big Data Analytics Capability, and Firm Performance." *Annals of Operations Research* 302 (1): 151–172. https://doi.org/10.1007/s10479-021-03976-7.

Hasan, R., M. M. Kamal, A. Daowd, T. Eldabi, I. Koliousis, and T. Papadopoulos. 2024. "Critical Analysis of the Impact of Big Data Analytics on Supply Chain Operations." *Production Planning & Control* 35 (1): 46–70. https://doi.org/10.1080/09537287.2022.2047237.

Hasnan, S., Hakim, A. A., Ab Rahaman, A. F., Zulkifli, F. N. F., Hazimi, N. H. M., & Shaifuddin, A. R. M. (2023). Determinants of Big Data Analytics (BDA) Adoption among Small and Medium Enterprises (SMEs). *Accounting and Finance Research*, 12(4), 1-54. https://doi.org/10.5430/afr.v12n4p54.

Hofmann, E., and E. Rutschmann. 2018. "Big Data Analytics and Demand Forecasting in Supply Chains: A Conceptual Analysis." *The International Journal of Logistics Management* 29 (2): 739–766. https://doi.org/10.1108/IJLM-04-2017-0088.

Hopkins, J., and P. Hawking. 2018. "Big Data Analytics and IoT in Logistics: A Case Study." *The International Journal of Logistics*

Management 29 (2): 575–591. https://doi.org/10.1108/IJLM-05-2017-0109.

Jeble, S., R. Dubey, S. J. Childe, T. Papadopoulos, D. Roubaud, and A. Prakash. 2018. "Impact of Big Data and Predictive Analytics Capability on Supply Chain Sustainability." *The International Journal of Logistics Management* 29 (2): 513–538. https://doi.org/10.1108/IJLM-05-2017-0134.

Jha, A. K., M. A. N. Agi, and E. W. T. Ngai. 2020. "A Note on Big Data Analytics Capability Development in Supply Chain." *Decision Support Systems* 138(: 113382. https://doi.org/10.1016/j.dss.2020.113382.

Kache, F., and S. Seuring. 2017. "Challenges and Opportunities of Digital Information at the Intersection of Big Data Analytics and Supply Chain Management." *International Journal of Operations & Production Management* 37 (1): 10–36. https://doi.org/10.1108/IJOPM-02-2015-0078.

Ketchen, D. J., Jr, K. D. Wowak, and C. W. Craighead. 2014. "Resource Gaps and Resource Orchestration Shortfalls in Supply Chain Management: The Case of Product Recalls." *Journal of Supply Chain Management* 50 (3): 6–15. https://doi.org/10.1111/jscm.12047.

Kgakatsi, M., O. Galeboe, and K. Molelekwa. 2024. "The Impact of Big Data on SME Performance: A Systematic Review." *Businesses* 4 (4): 632–695.

Khan, M. 2019. "Challenges with Big Data Analytics in Service Supply Chains in the UAE." *Management Decision* 57 (8): 2124–2147. https://doi.org/10.1108/MD-06-2018-0669.

Klein, H. K., and M. D. Myers. 1999. "A Set of Principles for Conducting and Evaluating Interpretive Field Studies in Information Systems." *MIS Quarterly* 23 (1): 67–93. https://doi.org/10.2307/249410.

Lade, P., G. Rumi, and S. Soundar. 2017. "Manufacturing Analytics and Industrial Internet of Things." *IEEE Intelligent Systems* 32 (3): 74–79. https://doi.org/10.1109/MIS.2017.49.

Lai, Y., H. Sun, and J. Ren. 2018. "Understanding the Determinants of Big Data Analytics (BDA) Adoption in Logistics and Supply Chain Management: An Empirical Investigation." *The International Journal of Logistics Management* 29 (2): 676–703. https://doi.org/10.1108/IJLM-06-2017-0153.

Lamba, K., and S. Singh. 2017. "Big Data in Operations and Supply Chain Management: current Trends and Future Perspectives." *Production Planning & Control* 28 (11-12): 877–890. https://doi.org/10.1080/09537287.2017.1336787.

LaValle, S., E. Lesser, R. Shockley, M. Hopkins, and N. Kruschwitz. 2011. "Big Data, Analytics and the Path From Insights to Value." *MIT Sloan Management Review* 52 (2): 21.

Lee, C., K, M. Cao, Y. Ng, and K. H. 2017. "Big Data Analytics for Predictive Maintenance Strategies." In *Supply Chain Management in the Big Data Era*, editd by H. K. Chan, N. Subramanian, M. D.-A. Abdulrahman, 50–74. Hershey: IGI Global.

Lepenioti, K., A. Bousdekis, D. Apostolou, and G. Mentzas. 2020. "Prescriptive Analytics: Literature Review and Research Challenges." *International Journal of Information Management* 50: 57–70. https://doi.org/10.1016/j.ijinfomgt.2019.04.003.

Li, J., F. Tao, Y. Cheng, and L. Zhao. 2015. "Big Data in Product Lifecycle Management." *The International Journal of Advanced Manufacturing Technology* 81 (1-4): 667–684. https://doi.org/10.1007/s00170-015-7151-x.

Lustig, I., B. Dietrich, C. Johnson, and C. Dziekan. 2010. "The Analytics Journey.' Institute for Operations Research and the Management Sciences." https://pubsonline.informs.org/do/10.1287/LYTX.2010.06.01/full/

Made Smarter. 2024. "Case Study – Beverston Engineering Revisit." Made Smarter UK Programme. https://www.madesmarter.uk/resources/case-study-beverston-engineering-revisit/

Made Smarter. n.d.a. "Bindatex: A Cut above the Rest [Case Study]." https://www.madesmarter.uk/media/l3mdl4z1/bindatex-case-study.pdf

Made Smarter. n.d.b. "Case Study: Storth Engineering." https://www.madesmarter.uk/resources/case-study-storth-engineering/

Magaletti, N., V. Notarnicola, M. Di Molfetta, S. Mariani, and L. Angelo. 2025. "Integrating IoT, AI, and Data Analytics in Food Machinery Production: A Digital Innovation Model for SMEs." *Preprints* 1–11. https://doi.org/10.20944/preprints202504.1958.v1.

Maheshwari, S., P. Gautam, and C. K. Jaggi. 2021. "Role of Big Data Analytics in Supply Chain Management: current Trends and Future Perspectives." *International Journal of Production Research* 59 (6): 1875–1900. https://doi.org/10.1080/00207543.2020.1793011.

Malik, M., H. Ghaderi, and A. Andargoli. 2021. "A Resource Orchestration View of Supply Chain Traceability and Transparency Bundles for Competitive Advantage." *Business Strategy and the Environment* 30 (8): 3866–3881. https://doi.org/10.1002/bse.2845.

Maroufkhani, P., M. Iranmanesh, and M. Ghobakhloo. 2023. "Determinants of Big Data Analytics Adoption in Small and Medium-Sized Enterprises (SMEs)." *Industrial Management & Data Systems* 123 (1): 278–301. https://doi.org/10.1108/IMDS-11-2021-0695.

Matthias, O., I. Fouweather, I. Gregory, and A. Vernon. 2017. "Making Sense of Big Data -Can It Transform Operations Management?" *International Journal of Operations & Production Management* 37 (1): 37–55. https://doi.org/10.1108/IJOPM-02-2015-0084.

Mikalef, P., J. Krogstie, I. O. Pappas, and P. Pavlou. 2020. "Exploring the Relationship between Big Data Analytics Capability and Competitive Performance: The Mediating Roles of Dynamic and Operational Capabilities." *Information & Management* 57 (2): 103169. https://doi.org/10.1016/j.im.2019.05.004.

Minshull, L. K., B. Dehe, and S. Kotcharin. 2022. "Exploring the Impact of a Sequential Lean Implementation within a Micro-Firm–a Socio-Technical Perspective." *Journal of Business Research* 151: 156–169. https://doi.org/10.1016/j.jbusres.2022.06.052.

Moraes, G. H. S. M. D., G. C. Pelegrini, L. P. de Marchi, G. T. Pinheiro, and A. Cappellozza. 2022. "Antecedents of Big Data Analytics Adoption: An Analysis with Future Managers in a Developing Country." *The Bottom Line* 35 (2/3): 73–89. https://doi.org/10.1108/BL-06-2021-0068.

Nguyen, T., L. Zhou, V. Spiegler, P. Ieromonachou, and Y. Lin. 2018. "Big Data Analytics in Supply Chain Management: A State-of-the-Art Literature Review." *Computers & Operations Research* 98: 254–264. https://doi.org/10.1016/j.cor.2017.07.004.

OECD. 2022a. "*Data Shaping Firms and Markets*." (OECD Digital Economy Papers No. 3442). OECD Publishing. https://doi.org/10.1787/7b1a2d70-en.

OECD. 2022b. "Closing the Italian Digital Gap: The Role of Skills, Intangibles, and Policies." (OECD Science, Technology and Industry Policy Papers, No. 126). Organisation for Economic Co-operation and Development. https://www.oecd.org/content/dam/oecd/en/publications/reports/2022/03/closing-the-italian-digital-gap_da101f86/e33c281e-en.pdf

OECD. 2023. *OECD SME and Entrepreneurship Outlook 2023: Policy Highlights*. Paris, France: OECD Publishing. https://doi.org/10.1787/342b8564-en.

OECD. 2025. *Enhancing Access to and Sharing of Data in the Age of Artificial Intelligence: Companion Document to the OECD Recommendation on Enhancing Access and Sharing of Data*. Paris, France: OECD Publishing. https://doi.org/10.1787/23a70dca-en.

Olabode, O. E., N. Boso, M. Hultman, and C. N. Leonidou. 2022. "Big Data Analytics Capability and Market Performance: The Roles of Disruptive Business Models and Competitive Intensity." *Journal of Business Research* 139: 1218–1230. https://doi.org/10.1016/j.jbusres.2021.10.042.

Olaniyan, O., B. Dehe, D. Bamford, and S. Ward. 2024. "Enhancing on-Pitch Learning Capabilities with Data Analytics and Technologies in Elite Sports." *European Sport Management Quarterly* 24 (6): 1195–1214. https://doi.org/10.1080/16184742.2023.2270565.

Papadopoulos, T., S. P. Singh, K. Spanaki, A. Gunasekaran, and R. Dubey. 2022. "Towards the Next Generation of Manufacturing: implications of Big Data and Digitalization in the Context of Industry 4.0." *Production Planning & Control* 33 (2-3): 101–104. https://doi.org/10.1080/09537287.2020.1810767.

Patton, M. Q. 2002. "Two Decades of Developments in Qualitative Inquiry: A Personal, Experiential Perspective." *Qualitative Social Work* 1 (3): 261–283. https://doi.org/10.1177/1473325002001003636.

Persaud, A., and J. Zare. 2024. "Beyond Technological Capabilities: The Mediating Effects of Analytics Culture and Absorptive Capacity on Big Data Analytics Value Creation in Small-and Medium-Sized Enterprises." *IEEE Transactions on Engineering Management* 71: 7147–7159. https://doi.org/10.1109/TEM.2023.3249415.

Potluri, R. M., and N. R. Vajjhala. 2021. "Risks in Adoption and Implementation of Big Data Analytics." *International Journal of Risk and Contingency Management* 10 (3): 1–11. https://doi.org/10.4018/IJRCM.2021070101.

Raffoni, A., F. Visani, M. Bartolini, and R. Silvi. 2018. "Business Performance Analytics: exploring the Potential for Performance Management Systems." *Production Planning & Control* 29 (1): 51–67. https://doi.org/10.1080/09537287.2017.1381887.

Raut, R. D., V. S. Yadav, N. Cheikhrouhou, V. S. Narwane, and B. E. Narkhede. 2021. "Big Data Analytics: Implementation Challenges in Indian Manufacturing Supply Chains." *Computers in Industry* 125: 103368. https://doi.org/10.1016/j.compind.2020.103368.

Richey, R. G., T. R. Morgan, K. Lindsey-Hall, and F. G. Adams. 2016. "A Global Exploration of Big Data in the Supply Chain." *International Journal of Physical Distribution & Logistics Management* 46 (8): 710–739. https://doi.org/10.1108/IJPDLM-05-2016-0134.

Sanders, N. R. 2016. "How to Use Big Data to Drive Your Supply Chain." *California Management Review* 58 (3): 26–48. https://doi.org/10.1525/cmr.2016.58.3.26.

Schoenherr, T., and C. Speier-Pero. 2015. "Data Science, Predictive Analytics, and Big Data in Supply Chain Management: Current State and Future Potential." *Journal of Business Logistics* 36 (1): 120–132. https://doi.org/10.1111/jbl.12082.

Sedkaoui, S. 2018. *Data Analytics and Big Data*. Hoboken, NJ: John Wiley & Sons.

Sharma, S., V. K. Gahlawat, K. Rahul, R. S. Mor, and M. Malik. 2021. "Sustainable Innovations in the Food Industry through Artificial Intelligence and Big Data Analytics." *Logistics* 5 (4): 66. https://doi.org/10.3390/logistics5040066.

Shi, Y. 2022. *Advances in Big Data Analytics*. Beijing, China: Springer.

Sirmon, D. G., M. A. Hitt, and R. D. Ireland. 2007. "Managing Firm Resources in Dynamic Environments to Create Value: Looking inside the Black Box." *Academy of Management Review* 32 (1): 273–292. https://doi.org/10.5465/amr.2007.23466005.

Sirmon, D. G., M. A. Hitt, R. D. Ireland, and B. A. Gilbert. 2011. "Resource Orchestration to Create Competitive Advantage: Breadth, Depth, and Life Cycle Effects." *Journal of Management* 37 (5): 1390–1412. https://doi.org/10.1177/0149206310385695.

Skipworth, H. D., M. Bastl, C. Cerruti, and C. Mena. 2023. "Supply Networks for Extreme Uncertainty: A Resource Orchestration Perspective." *International Journal of Operations & Production Management* 43 (5): 677–711. https://doi.org/10.1108/IJOPM-05-2022-0314.

Stevens, G., and M. Johnson. 2016. "Integrating the Supply Chain 25 Years on." *International Journal of Physical Distribution & Logistics Management* 46 (1): 19–42. https://doi.org/10.1108/IJPDLM-07-2015-0175.

Sun, S., C. G. Cegielski, L. Jia, and D. J. Hall. 2018. "Understanding the Factors Affecting the Organizational Adoption of Big Data." *Journal of Computer Information Systems* 58 (3): 193–203. https://doi.org/10.1080/08874417.2016.1222891.

Tabesh, P., E. Mousavidin, and S. Hasani. 2019. "Implementing Big Data Strategies: A Managerial Perspective." *Business Horizons* 62 (3): 347–358. https://doi.org/10.1016/j.bushor.2019.02.001.

Tao, F., J. Cheng, Q. Qi, M. Zhang, H. Zhang, and F. Sui. 2018. "Digital Twin-Driven Product Design, Manufacturing and Service with Big Data." *The International Journal of Advanced Manufacturing Technology* 94 (9-12): 3563–3576. https://doi.org/10.1007/s00170-017-0233-1.

techUK. 2022. December 15. "Closure of Help to Grow: Digital Leaves a Major Gap in Support for UK Digital Adoption." https://www.techuk.org/resource/closure-of-help-to-grow-digital-leaves-a-major-gap-in-support-for-uk-digital-adoption.html

Tiwari, S., H. M. Wee, and Y. Daryanto. 2018. "Big Data Analytics in Supply Chain Management between 2010 and 2016: Insights to Industries." *Computers & Industrial Engineering* 115: 319–330. https://doi.org/10.1016/j.cie.2017.11.017.

Tracy, S. J. 2010. "Qualitative Quality: Eight "Big-Tent" Criteria for Excellent Qualitative Research." *Qualitative Inquiry* 16 (10): 837–851. https://doi.org/10.1177/1077800410383121.

Tsai, C., C. Lai, H. Chao, and A. V. Vasilakos. 2015. "Big Data Analytics: A Survey." *Journal of Big Data* 2 (1): 2–21.

Umamaheswaran, S., S. Fernandes, V. G. Venkatesh, N. Avula, and Y. Shi. 2023. "What Do Employers Look for in "Business Analytics" Roles?–A Skill Mining Analysis." *Information Systems Frontiers* 25: 1–17. https://doi.org/10.1007/s10796-023-10437-y.

Verma, S., V. Singh, and S. S. Bhattacharyya. 2021. "Do Big Data-Driven HR Practices Improve HR Service Quality and Innovation Competency of SMEs." *International Journal of Organizational Analysis* 29 (4): 950–973. https://doi.org/10.1108/IJOA-04-2020-2128.

Vidgen, Richard, Sarah Shaw, and David B. Grant. 2017. "Management Challenges in Creating Value from Business Analytics." *European Journal of Operational Research* 261 (2): 626–639. https://doi.org/10.1016/j.ejor.2017.02.023.

Villegas, J. G., C. Prins, C. Prodhon, A. L. Medaglia, and N. Velasco. 2013. "A Matheuristic for the Truck and Trailer Routing Problem." *European Journal of Operational Research* 230 (2): 231–244. https://doi.org/10.1016/j.ejor.2013.04.026.

Wall, B., H. Jagdev, and J. Browne. 2007. "A Review of eBusiness and Digital Business—Applications, Models and Trends." *Production Planning & Control* 18 (3): 239–260. https://doi.org/10.1080/09537280601127245.

Wamba, S. F., A. Gunasekaran, S. Akter, S. J. F. Ren, R. Dubey, and S. J. Childe. 2017. "Big Data Analytics and Firm Performance: Effects of Dynamic Capabilities." *Journal of Business Research* 70: 356–365. https://doi.org/10.1016/j.jbusres.2016.08.009.

Wamba, S., A. Gunasekaran, T. Papadopoulos, and E. Ngai. 2018. "Big Data Analytics in Logistics and Supply Chain Management." *The International Journal of Logistics Management* 29 (2): 478–484. https://doi.org/10.1108/IJLM-02-2018-0026.

Wang, G., A. Gunasekaran, E. W. Ngai, and T. Papadopoulos. 2016. "Big Data Analytics in Logistics and Supply Chain Management: Certain Investigations for Research and Applications." *International Journal of Production Economics* 176: 98–110. https://doi.org/10.1016/j.ijpe.2016.03.014.

Wang, J., C. Xu, J. Zhang, and R. Zhong. 2022. "Big Data Analytics for Intelligent Manufacturing Systems: A Review." *Journal of Manufacturing Systems* 62: 738–752. https://doi.org/10.1016/j.jmsy.2021.03.005.

Waqas, M., X. Honggang, N. Ahmad, S. A. R. Khan, and M. Iqbal. 2021. "Big Data Analytics as a Roadmap towards Green Innovation, Competitive Advantage and Environmental Performance." *Journal of Cleaner Production* 323: 128998. https://doi.org/10.1016/j.jclepro.2021.128998.

Willetts, M., A. S. Atkins, and C. Stanier. 2020. "Barriers to SMEs Adoption of Big Data Analytics for Competitive Advantage." In *2020 Fourth International Conference on Intelligent Computing in Data Sciences (ICDS)*, 1–8. IEEE.

Willetts, M., and A. S. Atkins. 2024. "Evaluation of a Software Positioning Tool to Support SMEs in Adoption of Big Data Analytics." *Journal of Electronic Science and Technology* 22 (1): 100229. https://doi.org/10.1016/j.jnlest.2023.100229.

Winkelhaus, S., and E. H. Grosse. 2020. "Logistics 4.0: A Systematic Review towards a New Logistics System." *International Journal of Production Research* 58 (1): 18–43. https://doi.org/10.1080/00207543.2019.1612964.

Winkelhaus, S., E. H. Grosse, and C. H. Glock. 2022. "Job Satisfaction: An Explorative Study on Work Characteristics Changes of Employees in Intralogistics 4.0." *Journal of Business Logistics* 43 (3): 343–367. https://doi.org/10.1111/jbl.12296.

Wong, C. W., C. Y. Wong, and S. Boon-itt. 2018. "How Does Sustainable Development of Supply Chains Make Firms Lean, Green and Profitable? A Resource Orchestration Perspective." *Business Strategy and the Environment* 27 (3): 375–388. https://doi.org/10.1002/bse.2004.

Xie, W., Q. Zhang, Y. Lin, Z. Wang, and Z. Li. 2024. "The Effect of Big Data Capability on Organizational Innovation: A Resource Orchestration Perspective." *Journal of the Knowledge Economy* 15 (1): 3767–3791. https://doi.org/10.1007/s13132-023-01208-w.

Xu, J., and M. E. P. Pero. 2023. "A Resource Orchestration Perspective of Organizational Big Data Analytics Adoption: Evidence from Supply Chain Planning." *International Journal of Physical Distribution & Logistics Management* 53 (11): 71–97. https://doi.org/10.1108/IJPDLM-04-2022-0118.

Yu, W., R. Chavez, M. A. Jacobs, and M. Feng. 2018. "Data-Driven Supply Chain Capabilities and Performance: A Resource-Based View." *Transportation Research Part E: Logistics and Transportation Review* 114: 371–385. https://doi.org/10.1016/j.tre.2017.04.002.

Zhang, Y., M. Zhang, J. Li, G. Liu, M. M. Yang, and S. Liu. 2021. "A Bibliometric Review of a Decade of Research: Big Data in Business Research–Setting a Research Agenda." *Journal of Business Research* 131: 374–390. https://doi.org/10.1016/j.jbusres.2020.11.004.

Zheng, L. J., J. Z. Zhang, H. Wang, and J. F. Hong. 2025. "Exploring the Impact of Big Data Analytics Capabilities on the Dual Nature of Innovative Activities in MSMEs: A Data-Agility-Innovation Perspective." *Annals of Operations Research* 350 (2): 699–727. https://doi.org/10.1007/s10479-022-04800-6.

Zhong, R. Y., S. T. Newman, G. Q. Huang, and S. Lan. 2016. "Big Data for Supply Chain Management in the Service and Manufacturing Sectors: Challenges, Opportunities, and Future Perspectives." *Computers & Industrial Engineering* 101: 572–591. https://doi.org/10.1016/j.cie.2016.07.013.