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Customer-Driven Supply Management Facilitated by Digital Twins of Customer Demands

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Customer-Driven Supply Management Facilitated by Digital Twins of Customer Demands

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Abbreviations

DTCD	Digital Twin of Customer Demands
EurOMA	European Operations Management Association
IoT	Internet of Things
IT	Information Technology
IPSERA	International Purchasing and Supply Education and Research Association
NASA	National Aeronautics and Space Administration
PC	Personal Computer
RFID	Radio Frequency Identification
RQ	Research Question
SCM	Supply Chain Management

1 Relevance and Motivation

1.1 The Rising Relevance of Customer Demands

Ancient roman mythology featured an iconic deity named Janus, who was typically portrayed with two faces – provoking both a curse and a blessing to look simultaneously in two opposing directions (Wiseman, 2004). Transferred to supply management, a Janus-like approach would necessitate a concurrent observation of up- (supplier-sided) and downstream (customer-sided) flows in the supply chain (Ellram et al., 2020). For decades, however, organisations employed product-driven strategies, implying the concentration of managerial and supply chain activities on lean and functional silos (Potter et al., 2015), as probably most vividly portrayed by Henry Ford's (in-)famous quote: 'Any customer can have a car painted any colour that he wants so long as it is black.' (Ford, 1923, p. 72). Nowadays, the Fordian paradigm of *one-size-fits-all* has undergone a profound transformation as a result of rapidly evolving customer demands (Da Silveira et al., 2001; Piller, 2008; Piller et al., 2004; Pine, 1993). This is fuelled by two (intertwined) factors: On the one hand, technological advancements such as new manufacturing techniques, eased networking, declining computing prices, or continued connectivity of products and devices (Porter and Heppelmann, 2015, 2014) enabled novel modes of identifying and satisfying singular demands (Lanzolla et al., 2021). On the other hand, societal developments and shifts in customer behaviour diversified and fragmented the customer base (Cheng et al., 2023; Gupta et al., 2019; Pine, 1993).

In the textile market, companies such as Adidas (Stoetzel, 2012) or Nike (Ramaswamy, 2008) allow customers to co-create value and customise selected products, for instance by choosing everything from colours to materials. In the foodstuff sector, coffeehouses are no longer restricting customers on cows as sole provider of milk but offer a plethora of different dairy and non-dairy alternatives, may they originate from cereals, legumes, vegetables, seeds, or nuts (Bridges, 2018). In the realm of entertainment, streaming services like Netflix have reconfigured content consumption by employing algorithms to recommend movies and TV shows tailored to viewers' tastes, shifting standardised broadcasting schedules to on-demand, personalised content delivery (Gomez-Uribe and Hunt, 2016). Furthermore, the rise of e-commerce giants such as Amazon and Alibaba has redefined the notion of convenience in the retail sector. Based on customers' browsing and purchasing history a curated shopping experience is created (Lanzolla et al., 2020). The use of algorithms enables the analysis of vast amounts of data, understanding idiosyncratic preferences and providing a level of personalisation that transcends the traditional 'one-size-fits-all' approach (Lanzolla et al., 2020; Schilling, 2000).

Altogether, catering to various types and scales of demands[1] through targeted solutions increased substantially in significance (Pallant et al., 2020). In this light it is noteworthy, that an increasing share of customer value is not solely created by the focal organisation but by a chain of different suppliers (Bode et al., 2021; van Weele and Eßig, 2017). Managing and overseeing this chain is the responsibility of supply management (Bode et al., 2021; van Weele and Eßig, 2017). Consequently, the dynamic and heterogeneity of customer demand satisfaction creates constitutive challenges for supply management regarding activities such as product life cycle management (managing a product's development, launch, growth, maturity, and eventual decline) (Ameri and Dutta, 2005; Bayus, 1994; Mendez and Pearson, 1994; Pine, 1993; Steckel et al., 2004). One of the most protruding examples in this regard is the clothing industry where market leader *Inditex* minimised the entire process from design to distribution from eighteen to not even two months, requiring supply management strategies and procedures that can keep up with this fast paced environment (Hofmann and Rutschmann, 2018; Jacobs, 2006; Perera et al., 2019; Walters, 2006a, 2006b). Traditional methods may prove inadequate in accommodating the nuances of heterogeneous customer preferences leading to multiple risks, including but not limited to developing and producing goods that do not meet market requirements, stockouts, and excess inventories (Hofmann and Rutschmann, 2018). Consequently, information technological advancements translate to an estrangement of predominantly product-driven marketing strategies towards coordinating an organisation’s core competences with markets and eventually even single customers (Potter et al., 2015; Vargo and Lusch, 2004). In turn, this also means that supply

[1] It was decided to incorporate the outlined novel level of demand heterogeneity and scale by utilising *demands* in its plural form rather than the singular term *demand*

management strategies and practices are needed that enable both the effective and efficient satisfaction of dynamic and heterogenous customer demands.

1.2 The Role of Customer Demands in Supply Management

Historically, supply management research has an innately dominant focus on upstream activities, leading to the question phrased by Ellram et al.'s (2020, p. 5) seminal work on supply management identity, if the discipline has an ambilateral focus or is only 'reacting to internal customer demands and concentrating its gaze upstream'. While there certainly is research on internal customers (e.g. Hemsworth et al., 2007) in the context of dual buyer-supplier relationships (e.g. Olsen and Ellram, 1997; van der Valk and Wynstra, 2012), whether supply management's focus extends on external customers is indistinct (Ellram et al., 2020).

Interestingly, Ellram et al. (2020, p. 5) propagate that supply management research should not be bounded on one-sided affairs and 'progressively extended its interest in downstream flows'. Not committing to a limitation would also suit to supply management's historic emergence, which aligns with the development of the downstream-oriented industrial marketing as a research discipline, as the works on organisational buying behaviour (Robinson et al., 1967; Webster and Wind, 1972) and industrial marketing and purchasing models (Cunningham, 1980), constitute a pivotal foundation for both fields (Sheth et al., 2009). Furthermore, van Weele and van Raaij (2014, p. 57) argued that despite concentrating on analysing upstream interactions, supply management 'should fulfill [sic!] this responsibility with the needs of internal functions as well as the downstream customer(s) interests and demands in mind'. This point of view is shared by scholars such as Bai et al. (2021), Jääskeläinen and Heikkilä (2019), or Kähkönen and Lintukangas (2012) who emphasise the importance of downstream value created by supply management, as customers ultimately compensate the value provided to them and a product or service 'is valuable to customers only if it meets their demand, and the best factory in the world is useless if it is manufacturing wrong products' (Bai et al., 2021, p. 1269). This is also in line with the marketing discipline's self-perception as holistic management philosophy that centralises customers in all facets of organisational activities (Day, 1996; Kerin, 1996).

In contrast to the purported significance of incorporating downstream matters in supply management, typical supply management approaches consider customers 'as passive recipients of products and services, who engage mainly through the value exchange or value extraction' (Soosay and Hyland, 2015, p. 622). Then again, Reaidy et al. (2020) gathered empirical evidence that customer integration in supply chains is a real phenomenon in practice. Nonetheless, Reaidy et al. (2020) also observe that research on supply chains tends to forget the end customer. Additionally, Jääskeläinen and Heikkilä (2019) as well as Kähkönen and Lintukangas (2012) argue that customer value creation is, at large, neglected by supply management. It seems, however, as if scholars are aware of this shortcoming as, for instance, both Nath et al.'s (2020) and Nath and Eweje's (2021) works consider the lack of upstream incorporation a notable limitation to their studies that should be incorporated by future research. In this light, authors such as Sheth et al. (2009) or Ardito et al. (2019) lament that, despite their previously explained common origin, industrial marketing and supply management have divided the supply chain among themselves and operate in distinct silos. Or, as lately phrased by Martinelli and Tunisini (2019, p. 31), 'marketing and purchasing remain separated and involved in only downstream and upstream relationships, respectively'.

Having said that, it is crucial to emphasise that supply management and marketing still relate to interconnected elements such as the substantive focus on analysing and managing markets (the supply market on the one hand and the sales market on the other) (Koppelmann, 1998). Historically, this community even led scholars to call for new concepts such as *procurement marketing* which emphasised on establishing reciprocative exchange processes with both internal and external customers (Koppelmann, 1998). These developments were in line with the broadening of the marketing concept launched by scholars such as Kotler (1972) and even resulted in the claim that *buying is marketing too* (Kotler and Levy, 1973). From a supply management perspective, the underlying rationale behind this reasoning was that 'it is essential that purchasing is included in the early process of deciding what the end customer needs and what he is prepared to pay. Only then is the purchasing function in a position to work with other corporate functions on viable compromises for the supply of materials required for production. And only then can the purchaser search for creative, strategic supply solutions' (Koppelmann, 1998, p. 17). Hence, it is intriguing to systematically investigate the (potential) role of downstream integration for supply management.

1.3 Digital Twins: Novel Technological Opportunities for Demand Integration

In light of the previously explained significance, the integration of intelligence on customer demands is an important factor for supply management (Frohlich and Westbrook, 2002; Heikkilä, 2002; Shashi et al., 2020; Treville et al., 2004). However, due to their reliance on traditional technologies and basic digitalisation, which suffered both from a ‘lack of sophistication’ (Korhonen et al., 1998, p. 527) and excessive transaction costs, organisations have faced challenges in fully integrating downstream aspects into supply management (Srai and Lorentz, 2019). This implies that historic endeavours to integrate customer demands, which already concern supply management professionals for more than 30 years (e.g. Korhonen et al., 1998), have not only been limited in scope but also quantitative in nature (e.g. order volumes) (Thun, 2010).

In contrast to that, advanced digitalisation technologies offer a timely integration and coordination of information, functions, and activities (Heim et al., 2021; Heim and Peng, 2022; Porter and Heppelmann, 2014). Recent insights from Marzi et al. (2023) claim that digital platforms are an essential factor to align material sourcing, a primal supply management activity, with market and customer requirements. Additionally, Srai and Lorentz (2019) remark that digitalisation is connecting customer claims with supply causes. Consequently, the advancement of digital technologies offers supply management new and promising tools to incorporate customer demands located upstream into core supply management activities of (Agrawal and Narain, 2023; Martinelli and Tunisini, 2019; Srai and Lorentz, 2019). As research argues that information integration manifests itself along a spectrum, ranging by the piece from zero to absolute integration (Frohlich and Westbrook, 2001; Schoenherr and Swink, 2012; Thun, 2010), previous approaches lacked the means to max out the entire bandwidth (Korhonen et al., 1998; Srai and Lorentz, 2019).

Today, information travels faster, more convenient, and with higher volume and accuracy than ever before (Bhandal et al., 2022). In that regard, *Digital Twin*, a contemporary phenomenon that represent an environment of interacting with a precise and timely replication of a given entity, emerged (Bhandal et al., 2022; Tao et al., 2018). Digital Twins aggregate various advanced digitalisation techniques (Kritzinger et al., 2018) (defined as means that go beyond basic information-sharing mechanisms (Srai and Lorentz, 2019)), which results in profound penetration of market demands (Tao et al., 2019). Therefore, creating Digital Twins of individual customers' demands marks a conceptual maximum for gaining insight into these very demands. Hence, the consequential effects transcend efficiency gains through automation and ever-faster obtainment of quantitative information; rather, Digital Twins are expected to create a novel qualitative understanding of the downstream perspective and thus impact supply management in an integral and strategic manner (Bhandal et al., 2022). Consequently, customer demands could become the main driver of supply management activities. This culminates in the question if Digital Twins of customer demands are really a landmark for the management of supply chains through the enablement of customer-driven supply management or rather 'the emperor's new clothes' (Fabbe-Costes and Jahre, 2007).

2 Conceptual Foundation of Customer-Driven Supply Management and Digital Twins

2.1 Introduction to the Conceptual Foundation

The present work ties two concepts together. On the one hand, customer-driven supply management relates to customer demands as major determinant for operational and strategic practices in supply management (Martinelli and Tunisini, 2019). The dissertation's premise is that, despite its alleged merits, customer demands have so-far been underappreciated by the supply management discipline (Soosay and Hyland, 2015). The other concept is Digital Twin – a novel and auspicious technological method that has the potential to enable customer-driven supply management (Bhandal et al., 2022). Subsequently, both concepts are briefly defined and contextualised.

2.2 Customer Integration in Supply Management

This subchapter introduces customer-driven supply management. The realm in which customer demand integration takes place in the supply chain will be described, conceptualised, and put into its historical context.

2.2.1 Supply Management and Accompanied Dimensions of Integration

Supply management is a broad and applied field of study that refers to the strategic coordination and oversight of activities related to the acquisition of necessary resources to meet an organisation's needs at the most favourable conditions (Harland et al., 2006; van Weele and Eßig, 2017; Wynstra et al., 2019). In essence, supply management transcends mere functional activities; it stands as a strategic imperative with profound implications for an organisation's financial performance, competitive position, risk resilience, and ability to adapt to environmental changes (van Weele and Eßig, 2017; Wynstra et al., 2019). Notably, in the contemporary business landscape, suppliers wield an expanding and more substantial share in the overall value creation of the focal organisation (van Weele and Eßig, 2017). This pivotal role assumes a heightened responsibility for suppliers in contributing to the success of the demand side, ultimately shaping end customers' experiences and values delivered to them (Soosay and Hyland, 2015).

A centrepiece of supply management is the advocacy for integration across functional and organisational boundaries (Ellram et al., 2020; Harland et al., 2006; Pagell, 2004; Schoenherr and Swink, 2012). Integration refers to the combination of information-sharing and strategic alignment of various interconnected activities to create interdependent flows of information and resources across different stages of the supply chain (Pagell, 2004; Schoenherr and Swink, 2012). Given that this takes place thoroughly and systematically across the entire network of internal- and external supply chain stakeholders, the term *supply chain integration* has been established in the literature (Flynn et al., 2010; Leuschner et al., 2013; Wong et al., 2011). However, many scholar criticise that endeavours which contemplate the supply chain as single up- and downstream integrated system are often considered as more rhetoric than reality (Fabbe-Costes and Jahre, 2008, 2007; Fawcett and Magnan, 2002; Neuman and Samuels, 1996).

Typically, studies trying to capture the effects of integration within the supply chain break the concept down into several parts, each accompanied by respectively distinct foci: (a) internal or cross-functional integration, and (b) external or cross-organisational integration with entities up- and downstream (Flynn et al., 2010; Khanuja and Jain, 2020; Wong et al., 2011). To classify integration areas, the literature largely builds on the seminal arcs of integration by Frohlich and Westbrook (2001), who defined the extent of integration endeavours in the supply chain towards three dimensions, as depicted by Figure 1.

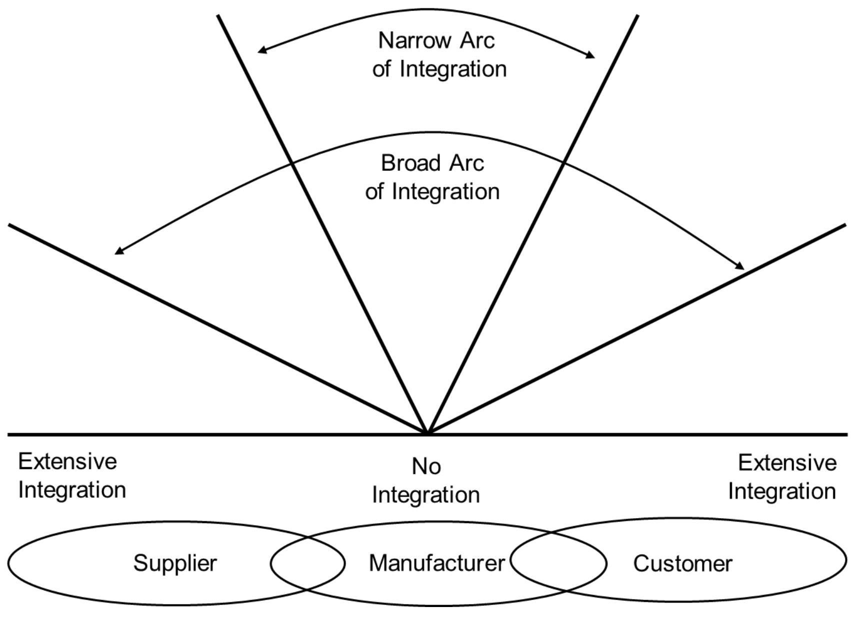

Figure 1. Arcs of integration in supply chains

Source: Adopted from Frohlich and Westbrook (2001, p. 187)

First, internal, or cross-functional, integration represents the degree to which operational, tactical, and strategic information exchange across an organisation's business units align with the overall goals of the organisation (Koufteros et al., 2010; Zhao et al., 2011). Internal integration breaks-down functional silos through information-sharing and collective responsibilities (Pagell, 2004; Wong et al., 2011). The strategic and operational significance of internally integrating supply management with other functions, and thereby overcoming prevalent silos, is undisputedly anchored in the literature for decades and substantiated by a plethora of empirical works (Ashenbaum et al., 2020; Franke and Foerstl, 2020; Pagell, 2004; Pagell and Wu, 2006; Wong et al., 2011; Zhao et al., 2011). Often, internal integration is claimed to be a major influencer if not even an indispensable precondition for any type of external integration (Flynn et al., 2010; Williams et al., 2013). Nonetheless, if only intraorganisational integration is pursued, without concurrently implementing external integration across the organisation's boundaries, the organisation will remain at a narrow arc of integration (Frohlich and Westbrook, 2001).

Second, supplier integration refers to strategic collaboration and the extent of communication between a focal organisation and its supplier(s) (Flynn et al., 2010). Unsurprisingly, supplier integration has been extensively covered by the supply management literature which identified effects on indicators for operations performance including but not limited to delivery (Ataseven and Nair, 2017; Wong et al., 2011), efficiency (Ataseven and Nair, 2017; Chen et al., 2013; Wong et al., 2011), flexibility (Ataseven and Nair, 2017; Ivanov et al., 2018; Vanpoucke et al., 2014b; Wong et al., 2011), or product development (Johnsen, 2009; Petersen et al., 2005; Wynstra and Pierick, 2000).

And third, customer integration represents the comprehensive involvement of customers to create an enhanced understanding for customer needs and tailor supply chain activities to meet those needs effectively (Wong et al., 2011). The concept of customer integration focuses on visibility on customer demand information defined as holistic, timely, and precise insights into customer needs, preferences, expectations, and buying patterns (Barratt and Oke, 2007). It may also entail the active collaboration of customers (for instance in form of value co-creation (Martinelli and Tunisini, 2019). There is a range of empirical studies that measured the impact of integrating customer information in supply chains. For instance, this has been successfully tested to positively influence fulfilment speed (Heikkilä, 2002; Wong et al., 2011; Zhao et al., 2013), production costs (Wong et al., 2011), product quality (Wong et al., 2011), flexibility (Wong et al., 2011), planning (van Landeghem and Vanmaele, 2002), but also product development success factors such as time-to-market (Filieri, 2013; Flint, 2002) or market success (Cooper, 2019; Narver et al., 2004). It is, however, essential to highlight that while the literature references customer integration, the existing discourse tends to remain somewhat superficial (Sampson and Spring, 2012; Ta et al., 2015). Until now, customer integration in supply management has predominantly focused on alignment of purchasing with sales and marketing functions, lacking a genuine connection with the tangible artefact of customer demand. Therefore, aiming to transcend the current surface-level discussions and explicitly expose the integration of the customer demand artefact in supply management becomes the focal point of this work's analysis.

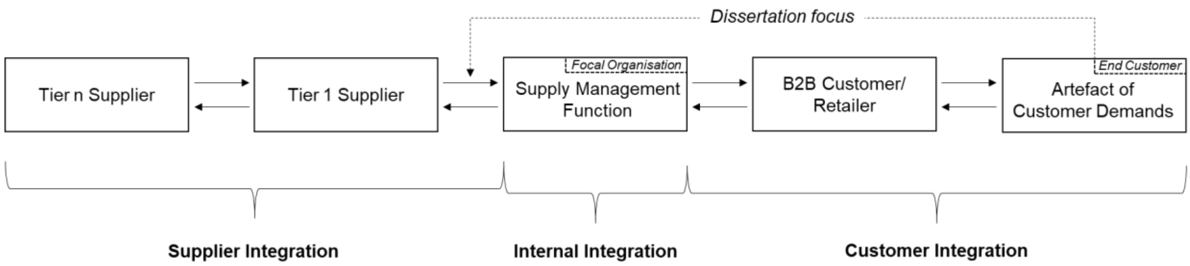

Figure 2. Focus of analysis in relation to dimensions of integration in supply chains
Source: Own depiction based on Frohlich and Westbrook (2001)

Figure 2 outlines the three integration dimensions in the supply chain and highlights the focus area of the present dissertation. What this work further distinguishes from related contributions, focusing on aspects such as co-design or co-creation, is the present emphasis on customer demands as exploitable artefact rather than customers themselves. As a matter of fact, the theoretical and empirical integration of customer demands is enshrined in marketing research (Jüttner et al., 2007; Jüttner et al., 2006; Jüttner and Christopher, 2013). Thus, further exploration of the significance of customer integration requires a brief excursus to the marketing discipline's historic development and its contemporary managerial implications.

2.2.2 Marketing as Customer-Driven Management Philosophy

Marketing experienced a fundamental transformation from being construed as business function to a holistic management philosophy (Kohli and Jaworski, 1990).

During its origin in the 1930s until the Post-World War II area, marketing concentrated on sales-related managerial activities (Kerin, 1996). It then became increasingly strategic and at the latest in the 1980s, marketing started to perceive itself as integrative science (Day, 1996; Easton, 2002; Kerin, 1996), managerial mindset (Bruhn, 2014; Meffert et al., 2015), or management philosophy (Houston, 1986; Kohli and Jaworski, 1990; Mcnamara, 1972; Slater and Narver, 1998). The term *management philosophy* refers to the set of guiding principles, beliefs, and values that inform the practices, decisions, and behaviour of organisations (Augusto et al., 2014; Bhasin and Burcher, 2006; Johannessen et al., 2005). Thus, a management philosophy reflects the organisation's culture and influences decisions on a strategic and operational level (Augusto et al., 2014; Bhasin and Burcher, 2006; Johannessen et al., 2005). With respect to marketing, this management philosophy indicates that customer demands constitute as fulcrum that guides all managerial activities (Kohli and Jaworski, 1990; Lusch and Laczniak, 1987).

Furthermore, and in accordance with scholars such as Potter et al. (2015) and Vargo and Lusch (2004), the development towards embracing marketing as business philosophy entails a strategic transformation in attitude as what constitutes as driving force for business activities. Potter et al. (2015) termed this development as evolution phases in which during the initial phase, organisations are driven by products, then by markets in the final phase by customers. This corresponds to the fact that the implementation of a marketing management philosophy is often classified as market- or customer orientation (Becker and Homburg, 1999). It involves including customer demands in all practices throughout the entire company, going beyond the superficial notion of merely ‘getting close to the customer’ (Shapiro, 1988, p. 120). At large, the literature identified a range of characteristics incremental to a market-/ customer-oriented organisation such as a company-wide commitment to understanding and responding to market dynamics, holistic customer information integration across functions and systems, cross-functional collaboration and coordination, and top-management involvement (Becker and Homburg, 1999; Jaworski and Kohli, 1993; Shapiro, 1988). This entails that virtually all business functions adhere to developing, producing, distributing, and promoting customer value (Kohli and Jaworski, 1990).

Ultimately, a successfully implemented market-/ customer-oriented strategy makes organisational processes more responsive to market and customer demands (Jaworski and Kohli, 1993; Jüttner and Christopher, 2013; Kohli and Jaworski, 1990), defined as 'the action taken in response to intelligence that is generated and disseminated' (Kohli and Jaworski, 1990, p. 6). In other words, valuable customer information is adequately gathered, analysed, and shared to ensure the effective and timely satisfaction of existing and/or potential customer demands (Becker and Homburg, 1999) and therewith create a favourable end-customer response (Kohli and Jaworski, 1990).

2.2.3 A Brief Note on Marketing-Supply Chain Integration

In line with the previously presented definition of customer-orientation, which called for cross-functional integration, a school of research emerged that engaged in analysing the integration of the supply management and the marketing functions as depicted by Figure 3.

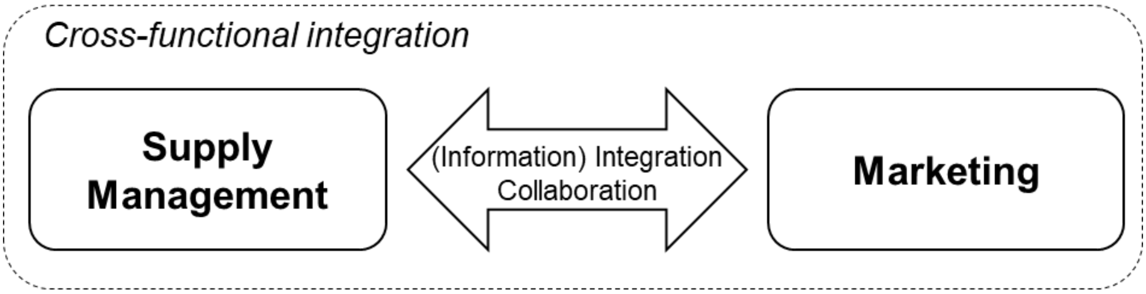

Figure 3. Illustration of research on marketing supply chain integration
Source: Own depiction based on Jüttner and Christopher (2013)

Research extensively engaged in marketing-supply management integration through multiple conceptual frameworks (e.g. Alvarado and Kotzab, 2001; Ellinger, 2000; Jüttner et al., 2010; Jüttner et al., 2007; Jüttner and Christopher, 2013) and empirical investigations of integration prerequisites and effects (e.g. Ardito et al., 2019; Ellinger, 2000; Jüttner and Christopher, 2013; Parente et al., 2008). However, and with respect to Frohlich and Westbrook's (2001) integration dimensions introduced in Figure 1, these studies tend to see marketing as function rather than management philosophy and thus, investigate the topic predominantly from an internal and functional point of view. This implies that rather than a direct and interorganisational integration of customer demands in supply management, information is channelled through the respective functional department. Arguably, this reliance on intermediaries might entail distortions and the impediment of optimal information exploitation.

2.2.4 Conceptualising Customer-Driven Supply Management

In contrast to the previous chapter, this work defines customer-driven supply management as a strategic approach beyond mere functional integration. Customer-driven supply management aims to establish supply management procedures that align closely with what customers want and value. Hence, customers are both, activator as well as destination of supply chain processes (Martinelli and Tunisini, 2019; Tunisini and Sebastiani, 2015). Consequently, supply chain activities and buyer-supplier interactions, such as sourcing materials or delivering products or services, are optimised to cater to the specific needs of customers effectively and efficiently (Jüttner et al., 2007).

By tailoring supply chain processes to customer demands, organisations can reduce waste, optimise resource utilisation, and ensure that the right products and services are readily available when and where customers want them (Tunisini and Sebastiani, 2015). Additionally, the concept of customer-driven supply management is inherently affiliated with customisation and flexibility capabilities that allow for the satisfaction of singular needs and, in its most extreme state, even saturate a 'market-of-one' (Martinelli and Tunisini, 2019, p. 30).

2.3 Conceptualising Digital Twins (of Customer Demands)

Transitioning from the conceptualisation of customer-driven supply management to its technical enablement, the following chapter introduces and explains the Digital Twin phenomenon. The focus turns to its foundational definition, the technical underpinnings that facilitate its realisation, and the diverse array of real-world application cases.

2.3.1 Technological Customer Demand Integration

To make supply management customer-driven, mechanisms are vital that provide an accurate understanding of (end-) customer needs (Martinelli and Tunisini, 2019). Over time, a notable evolution occurred that accompanies the technological development of the digital age (Srai and Lorentz, 2019). A comprehensive chronology of customer integration mechanisms is provided by Figure 4, which is an own depiction of the based on thereafter listed citations. The sample of technologies reflects a strategic alignment with the evolving landscape of technological capabilities. Each chosen technological milestone, from mainframe computers to contemporary innovations, addresses distinct challenges and opportunities associated with customer demand integration. Thus, this selection demonstrates the chronological adaption to changing customer behaviours and preferences. It should be noted that periods and mechanisms are approximations and may vary depending on specific industries, technological advancements, and regional adoption pace.

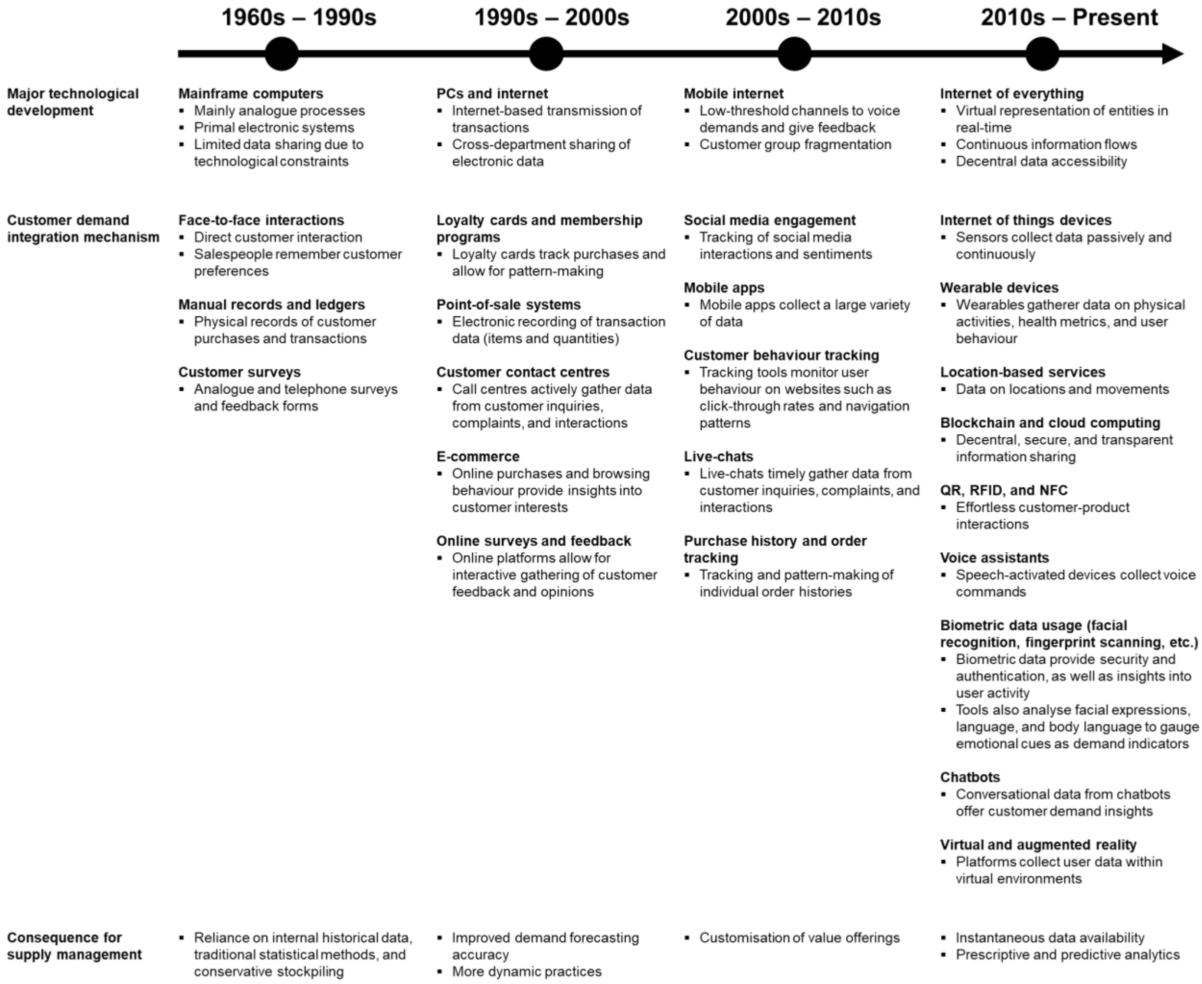

Figure 4. Chronology of customer integration mechanisms

Early businesses maintained physical registers or ledgers to record customer purchases and preferences while salespeople often developed personal relationships with customers, allowing them to remember individual preferences (Welch and Sevin, 1942). Introduced in the 1980s, loyalty cards offered discounts or rewards to customers who made repeated purchases and allowed companies to track customer buying behaviour and preferences (Passingham, 1998; Wright and Sparks, 1999). In the late 20th century, electronic point of sales systems replaced manual cash registers and allowed for more accurate tracking of sales and inventory (Steckel et al., 2004). These systems recorded detailed transaction data, which could be used to analyse purchasing patterns and trends (Steckel et al., 2004). With the widespread adoption of personal computers (PCs) and the internet during the early 21st century, e-commerce platforms enabled companies to collect data on customer behaviour such as online purchases, browsing history, and click-through rates (Davidrajuh, 2003). Furthermore, social media platforms and smartphone apps allowed companies to engage directly with customers and gather insights from comments, likes, and shares while gathering data on specific responses, interests, and demographics (Müller et al., 2018).

The latest stage of this development entails instantaneous, decentral, and holistic data availability, as companies started harnessing vast volumes of customer data from a high variety of sources that could be actively shared as well as passively skimmed through sensors and microchips related to internet of things (IoT) devices, wearables, and smartphones (Jabbar et al., 2020; Singhal et al., 2018).The significance of this development transcends quantitative expansion, representing a transformative impact ascribed to advanced digitalisation through qualitatively influencing value creation. With contemporary technologies rushing towards maturity, the development is approaching its peak (Sjödin et al., 2018), as there would be no further augmentation to the real-time availability of holistic and precise customer demand data.

2.3.2 A Brief Introduction to Digitalisation

According to Lorentz et al. (2020), the development and retention of market and supply chain knowledge requires managing information processing capacity, defined as the focal organisation's ability to leverage technological mechanisms that combat uncertainties (Busse et al., 2017; Duncan, 1972). Bensaou and Venkatraman (1995) introduced information technology (IT) mechanisms which Lorentz et al. (2020) specified in the narrow and broad focus of information systems and collaboration platforms. Ultimately, these mechanisms introduce digital components and transfer the topic to the realm of digitalisation (Srai and Lorentz, 2019; Verhoef et al., 2021). Depending on the respective extent and constituting characteristics of these digital mechanisms, their impact includes informational, automational, and transformational effects, leading to a range of different terms and understandings (Mooney et al., 1996; Srai and Lorentz, 2019). To clarify the different levels of abstraction (Elsäßer et al., 2019), Table 1 defines and separates various digitalisation concepts.

Table 1. Digitalisation concepts' levels of abstraction

Source: Adopted from Verhoef et al., 2021, p. 892

Concept	Definition	Goals	Examples
Digitisation	Encoding of analogue information into a digital format	Cost saving; Efficiency increase	Automated routines and tasks; Conversion of analogue into digital information
Digitalisation	Usage of IT to alter existing business processes	Cost saving; Increased revenues; Process re-engineering	Use of robots in production; Digital components of product or service offering; Digital distribution and communication channels
Digital Transformation	Organisation-wide change that leads to the development of new business models	New business models; Asset reconfiguration	Introduction of new data-driven business models; Digital collaboration platforms

The extant literature, however, often lacks the rigour to clearly discriminate these concepts and typically applies *digitalisation* as umbrella term for the use of digital technologies (e.g. Srai and Lorentz, 2019). For the sake of simplicity and despite the consequential imprecision, this work will also refrain from applying too many competing terms and rather rely on the general notation *digitalisation* while providing further clarification in then discussed effects. Altogether, the present work defines *digitalisation* as the synergetic usage of IT (digital) means to change prevalent business procedures, thereby affecting incumbent socio-technical structures (Elsäßer et al., 2019; Vendrell-Herrero et al., 2017; Verhoef et al., 2021).

2.3.3 Origin of the Digital Twin Phenomenon

In April 1970, NASA scientists in Houston had a problem. They have just received a startling damage report concerning one of their spacecrafts. The detonation of an oxygen tank suspended the spacecraft's supply with oxygen, water, electric power, and light. In a split second, Apollo 13's objective changed from putting boots on the moon to getting the crew safely back to earth. Alas, managing an asset across a 300,000 km distance is rather troublesome (NASA, 2014). Fortunately, an ingenious approach proved itself valuable: the deployment of a simulator of the very spacecraft (Bonney and Wagg, 2022; Rosen et al., 2015). Throughout the mission, NASA was able to take data from the real vehicle up in space and feed it into the simulator down in Houston, thus precisely mirroring the vehicle's conditions (Rosen et al., 2015). Therefore, the simulator in Texas was referred to as the spacecraft's *Digital Twin* (Rosen et al., 2015). This approach enabled NASA to dynamically evolve the simulator until it corresponds to the situation of the damaged spacecraft, meaning that predictions could be tested, optimised, and implemented which led to the strategy that brought the crew back safe and sound.

The technological developments that escorted the five decades that passed since the infamous Apollo 13 incident accelerated the attention given to Digital Twins (Bhandal et al., 2022). In 2018, Digital Twin arrived at the *Peak of Inflated Expectations* of Gartner's hype cycle for emerging technologies with prospect of reaching the *Plateau of Productivity* in five to ten years (see Appendix A1). Digital Twins of supply chains were named one of the top eight supply chain technology trends of 2020 by Gartner (Hippold, 2020). In 2021, Accenture featured Digital Twins as one of the five most important strategic technology trends of the year (Daugherty et al., 2021). In 2020 the total market for Digital Twins has been estimated to accumulate to roughly USD 3b (IBM, 2022) with a compound annual growth rate of at least 40%[2]. By 2026, Digital Twins are foretold to penetrate more than three-quarters of the IoT market (Costello and Omale, 2019), with a total market volume between USD 26b (Dohrman et al., 2019) and USD 48b (Abraham et al., 2022). By 2030 the Digital Twin market is projected to reach a triple-digit billion US dollar figure (Bloomberg, 2022)[3].

2.3.4 Definition of Digital Twin

Generally, Digital Twin refers to an overall methodology of timely, dynamically, and realistically replicating a given entity (Tao et al., 2018). The Digital Twin has multiple components: original entity, digitally replicated entity, and the information flow that connects both as well as the techniques leveraged to transform data into action (Grieves, 2014). Of course, data-based simulations are not novel. Digital Twins, however, exceed the limitations of static simulations as they represent an entire environment of interconnected and expeditious information flows that allow for iterative optimisation of courses for action (Glaessgen and Stargel, 2012).

The term *Digital Twin* has been coined in the early 2000s, and defined as 'a virtual, digital equivalent to a physical product' (Grieves, 2014, p. 1). Nonetheless, there are still various diverging understandings of what Digital Twin actually means (Dohrman et

[2] In fact, some sources such as Dohrman et al. (2019) speak of 38%, some like Bloomberg (2022) compute 42.7%, while others estimate even a compound annual growth rate of 58% Abraham et al. (2022).
[3] Recent predictions by Bloomberg (2022) expect 2030's Digital Twin market size to accumulate to 113.3bn USD.

al., 2019)[4]. Generally speaking, academic definitions of digital twin are highly context-specific with an overwhelming focus on the manufacturing sector (Bhandal et al., 2022). Based on the citations received as of January 2024, Table 2 lists the definitions for Digital Twins of the ten most influential academic contributions.

Table 2. Most influential academic articles' definitions of Digital Twin

Source	Digital Twin definition	Context
Tao et al., 2018, p. 3564	'Digital twin is an integrated multi-physics, multi-scale, and probabilistic simulation of a complex product and uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin. The idea and concept of digital twin, which is composed of physical product, virtual product, and connected data that ties physical and virtual product, can realize the convergence between product physical and virtual space.'	Product life cycle management, Manufacturing
Tao et al., 2019	Cited definition of Glaessgen and Stargel (2012).	Manufacturing
Kritzinger et al., 2018	Cited definitions of Glaessgen and Stargel (2012) and Negri et al. (2017) and complemented them through a tripartite differentiation based on the prevalent level of integration ((1) Digital Model, (2) Digital Shadow, and (3) Digital Twin).	Manufacturing
Grieves and Vickers, 2017, p. 94	'Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin.'	Product life cycle management
Ivanov, 2020, p. 101922	'Digital SC […] – i.e., the computerized SC models that represent the network state for any given moment in real time'	Risk management
Negri et al., 2017, p. 946	'The DT consists of a virtual representation of a production system that is able to run on different simulation disciplines that is characterized by the synchronization between the virtual and real system, thanks to sensed data and connected smart devices, mathematical models and real time data elaboration.'	Manufacturing
Rosen et al., 2015, p. 567	'Very realistic models of the current state of the process and their own behaviour in interaction with their environment in the real world.'	Manufacturing
Qi and Tao, 2018, p. 3585	'Digital twin is to create the virtual models for physical objects in the digital way to simulate their behaviors. The virtual models could understand the state of the physical entities through sensing data, so as to predict, estimate, and analyze the dynamic changes. While the physical objects would respond to the changes according to the optimized scheme from simulation. Through the cyber-physical closed loop, digital twin could achieve the optimization of the whole manufacturing process.'	Manufacturing
Jones et al., 2020	Basic definition adopted from Grieves and Vickers (2017). Extended the Digital Twin conceptualisation by listing 19 attributive themes through a systematic literature review.	Manufacturing
Glaessgen and Stargel, 2012, p. 7	'Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin. The Digital Twin is ultra-realistic and may consider one or more important and interdependent vehicle systems.'	Product life cycle management, Manufacturing

[4] Marc Lind, Vice President of Aras, has been famously quoted: 'If you ask three people what the Digital Twin is, you get five answers' (Boyles (2017).

The heterogeneity in definitions also persists in the extant industry. Table 3 provides a glimpse on managerial understandings of Digital Twin based on a selection of five different companies.

Table 3. Managerial understanding of Digital Twin

Digital Twin Definition
Detecon (Weber and Grosser, 2019) The virtual representation of a physical object using operating data and other data sources to enable monitoring and dynamic control of the object. This covers the full scope from a life cycle phase to the complete product life cycle. The maturity of a digital twin is defined in dependence on the level of communication and the degree of standardization. The degree of communication describes the connection between the Digital Twin and the physical object. The degree of standardization reflects the modelling of the data and data sources.
Deutsche Bahn (Mohn et al., 2020) Digital Twins: ▪ describe an object, a human being or a process ▪ are digital representations of things in the real world (the existence of the respective 'thing' is irrelevant) ▪ offer different types of information in an intuitive format and thus enable overarching information exchange ▪ could contain algorithms, simulations, and services that represent, describe, or influence past, present, and future behaviour
DHL (Dohrman et al., 2019) A Digital Twin: ▪ is a virtual model of a real 'thing' ▪ simulates both the physical state and behaviour of the thing ▪ is unique, associated with a single, specific instance of the thing ▪ is connected to the thing, updating itself in response to known changes to the thing's state, condition, or context ▪ provides value through visualization, analysis, prediction, or optimization
Gartner (Gartner, 2022a) A digital representation of a real-world entity or system. The implementation of a digital twin is an encapsulated software object or model that mirrors a unique physical object, process, organization, person or other abstraction. Data from multiple digital twins can be aggregated for a composite view across a number of real-world entities, such as a power plant or a city, and their related processes.
IBM (IBM, 2022) A Digital Twin is actually a virtual environment, which makes it considerably richer for study [than a simulation]. […] While a simulation typically studies one particular process, a digital twin can itself run any number of useful simulations in order to study multiple processes. […] Digital twins are designed around a two-way flow of information that first occurs when object sensors provide relevant data to the system processor and then happens again when insights created by the processor are shared back with the original source object.

Altogether, this work defines Digital Twin as follows:

> *Digital Twin is a technological method that creates a virtual environment in which the characteristics, behaviours, and interactions of a particular object, system, or process are timely, holistically, dynamically, and realistically reproduced beyond conventual data augmentation. Hence, Digital Twins provide an unprecedented understanding of the authentic entity. More significantly, the innovation lies not in amassing more data but in ushering in a new quality of integration and interaction.*

2.3.5 Technical Background of Digital Twin

As previously mentioned, Digital Twin is a multidisciplinary endeavour that represents the technological, qualitative, and strategic peak of the technical development described in chapter 2.3.1. In the recent years, the expenses for computing hardware and cloud service providers plummeted while simultaneously a wide range of powerful simulation software offerings for various contexts was launched (Defraeye et al., 2021; Mack, 2011) pathing the way for Digital Twin establishment. The Digital Twin's technical background can be divided in four major activities: data gathering, data transfer, data storing, and data analysis. Table 4 explains the technical specifications of the Digital Twin approach through a morphological box.

Table 4. Morphological box of technical specifications of a Digital Twin

Feature		Specification				
Gathering	*Type of collector*	Condition sensors (e.g. GPS modules, thermometers, etc)	RFID tags	Imaging sensors (e.g. cameras, lidar, laser)		
	Type of data	Condition (e.g. temperature)	Activity and behaviour	Location	Process	Human interaction
	Data source	Organisational entity	Downstream stakeholder	Upstream stakeholder	Public data	Open data
Transmission	*Wired connections*	Physical cables (e.g. ethernet)	USB ports and sticks			
	Wireless connections	Wi-Fi	Bluetooth	Zigbee	Cellular networks (e.g. 5G)	
	IoT protocols	Sage queuing telemetry transport	Constrained application protocol			
Storage		Edge-computing	Cloud-computing	Edge-cloud hybrid	Blockchain	
Analysis		Visual representations (e.g. apps, 3D-models, graphs, dashboards)	Manual analysis	Statistical methods	Simulation modelling	Artificial intelligence

Data Gathering. Data is typically collected through a variety of sensors related to the Digital Twin's original counterpart (Negri et al., 2017). The decreasing costs of sensors and sensor sizes boosted the number of measurements points available (Defraeye et al., 2021). The type of sensor used depends on the original entity's nature and can include accelerometers (Kim et al., 2019), thermometers (Tuegel et al., 2011), pressure sensors (Pesantez et al., 2022), GPS modules (Raza et al., 2022), RFID readers (Visich et al., 2009), but also cameras, lidar, and other imaging sensors for more complex objects (Raza et al., 2022; Wu and Kuzmichev, 2021). Sensors continuously capture data about various parameters about the entity and its direct as well as extended environment (Rosen et al., 2015). This may include condition (Ivanov et al., 2014), activity (Kim et al., 2019), shape (Wu and Kuzmichev, 2021), position and orientation (Pesantez et al., 2022), behaviour (Haag and Anderl, 2018), temperature (Tuegel et al., 2011), and more. Beyond that, data could also be gathered through other mechanisms and represent for example historical records (Negri et al., 2017), process data (Tao et al., 2019; Tao and Zhang, 2017), financial flows (Badakhshan and Ball, 2023), or even human interaction data (e.g. user behaviour, preferences, and feedback) (Truby and Brown, 2021). It might also not be strictly necessary for the focal organisation to collect the data by itself as the amount of openly available data is skyrocketing and could also be used as baseline for Digital Twins (Defraeye et al., 2021; Qi et al., 2021; Weerakkody et al., 2017).

Data Transmission. Transmission involves moving data from sensors to storage locations or between different parts of the overall Digital Twin system (for example between business functions or stakeholder). The maturing of networking technologies simplified and accelerated the transfer of large volumes of data and was thus a major driver for Digital Twin adoption (Defraeye et al., 2021). Examples how data could be transmitted include wired connections (physical cables such as ethernet or universal serial bus) (Zhou et al., 2022), wireless connections (e.g. Wi-Fi, Bluetooth, Zigbee), (Dolgui and Ivanov, 2022; Yaakop et al., 2017), cellular networks such as 5G (Ramirez et al., 2022), and IoT Protocols (e.g. message queuing telemetry transport or constrained application protocol) (Haag and Anderl, 2018). For cross-functional and interorganisational data transmission, standardisation and interoperability of systems are crucial requirements (Dohrman et al., 2019; Ríos et al., 2020).

Data Storage. The gathered data needs to be stored in a way that allows for efficient access and analysis. To ensure data security and privacy, encryption techniques have to be applied to the stored data, especially if sensitive information is involved (Stergiou et al., 2023). Options for storing data are multifarious. In some cases, data is processed and stored close to the data source at the edge of the network (hence the name edge-computing) (Zhang et al., 2022). Second, data can be stored in cloud-based databases which provide scalable and easily accessible solutions (Cegielski et al., 2012). Third, some systems use a hybrid of cloud and edge storage to balance real-time processing with long-term data retention and remote accessibility (Qi and Tao, 2019). And fourth, although less common due to its complexity, blockchain offers a secure solution and can be used when data integrity and immutability are critical (Putz et al., 2021).

Data Analysis. Finally, the data has to be processed and analysed for decision-making purposes. Digital Twins are often visualised through specialised software interfaces that allow users to interact with the virtual representation which may include 3D models, real-time graphs, and dashboards (Qi et al., 2021). Visualisation aids in identifying trends, outliers, and patterns. Recently, 'new apps have emerged on smartphone and tablet platforms as low-level, extremely user-friendly interfaces for end-users' (Defraeye et al., 2021, p. 250). Moreover, Digital Twins are often used for the creation of 'what-if' scenarios. By simulating various conditions and changes in parameters of the virtual environment, decision-makers can anticipate outcomes and select the best course of action (Burgos and Ivanov, 2021; Ivanov and Dolgui, 2021). Furthermore, statistical methods like regression analysis, time series analysis, and hypothesis testing can provide valuable insights into the captured factors (Negri et al., 2017). In its most advanced state, data analysis can be performed automatically through machine learning and artificial intelligence techniques which can autonomously recognise patterns, detect anomalies, predict the outcomes of certain actions and initiate optimisation strategies (Min et al., 2019; Ritto and Rochinha, 2021). Nonetheless, human expertise remains crucial for understanding the nuances of data. Domain experts can interpret data patterns that automated systems might miss (Fan et al., 2019). Manual analysis can involve comparing real-world events with predictions in the virtual environment (Fan et al., 2019).

Three layers have to be taken into consideration when describing a Digital Twin, which are visualised by Figure 5. The first is the physical layer. It entails all relevant original entities, their behaviour and their interaction with their extant environment (Kamble et al., 2022; Sacks et al., 2020). These original entities emit data which are captured through different types of sensors (Defraeye et al., 2021). In the digital layer, the actual Digital Twin is created as thorough virtual representation of the original entity (Kamble et al., 2022). Software is used to visualise the Digital Twin, for instance in form of dashboards, allowing for monitoring and controlling (Kamble et al., 2022; Qi et al., 2021). Finally, in the analytical layer, the data is examined, evaluated, and ultimately exploited to manipulate the original entity (Kamble et al., 2022). It should be noted, that different degrees of velocity, system autonomy, and influential power are possible, depending on the level of sophistication of the respective system employed (Kritzinger et al., 2018). Moreover, in reality the processes of data gathering, storage and analysis are not taking place in isolated layers as Figure 5 might suggest. But, for the sakes of simplicity and clarity, it was decided to locate them in the layer of their greatest influence.

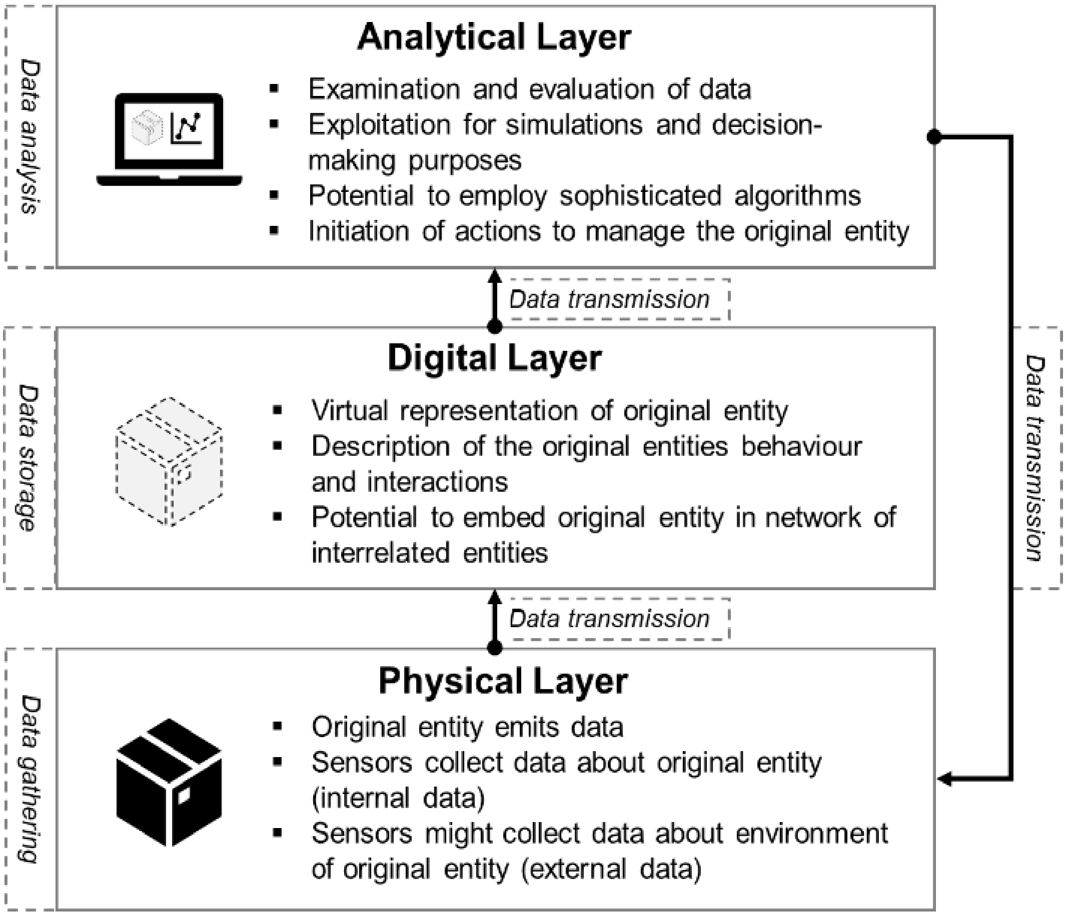

Figure 5. Basic Digital Twin architecture

Source Own depiction based on Kamble et al., 2022

2.3.6 Digital Twin Application Cases and Unit of Analysis

The central novelty of the Digital Twin approach lies in its transformative capacity to extend integration and interaction aspects (Bhandal et al., 2022). Ever-new forms of seamless data gathering, interorganisational information sharing, and novel opportunities for data analysis and simulation-building enables application areas to move beyond their original focus on spacecrafts. Consequently, hypothetical and observable cases display an extensive and divers range of potential ambits (Bhandal et al., 2022). This diversity, while showcasing the versatility of Digital Twins, contributes to their conceptual blurriness, necessitating a comprehensive exploration of their potential and intriguing aspects beyond their technical novelty (Dohrman et al., 2019).

Table 5. Digital Twin application areas

Type	Object	Domain and Purpose: Behaviour Prediction	Logistics	Maintenance	Manufacturing	Research & Development	Risk Management	Key Citations
Tangible Entity	Aircraft	X			X	X		Mandolla et al., 2019; Tuegel et al., 2011
	Construction Side			X		X		Sacks et al., 2020
	Crane					X		Autiosalo et al., 2021
	Hauling Silo	X	X					Greif et al., 2020
	Horticultural Products						X	Defraeye et al., 2021; Henrichs et al., 2021
	LEDs					X		Martin et al., 2019
	Ship			X		X		Arrichiello and Gualeni, 2020
	Train							Mohn et al., 2020
	Warehouse	X						Elbouzidi et al., 2023; Maheshwari et al., 2023b
	Wind Turbine	X		X				Kim et al., 2019
Intangible Entity	Traffic	X	X					Lee and Lee, 2021
	User Personality	X						Sun et al., 2021
Network/ System	City	X					X	Ham and Kim, 2020
	Energy Grid	X					X	Dohrman et al., 2019
	Factory	X			X			Chabanet et al., 2023
	Organisation	X					X	Li et al., 2020; Parmar et al., 2020
	Port	X					X	Wang et al., 2021
	Power Plant	X		X				Parris, 2022
	Production Line	X			X			Kamble et al., 2022
	Supply Chain	X					X	Burgos and Ivanov, 2021; Lv et al., 2022; Wu et al., 2023

For instance, Digital Twins could be created for different types of buildings such as wind farms to enhance efficiency and decrease downtime (Sivalingam et al., 2018), bridges to enable predictive maintenance (Shim et al., 2019), or houses to increase energy efficiency (Francisco et al., 2020). In geoscience, Digital Twins of the polar ice sheet help to monitor climate effects (British Antarctic Survey, 2022), or coastal area Digital Twins raise hurricane predictability (Holden, 2021). In the medical world, Digital Twins of patients or organs could foster the treatment personalisation (van Houten, 2018). But also in the supply chain context, many (potential) application areas are contemplated including but not limited to warehouses to streamline inventory management (Dohrman et al., 2019), vehicles for spare part management (Dohrman et al., 2019), or infrastructure for risk management (Ivanov and Dolgui, 2021). Table 4 sheds light on a selection of application areas by listing the mentioned ‘object of digitalisation' (original entity) as well as application domains and purposes. As the precise digitalisation object has only been clearly stated by a minor share of academic articles, Table 5 also features grey literature. The list of applications intends by no means to be complete but rather aims to demonstrate the conceptual versatility of Digital Twins.

Research articles that feature empirical economic effects of Digital Twins are scarce (Bhandal et al., 2022). This leads to lack of comprehensive understanding of the effects and usability factors of Digital Twins for supply management. In fact, research focuses almost exclusively on technical requirements or obstacles such as hard- and software determinates (e.g. Simchenko et al., 2019). This hypotheticality impedes the assessment of Digital Twin value (Palla, 2022). Nonetheless, two supply chain related areas already acknowledged the auspiciousness of Digital Twins. One being the manufacturing and engineering sector (e.g. Austin et al. (2020), Leng et al. (2021), or Wang et al. (2019)). However, Bhandal et al. (2022) argue that Digital Twins are surmounting manufacturing, which allows for various new possibilities for researching their specificities, challenges, and values for supply chain purposes. The other is risk management, where works such as Burgos and Ivanov (2021), Ivanov and Dolgui (2021), or Lv et al. (2022) demonstrate how simulations of entire supply chains could be used as resilience-enhancing decision-making tools. As Digital Twin is a multifaceted phenomenon (Kritzinger et al., 2018), the existing research fails to account for all potential and intriguing aspects. Although, it is certainly necessary and appropriate to start by discerning their technical novelty, it is similarly intriguing to investigate their versatile contentual abilities.

2.3.7 Digital Twins as Potential Enabler of Advanced Demand Management

As technically described in Figure 5 and deduced from the indications provided by the applications presented in Table 5, the Digital Twin phenomenon is associated with a range of attributes that have preeminent significance for the management of customer demands in the supply chain context (Gussen et al., 2020; Mertens et al., 2021; Tao et al., 2019).

First, Digital Twins represent the timely collection and analysis of data (Cimino et al., 2019; Kritzinger et al., 2018; Tao et al., 2018). As this data could include customer usage patterns, preferences, and feedback, Digital Twins could enable organisations to gain a deeper understanding of customer demands by providing valuable insights into customer needs and expectations. The unique leap lies in the depth and velocity of data acquisition, enabling organisations to promptly garner profound insights into customer needs and expectations.

Second, Digital Twins virtually represent entities in a precise manner (Cimino et al., 2019; Kritzinger et al., 2018; Tao et al., 2018). This implies that individual customer preferences could be singled and observed (Bhandal et al., 2022). Possessing these insights allows organisations to tailor products or services to single customer preferences with unprecedented granularity. (Bhandal et al., 2022).

Third, through Digital Twins organisations can continuously receive feedback from customers (Bolton et al., 2018). This gives organisations the ability to quickly iterate processes concerning their products or services to meet evolving demands, ultimately leading to agile decision-making and higher responsiveness to customer needs (Tao et al., 2018). Consequently, Digital Twins accompanied by adaptability feedback loops.

Fourth, Digital Twins couple analytical and predictive methods (Negri et al., 2021). By analysing historical and concurrent data, organisations are provided with tools to anticipate customer demands and make accurate predictions about future customer behaviours (Negri et al., 2021). Thus, Digital Twins are enabling proactive planning and resource allocation.

Fifth, Digital Twins involve customers in the virtual representation of their demand (Bolton et al., 2018). This facilitates opportunities for collaboration (Bolton et al., 2018). Hence, organisations can gather input and test different scenarios to ensure alignment with customer demands, fostering a deeper sense of involvement and customer satisfaction (Bolton et al., 2018).

And sixth, the virtual representation of customer demands allows for ongoing monitoring, analysis, and optimisation based on customer feedback and performance data (Bolton et al., 2018). This enables organisations with a continuous flow of feedback ensuring continuous alignment with customer demands (Bolton et al., 2018).

On the whole, these six factors highlight the novel quality of ultimate demand integration enabled through digital twins. Therefore, a concept that reconciles these attributes could be termed as ***Digital Twin of Customer Demands*** (**DTCD**). Similar notation have recently been featured in Gartner’s Hype Cycle: *Digital Twin of the Person* in 2020 (see Appendix A2) and *Digital Twin of a Customer* in 2022 (see

Appendix A3). Both concepts were given a prospect of five to ten year for reaching productivity (Gartner, 2022b, 2021). The corresponding impact supposedly goes beyond mere informational and automational effects (Bailey et al., 2019) as DTCDs represent pervasive connectivity, transparency, and collaboration (Lanzolla et al., 2021; Lanzolla et al., 2020; Srai and Lorentz, 2019). This implies that DTCD value would not be limited to streamlining prevalent transactions but also affect ‘the modalities through which control is exerted and […] the very nature of (inter)organizational [sic!] knowledge’ (Lanzolla et al., 2020, p. 343).

It should, however, be noted that the presented thoughts are conceptual considerations based on educated reasoning and that the actual impact of DTCD is so-far lacking empirical precedents (Bhandal et al., 2022). Since supply chain managers also have to guarantee that technological means with extensive strategic implications are aligned with strategic sourcing and delivery demands and capabilities (Heim et al., 2021; Heim and Peng, 2022), a thorough investigation of DTCD value and usability is necessary to discern hype from actual impact.

3 Research Status on Digital Customer-Driven Supply Management

3.1 Introduction to the Literature Review

As thoroughly explained in chapter 2.2.2, marketing has evolved into a comprehensive and customer-centric management philosophy (Becker and Homburg, 1999; Day, 1996; Kerin, 1996). Despite the common roots of supply management and (industrial) marketing (Robinson et al., 1967; Sheth et al., 2009; Webster and Wind, 1972), there are noticeable indications that supply management research lags behind, maintaining a predominant focus on upstream considerations rather than adopting the Janus-like ambilateral perspective encompassing both supply and customer aspects (Ellram et al., 2020). This boils down to two major issue the supply management literature is facing: On the one hand, there is a theoretical ambiguity, as some scholars argue that supply management analyses both up- and downstream flows (Bai et al., 2021; Ellram et al., 2020; van Weele and van Raaij, 2014), while others claim that supply management exclusively investigates the upstream side (Ardito et al., 2019; Jääskeläinen and Heikkilä, 2019; Kähkönen and Lintukangas, 2012; Martinelli and Tunisini, 2019; Reaidy et al., 2020; Sheth et al., 2009; Soosay and Hyland, 2015). On the other hand, it is unclear whether the developments of accelerating technological sophistication, which provided supply management with novel and auspicious digital tools to integrate upstream-located customer demands (Martinelli and Tunisini, 2019; Srai and Lorentz, 2019), are adequately reflected in the current state of the supply management literature.

On these grounds, the primary aim of this literature review is to systematically assess the supply management literature's consideration of digital customer integration, as depicted in Figure 6. Thereby, the precise gap that the overall dissertation aims to fill is located and contoured. This chapter’s content has been largely adopted from a research article accepted for presentation at the IPSERA Conference 2024.

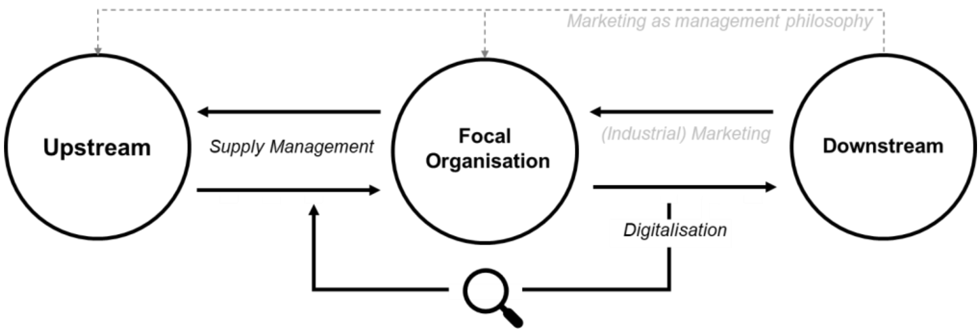

Figure 6. Schematic illustration of the literature review’s research goal

3.2 Methodology of the Systematic Literature Review

The present method followed the guidelines proposed by Durach et al. (2017), who advocate that a systematic literature review should be conducted in six steps. These steps are illustrated by Figure 7 and are subsequently explained and executed.

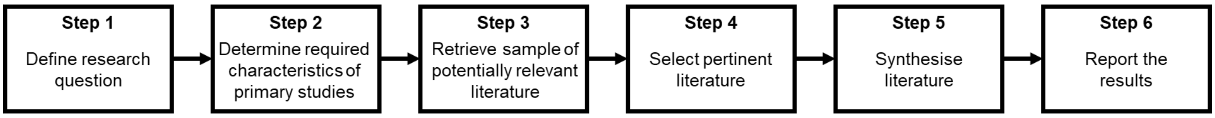

Figure 7. Steps of a systematic literature review

Source Own depiction based on Durach et al. (2017)

The first step relates to defining the focus of the research question (Durach et al., 2017). As motivated earlier, the aim of this work is to unravel whether supply management research contemplates the active incorporation of customer demands in supply management core activities in the wake of the digitalisation or if customers are merely considered as passive recipients. As previously described, the need for this review is justified with conceptual ambiguity (Ellram et al., 2020) and recent technological advancement that offer novel opportunities for supply management (Srai and Lorentz, 2019) with unclear performance measures for the procurement function (Jääskeläinen and Heikkilä, 2019). The review's goal is reached by splitting the research goal in sub categories that follow Marty's (2022) observations on research clusters regarding customer integration in supply chains: (1) theoretical development in terms of scope and assessment of integration, (2) integration drivers, and (3) integration outcome. Hence, three research questions are raised to identify concepts and terms that describe digital customer integration, their accompanying socio-technical perquisites, and their consequential performance impact:

RQ 1: Which concepts and terms related to digital customer integration in supply management are contemplated in the literature and how can they be characterised?

RQ 2: What are socio-technical perquisites for digital customer integration in supply management?

RQ 3: What are performance factors of digital customer integration in supply management?

The actions taken in step two served to establish criteria that assessed the suitability of publications to provide valuable insights on the research goal (Durach et al., 2017). Contrary to Denyer and Tranfield's (2009) reasoning, this systematic literature review does not incorporate books or non-peer reviewed sources but only takes English peer-reviewed journal articles in the business science domain into consideration. As further quality criterium, the renown ranking of international business journals by the German Academic Association for Business Research (VHB, 2022) was consulted and publications were excluded which were made in journals that do not match the VHB's quality threshold. Although this may lead to a selection-bias (Durach et al., 2017), it serves as a quality criterium to safeguard the analysis' validity (Webster and Watson, 2002). Content wise, only articles and reviews are considered whose research focus incorporates the integration of downstream matters through digital technologies in supply management activities. To paint a holistic picture, the review is not limited to contributions to the supply management field alone, as long as the content criteria are fulfilled. Due to the previously described innate ties with industrial marketing (Håkansson and Östberg, 1975; van Weele and Eßig, 2017) regarding organisational buying behaviour (Robinson et al., 1967; Webster and Wind, 1972), this field is also incorporated. Furthermore, it is reasoned that the extant literature will lack the rigidness to conceptually delimit supply management studies from the interrelated domains operations and supply chain management (SCM) (Harland et al., 2006). Thus, a contribution to these fields is also included if it engages in digital customer integration on the premise that the core of the respective study contemplates supply management matters. Vice versa, articles that only concentrate on downstream flows but neglect the supplier side were excluded. Logistics and operations research, albeit distantly related to supply management, are not considered to belong to core supply management activities and thus also excluded.

In the third step, a sample of germane articles was created (Durach et al., 2017). This requires the establishment of plausible keywords that comprehensively cover the domain of interest (Durach et al., 2017). In October 2023, the SCOPUS database was used for this matter due to its comprehensive coverage, global reach, quality control measures, and advanced search capabilities. Three search strings were applied that narrow the topic down in a funnel-like manner. String 1 served as a reference to grasp the overall number of contributions related to supply management. Hereby, 58,495 articles were found that relate to one of eight keywords which can generally be seen as synonyms for the supply management domain and its immediate environment. String 2 introduced the customer concept and its synonyms: demand, consumer, and downstream; resulting in 23,376 matches. Finally, the usage of digital technologies was incorporated, as only with advanced digitalisation technologies, a thorough incorporation of downstream matters becomes feasible (Srai and Lorentz, 2019). Hence, in string 3 only one general term was used that is assumed to be pivotal for all studies that feature this fact: digital*. String 3 leads to 918 peer reviewed journal articles and reviews which serve as baseline sample of this review. A comprehensive overview of the described procedure is provided in Table 6.

Table 6. Description of the literature review's sampling procedure

String	Keyword group 1	Keyword group 2	Keyword group 3	Matches
	"Supply management" Procurement Purchasing Sourcing "Industrial marketing" "Supply Chain" "Demand Chain" "Value Chain"	Customer Demand Consumer Downstream	Digital*	
1	**X**			**58,495**
2	**X**	**X**		**23,376**
3	**X**	**X**	**X**	**918**
Search area: Abstract, tile, keywords *Limitations: Articles & reviews; Business science domain* *Keywords connection within keyword groups: OR* *Keywords connection across keyword groups: AND*				

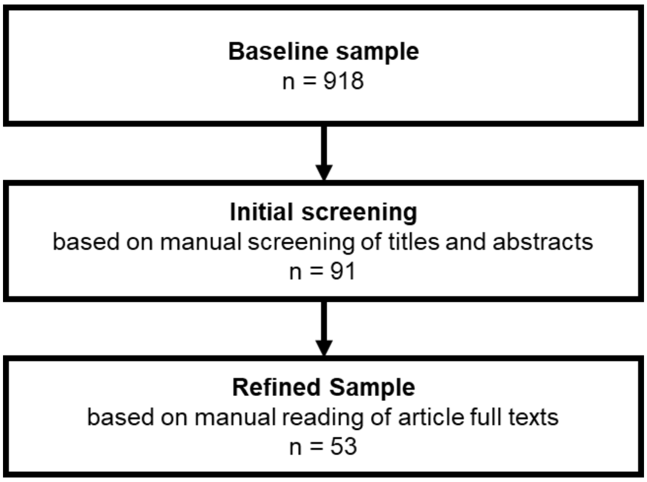

Figure 8. Refinement of the literature review's sample

Source Own depiction adopted from Martinelli and Tunisini (2019)

In step four, the baseline sample is refined as illustrated Figure 8. Firstly, an initial screening on all 918 matches was performed. Based on whether the articles' titles and abstracts indicate a fit with the research goal, matches were transferred to a shortlist. This reduced the sample to 91 articles which were then carefully read. Thereafter, all contributions were eliminated that turned out unsuitable. Reasons for exclusion are:

lack of connection to supply management activities with exclusive emphasis on other areas such as marketing, logistics, operations research, project management, construction, and manufacturing, and the predominant investigation of technical rather than economic factors (for instance the development of specific algorithms). This refines the sample to 53 articles.

In step five, the sample was synthesised (Durach et al., 2017) by splitting the research goal into subthemes, each entailing a distinct and instructive perspective. First, more clarity was needed on the phenomenon of customer integration. Thence, terms and concepts used in the literature to describe this phenomenon were analysed. Second, prerequisites for integrating customers in supply management were extracted. This served particularly to investigate the role digital means. And third, the central phenomenon’s impact was parsed by seeking for specific performance constructs. To facilitate this concept centric approach, several concept matrices were created whose content and categories were progressively generated according to the emergence of new and relevant concepts in the sample (Webster and Watson, 2002).

3.3 Literature Review Findings

In the sixth and final step of the systematic literature review, findings are reported (Durach et al., 2017). This entails describing the sample as well as defining and discussing key concepts and terms, prerequisites, and performance constructs related to digital customer integration in supply management.

3.3.1 Description of Articles Included in the Literature Review’s Sample

The first noteworthy observation relates to the temporal proximity of included articles. Although no explicit restrictions were imposed with regard to publication dates, merely seven articles were published prior to the year 2010, whereas 17 articles were published between 2010 and 2019, and a notable 29 articles emerged in the year 2020 or thereafter. In other words, approximately 74 % of the sample's articles, amounting to 39 in total, have been published within the most recent five-year period. Beyond that, seven articles (13 %) originate from 2023 – the very year in which this review is being conducted. Most articles were published in industrial marketing journals such as Industrial Marketing Management or Journal of Business and Industrial Marketing. It is striking that not a single article within the sample found their place in the two primary journals dedicated to supply management, namely the Journal of Purchasing & Supply

Management and the International Journal of Integrated Supply Management. A comprehensive overview of the included journals can be found in Appendix A4.

For research domains, approximately one-fifth of the articles, totalling 12, exhibited an explicit emphasis on supply management. An equivalent number of articles could be classified within the domain of industrial marketing, while nine articles relate to the field of operations. The network-oriented sphere of SCM predominates, encompassing half of the articles within the sample. A comprehensive summary is presented in Table 7.

Table 7. Articles in the refined sample classified according to research focus domain

<table>
<tr><th>Domain</th><th>Supply management</th><th>Industrial marketing</th><th>Supply chain management</th><th>Operations</th></tr>
<tr><td>Total</td><td>12</td><td>12</td><td>27</td><td>9</td></tr>
<tr><td>Quota</td><td>23 %</td><td>23 %</td><td>51 %</td><td>17 %</td></tr>
<tr><td rowspan="2">Articles</td><td>Gallear et al., 2008; Jääskeläinen and Heikkilä, 2019; Marzi et al., 2023; Sheth et al., 2009; Sjödin et al., 2018</td><td>Boldosova, 2020; Herhausen et al. 2020; Hsieh et al. 2008; Mahlamäki et al., 2020; Purmonen et al., 2023</td><td rowspan="2">Agrawal and Narain, 2023; Agrawal et al., 2022; Ardito et al., 2019; Aspara et al., 2021; Attaran and Attaran, 2004: Bai et al., 2021; Burgos and Ivanov, 2021; Choi et al., 2019; Chong and Zhou, 2014; Dolgui and Ivanov, 2023; Feng et al., 2022; Hasija and Esper, 2022; Huikkola et al., 2020; Huynh, 2022; Kazantsev et al., 2022; Lau and Lee, 2000; Maheshwari et al., 2023; Martinelli and Tunisini, 2019; Marty et al., 2023; Marty, 2021; Rai et al., 2006; Reaidy et al., 2020; Reyes et al., 2023; Santos and D'Antone, 2014; Shashi et al., 2020; Thun, 2010; Veile et al., 2022</td><td rowspan="2">Akmal et al., 2022; Andersson and Jonsson, 2018; Bogers et al., 2016; Gallino and Moreno, 2018; Gawankar et al., 2020; Gustafsson et al., 2019; Gustafsson et al., 2021; Holmström and Partanen, 2014; Martinez et al., 2019</td></tr>
<tr><td colspan="2">Kamalaldin et al., 2020; Marcon et al., 2022; Piercy, 2009; Raddats et al., 2019; Steward et al., 2019; Truong et al., 2012; Tunisini and Sebastiani, 2015</td></tr>
<tr><td colspan="5">7 articles were attributes to both supply management and industrial marketing</td></tr>
</table>

3.3.2 Concepts and Terms Related to Customer-Driven Supply Management

Few studies employed terms that centralise the usage of digital technologies already in their notation. Nonetheless, three concepts stick out because they emphasise on the idiosyncrasies of advanced digital technologies by highlighting not only the analytical value but also the encouragement of timely and encompassing information sharing and interaction in the virtual realm: digital supply chain, digital supply chain twin, and supply chain visibility. Please refer to Table 8 for definitions and references.

Table 8. Identified supply chain digitalisation concepts

Concept	Definition	References
Digital supply chain	An intelligent, value-driven network that leverages new approaches with technology and analytics to create new forms of revenue and business value, through a centric platform that captures and maximises the utilisation of real-time information emerging from a variety of sources.	Agrawal and Narain, 2023; Herhausen et al., 2020
Digital supply chain twin	Computerised models that represent the network state for any given moment in time.	Burgos and Ivanov, 2021; Dolgui and Ivanov, 2023
Supply chain visibility	The extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit.	Agrawal et al., 2022; Herhausen et al., 2020

There is a great heterogeneity in describing the integration of downstream matters in the supply chain. While some terms relate to integrational acts (e.g. integration, interaction, or involvement), others focus on the strategic level and employ terms that describe the associated management philosophy (e.g. centricity, drivenness, or orientation). Table 9 provides insights into all customer integration concepts identified. Strictly speaking, there is a range of minor and major conceptual differences between these terms, however, most 'contributions consider various customer integration approaches to be synonymous to one another' (Martinelli and Tunisini, 2019, p. 25). Because this step served to create an oversight of extant concepts for later analysis, no rating or quantitative assessment of concepts was undertaken at this stage.

Table 9. Identified customer integration concepts

Terms	Definition	References
Customer centricity	Customers are recognised as pivotal and proactive part within the supply chain. The supply chain is thereby outcome not output oriented.	Bogers et al., 2016; Martinelli and Tunisini, 2019; Purmonen et al., 2023; Veile et al., 2022
Customer-/ demand-driven	Customers are seen as activators of supply chain processes, as well as the ultimate destination of such processes.	Agrawal and Narain, 2023; Kazantsev et al., 2022; Martinelli and Tunisini, 2019
Customer-integration	Involving the customers in supply chain processes, demonstrating the willingness to work together, and sharing information on time to satisfy customers' needs.	Martinelli and Tunisini, 2019; Marty, 2022; Reaidy et al., 2020; Thun, 2010
Customer interaction	Facilitation of a co-constructed dialogue.	Boldosova, 2020; Truong et al., 2012
Customer involvement	Besides purchasing end-products at the end of the supply chain, customers are acting as suppliers of various inputs to supply networks.	Aspara et al., 2021
Customer journey	Refining all stages and touch points between customer and the supply chainto optimise the customer experience.	Steward et al., 2019
Customer-orientation	A culture in which everyone in the organisation continuously improves operations to satisfy customer needs.	Reyes et al., 2023
Customer relationship management	Usage of supply chain capabilities to effectively and efficiently manage upstream flows with the aim of improving customer satisfaction and optimising long-term relationships.	Akmal et al., 2022; Attaran and Attaran, 2004; Gustafsson et al., 2019; Herhausen et al., 2020; Piercy, 2009; Rai et al., 2006; Sheth et al., 2009
Demand chain management	Integrating marketing and supply chain management to create an optimal alignment between supply- and demand related processes.	Bai et al., 2021; Chong and Zhou, 2014; Santos and D'Antone, 2014
Market integration	Minimising the mismatch between demand and supply.	Ardito et al., 2019
Market orientation	Information generation and dissemination of and responsiveness to market intelligence.	Hsieh et al., 2008
Market sensitive	Demand is detected directly from the market. Thus, demand forecasting is not based on past trends but on the daily point of sale and daily feedback.	Shashi et al., 2020

3.3.3 Socio-Technical Prerequisites for Customer-Driven Supply Management

The extant literature agrees that customer integration cannot be achieved in a void but is the consequence of distinct social and technological prerequisites (Agrawal et al., 2022; Reaidy et al., 2020; Schoenherr and Swink, 2012; Thun, 2010). This is in line with research on managing information flows in supply management which is also strongly dependent on so-called socio-technical factors (Bailey and Francis, 2008; Hsu, 2005; Xu et al., 2023; Xu et al., 2014). In this light, 13 prerequisite themes were identified. An initial overview is given by Figure 9. For the sake of simplicity the subsequent running text only entails a selection of key articles for each theme. A thorough explanation of themes with the corresponding complete list of references is provided by A5 in the Appendix.

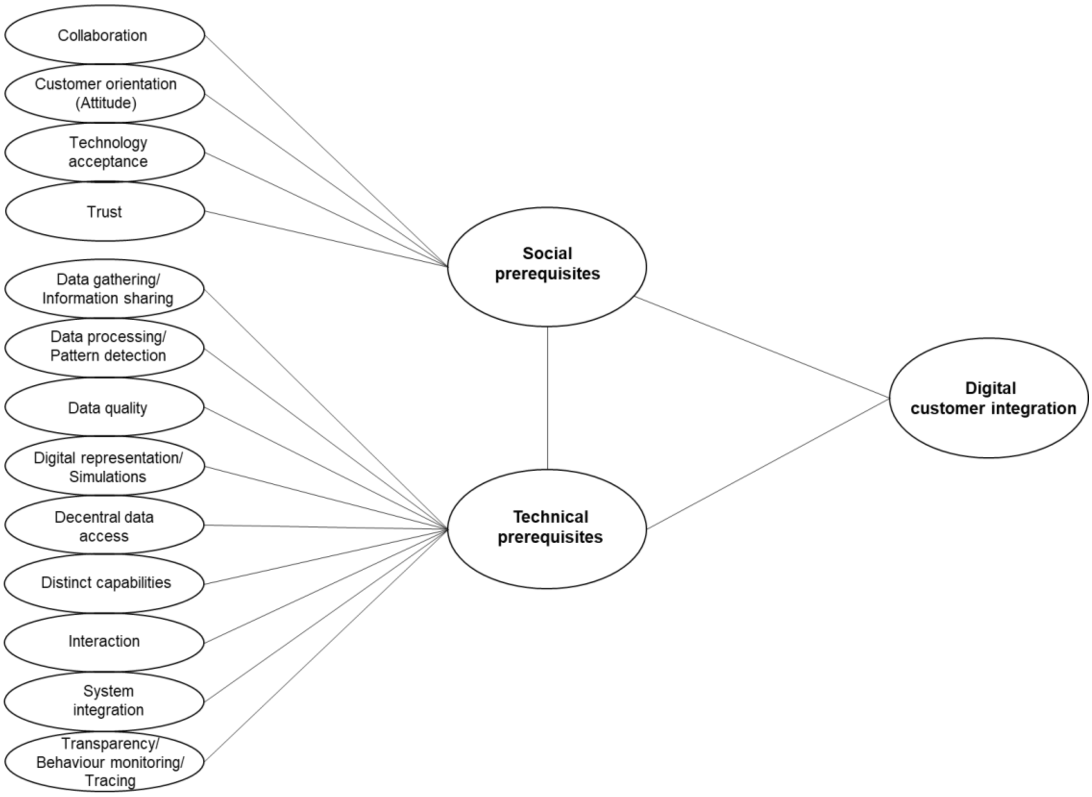

Figure 9. Socio-technical prerequisites for digital customer integration in supply management

At the social level, collaboration emerges as a foundational element, representing a collaborative effort that assembles customers and other supply chain stakeholders in pursuit of shared objectives (Shashi et al., 2020). The concept of customer orientation accentuates the importance of prioritising customer needs and satisfaction in the decision-making process (Purmonen et al., 2023).

Nestled in the social prerequisites is technology acceptance, which denotes the willingness and preparedness of customers, suppliers as well as intra-organisational functions to embrace novel technological means (Hasija and Esper, 2022; Mahlamäki et al., 2020). Trust plays an equally important role, underpinned by belief, and founded upon reliability and integrity (Chong and Zhou, 2014). Trust serves as the bedrock upon which confidence and positive expectations are built concerning the actions and behaviours of the stakeholders engaged in the integration process (Chong and Zhou, 2014).

Within the technical sphere, data management takes centre stage, with data serving as the artery of digital integration (Agrawal and Narain, 2023). The efficiency of data gathering and information sharing processes is crucial in facilitating the exchange of downstream insights (Andersson and Jonsson, 2018). Data quality, characterised by accuracy, consistency, reliability, and completeness, emerges as an indispensable prerequisite for data analytics (Agrawal et al., 2022). Decentralised data access heralds a shift in paradigm, empowering authorised users from both the up- and downstream sphere, to retrieve data from distributed locations within a network, reducing reliance on a central repository (Marzi et al., 2023). Concurrently, interactions form the core of the integration process, fostering mutual communication and enabling the seamless exchange of vital information (Thun, 2010). The landscape of system integration emerges as the unifying force, harmonising various software, hardware, or data systems into a cohesive whole, ensuring the unfettered flow of data and communication between previously disconnected components (Thun, 2010).

Furthermore, the realm of digital representation and data visualisation offers a suite of powerful tools, aimed at simplifying the comprehension of intricate customer demands (Gallino and Moreno, 2018). Simulations, whether computer-based or mathematical models, emerge as essential, mirroring real-world processes and enhancing the customer integration process (Burgos and Ivanov, 2021; Dolgui and Ivanov, 2023). This relates to the sphere of behaviour monitoring and tracing where systematic observations enable insight not only into the flow and movement of goods, services, and information, but also provide qualitative insights on both customer and product behaviour (Agrawal and Narain, 2023; Andersson and Jonsson, 2018). This creates pervasive transparency on customer demands for the entire supply chain (Kazantsev et al., 2022). Simultaneously, distinct capabilities are necessary to leverage novel technological opportunities (Herhausen et al., 2020). For instance, this could relate to unique manufacturing resources which empower companies to collaborate effectively and tailor product solutions (Bogers et al., 2016; Kazantsev et al., 2022).

3.3.4 Performance Constructs of Customer-Driven Supply Management

To elucidate the rationale for the inclusion of customer integration in supply management a systematic inquiry into performance-related factors was conducted, leading to a categorisation and assessment of 20 performance constructs. A comprehensive breakdown of these constructs can be found in Appendix A6. Additionally, Figure 10 serves as a visual representation of the performance constructs within the broader research landscape. Notably, the size of each icon in Figure 10 corresponds to the volume of contributions from the respective research domain within the sample: the absence of an icon indicates the absence of relevant articles in that field pertaining to the performance topic, a small icon signifies 1-2 relevant articles, a medium-sized icon denotes 3-4 articles, and a large icon reflects the presence of 5 or more articles. Furthermore, the findings have been systematically organised along two essential dimensions: strategic and operational implications, as well as the dichotomy between efficiency and effectiveness.

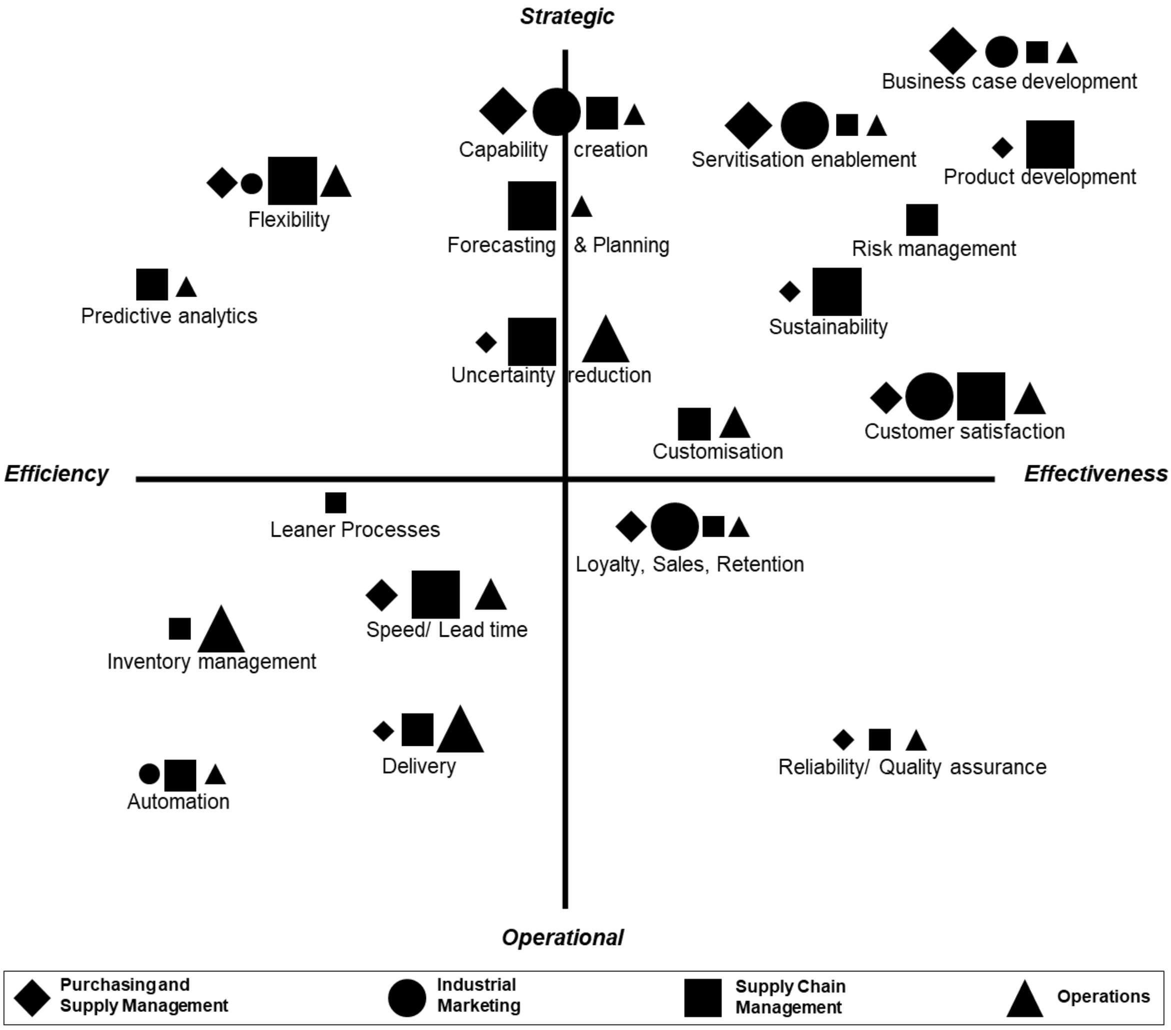

Figure 10. Customer integration performance factors in different research domains

For supply management, servitisation enablement emerges as the predominant impetus for customer integration, as evidenced by Kamalaldin et al. (2020), Marcon et al. (2022), Piercy (2009), Raddats et al. (2019), Sjödin et al. (2018), and Tunisini and Sebastiani (2015). Notably, over half of supply management studies in the sample are centred around unravelling how a deeper comprehension of customer demands can facilitate the transformation of products into service-oriented offerings. This transformation aligns seamlessly with the overarching pursuit of cultivating distinct capabilities (Jääskeläinen and Heikkilä, 2019) and the exploration of novel business models (Sjödin et al., 2018), representing the other principal themes within supply management-centric research.

In a parallel vein, the field of industrial marketing follows a similar path. Servitisation is also here the most prominent topic (Boldosova, 2020). Furthermore, this domain is driven by the imperative customer satisfaction (Boldosova, 2020), engendering both augmenting sales (Herhausen et al., 2020; Purmonen et al., 2023) and customer retention (Herhausen et al., 2020; Purmonen et al., 2023).

Regarding SCM, the essence of customer integration primarily revolves around the mitigation of uncertainties (Santos and D'Antone, 2014), thereby enhancing forecasting and planning activities (Huynh, 2022). This motivation is underpinned by a dual rationale. Firstly, it aims at bolstering efficiency by streamlining processes (Reyes et al., 2023), reducing lead times (Agrawal et al., 2022), and enhancing flexibility (Lau and Lee, 2000). Secondly, customer integration in SCM is harnessed for the optimisation of processual reliability (Agrawal et al., 2022) and risk management (Choi et al., 2019).

Lastly, operations demonstrates a pronounced interest in the intricacies of delivery procedures (Gustafsson et al., 2021, 2019), inventory management (Andersson and Jonsson, 2018), and manufacturing (Bogers et al., 2016; Holmström and Partanen, 2014) – all particularly with respect to spare-part management (Andersson and Jonsson, 2018; Bogers et al., 2016). It is noteworthy that this focus would have been even more pronounced, given that a substantial number of articles in the baseline sample delved into these aspects. However, due to their substantial alignment with logistics or operations research, they were excluded from the analysis.

3.4 Discussion of the Literature Review's Findings

Subsequently, findings are discussed with particular emphasis on the general state of the literature, and the facilitation, scope, and impact of digital customer integration.

3.4.1 Contemplations on the State of the Literature

As previously stated, supply management and marketing share a common origin manifested in conjoint industrial marketing and purchasing models (e.g. Cunningham, 1980). In this light it is worth to stress again the substantial transformation marketing underwent: from a business function confined to the tactical aspects of product promotion and sales into a comprehensive management philosophy that permeates every aspect of an organisation (Becker and Homburg, 1999; Jaworski and Kohli, 1993; Kotler and Levy, 1969; Morgan, 1996). There are parallels between these considerations and the one made by Mentzer et al. (2001) who contemplated whether SCM can be classified as (a) set of management processes, (b) a management philosophy, or (c) an implementation of a management philosophy. Marketing's metamorphosis signifies a reorientation, emphasising the (end-) customer as the driving force behind all business actions (Reinartz et al., 2004). Astonishingly, the findings show that supply management did not partake in this change in school of thought and still concentrates on the associated functional aspects when contemplating downstream matters (Martinelli and Tunisini, 2019).

This is exemplified by the foremost observation of the present review which evinced the absence of articles from core supply management journals. Consequently, this raises critical questions about the scope of academic discourse within the field. Albeit scholars such as Ellram et al. (2020) or Bai et al. (2021) advocate for a more ambilateral focus that encompasses both upstream and downstream considerations, the disconnect between these scholarly discussions and the content published in core supply management journals raises questions about the dissemination and visibility of these ideas within the discipline. It seems as if the supply management academic community might be segmented, with discussions on customer integration flourishing in alternative channels or interdisciplinary spaces rather than the traditional supply management centric outlets (Martinelli and Tunisini, 2019). This could be indicative of a disciplinary boundary (Harland et al., 2006) that separates the mainstream supply management discourse, which predominantly concentrates on supplier-sided flows, from the evolving conversations around downstream perspectives. The lack of findings in core supply management journals may also point to a potential reluctance or oversight within the discipline to fully embrace the broader conceptualisations advocated by scholars emphasising downstream considerations (Jääskeläinen and Heikkilä, 2019; Sheth et al., 2009; Tunisini and Sebastiani, 2015). It could thus suggest a resistance to expanding the traditional upstream focus and recognising the (end-) customer as an integral component of the supply management research landscape.

Moreover, the observed temporal distribution of articles, with approximately 74% of articles emerging within the last five years presents intriguing insights into the dynamics of research on digital customer integration in supply management. The preponderance of recent articles may signify the evolving nature of the research landscape, suggesting that digital customer integration in supply management is a burgeoning field of inquiry which would be in line with Reaidy et al. (2020). This reasoning is also reflected by the diversity in terminology which underscores the absence of a standardised lexicon (Martinelli and Tunisini, 2019). This indicates that the field may not have reached a level of maturity where a unified set of terms is established. This lack of consistency in terminology poses challenges for scholars and practitioners alike, demanding a nuanced interpretation of the literature and a cautious consideration of context. Nonetheless, a contemporary effort to consolidate notations has been noted, for instance by Martinelli and Tunisini's (2019) endeavour to contrast customer-driven and customer-centric supply chains, or Reaidy et al.'s (2020) taxonomy on customer integration in supply chain management. On the other hand, the present heterogeneity in terminology portrays the complexity of advanced digital technologies where different technical methods involve distinct capabilities that may justify unique terms to describe them (Agrawal and Narain, 2023). This emphasises the need for a more nuanced exploration of the intricacies inherent in customer integration in supply management which goes in line with Potter et al.'s (2015) supply chain migratory model.

3.4.2 Contemplations on the Scope and Facilitation of Digital Customer Integration

As illustrated by Figure 1 in chapter 2.2.1, the contemplation of integration endeavours in supply chains is typically depicted in form of hemicycle-shaped models. These allow to mark different degrees of customer, supplier, or technology integration. The degrees are typically termed as integration arcs (Frohlich and Westbrook, 2001; Schoenherr and Swink, 2012) or angles (Thun, 2010). The terms are used interchangeably and entail similar implications which, however, interpret integration overwhelmingly from a quantitative dimension (e.g. information on order volumes). This work follows the arc-based thread of Frohlich and Westbrook (2001) and Thun (2010): By delineating three distinct arcs, each representing a stage in the continuum of customer integration achieved through varying degrees of technological sophistication, an intuitive understanding for the findings' implications is created and illustrated by Figure 11. As organisations progress along the continuum from low to high integration, as technically explained by Figure 4 in chapter 2.3.1, they navigate the challenges and opportunities presented by evolving technologies. It should be noted, that the intricate web of socio-technical prerequisites presents a delicate balance (Asare et al., 2016) that has, for the sake of simplicity, been neglected by Figure 11. Integration success is contingent upon the alignment of collaboration and technology acceptance with management and system integration (Asare et al., 2016), implying a fit between supply chain strategy and IT activities (Thun, 2010).

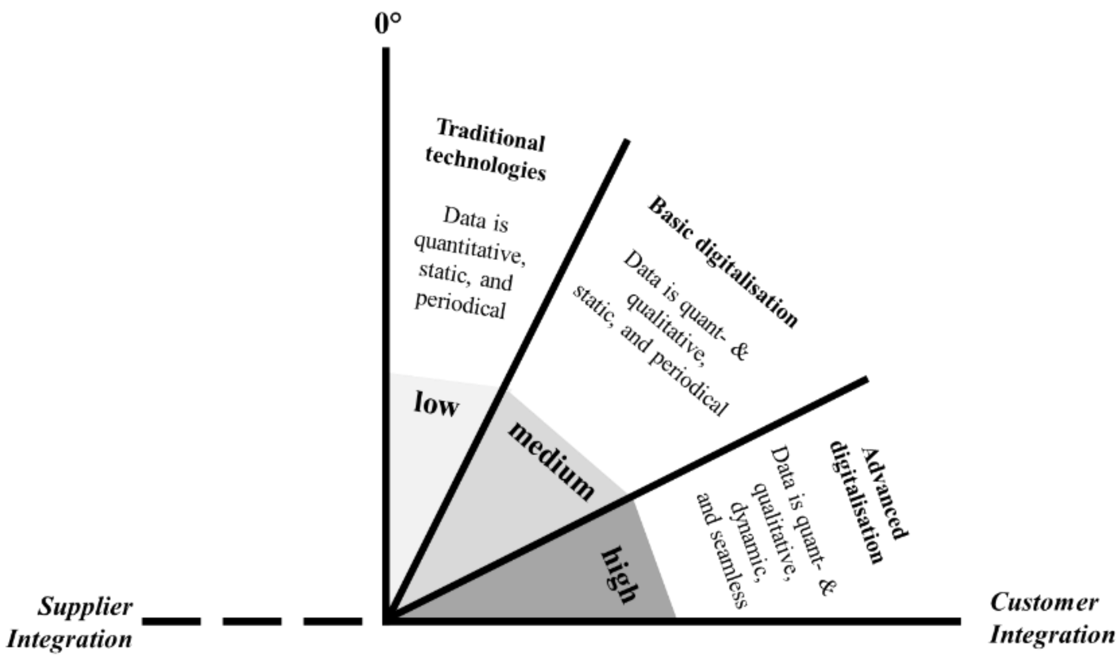

Figure 11. Arcs of digital customer integration

(1) Low customer integration is characterised by traditional, communication methods that lack velocity, scalability, and comprehensiveness (Attaran and Attaran, 2004). In this stage, interaction is primarily based on personal relationships and direct engagement to build trust, exchange information, and collaborate (Santos and D'Antone, 2014).

(2) Moving along the continuum, the medium customer integration arc leverages basic digitalisation technologies (Srai and Lorentz, 2019). Examples include periodic information sharing on data exchange platforms (Attaran and Attaran, 2004), or standardised communication channels (Lau and Lee, 2000). Data management, characterised by the efficiency of data gathering and information sharing processes, aligns with the basic digitalisation technologies but remain mainly on a quantitative level (Dominguez et al., 2014).

(3) At the apex of the model is high customer integration, which embraces advanced digitalisation technologies enabling timely and holistic replications of reality (Srai and Lorentz, 2019). Advanced data analytics (Agrawal et al., 2022), decentralised data access (Marzi et al., 2023), system integration (Thun, 2010), and digital representation, simulations, and behaviour monitoring (Agrawal and Narain, 2023; Andersson and Jonsson, 2018; Dolgui and Ivanov, 2023) facilitate a seamless exchange of vital information and provide a comprehensive view of customer demands (Bai et al., 2021). Furthermore, past buying process including situations, influences, and relationships can be grasped (Steward et al., 2019). Thus, technical prerequisites reach their zenith in the high integration arc and in line with the identified supply chain digitalisation concepts, this technological peak could be termed as digital twin of customer demands (Burgos and Ivanov, 2021; Dolgui and Ivanov, 2023; Maheshwari et al., 2023a; Oehlschläger et al., 2023b; Oehlschläger et al., 2021).

3.4.3 Contemplations on the Impact of Digital Customer Integration on Supply Management

As earlier explained, marketing’s transformation towards a management philosophy (Hsieh et al., 2008; Morgan, 1996), is accompanied by a change in mindset regarding the driving force of business activities: first by sales, then by markets, and ultimately by customers (Kumar et al., 2000). Although Sheth et al. (2009, p. 867) argued that an estrangement of a product-centric management philosophy means that ‘purchasing or sourcing becomes the internal supplier to the marketing department. Purchasing no longer is driven by the manufacturing process but by the marketing process’; the transference of these considerations to supply management lacks popularity. However, such reflections are already entrenched in cognate domains as Potter et al. (2015) discerned similar phases, each subject to the specific rational of a certain philosophical perspective, delineating the pivotal determinants of supply chain design and objectives. Another example is Bogers et al. (2016), who compared value-adding activities during the shift from a manufacturer-centric to a consumer-centric logic.

Building on these considerations combined with the previously described customer integration arcs, Figure 12 and Table 10 encapsulate the pivotal points where different customer integration philosophies spark enhancements and transformative shifts in the performance factors of supply management. This rationale corresponds to the scholarly discourse positing that digitisation precipitates the reassessment and adjustment of product-centric relationships (Jaworski and Kohli, 1993; Kamalaldin et al., 2020). It is thereby reasoned that the journey towards digital maturity illustrates how digital customer integration becomes a potent enabler for advancing supply management objectives from a product-, via a market-, to a customer-driven philosophy (Kumar et al., 2000; Potter et al., 2015; Ta et al., 2015).

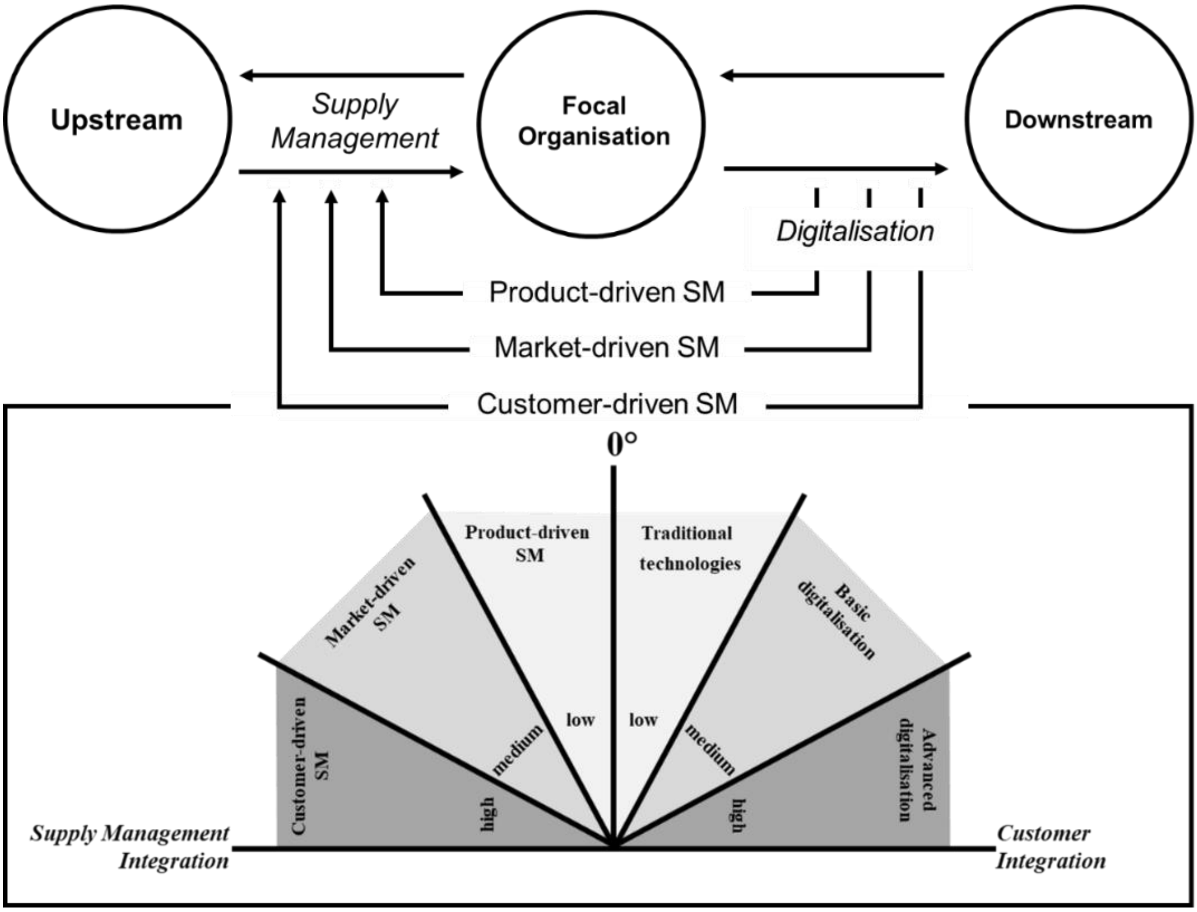

Figure 12. Schematic illustration of distinct customer integration philosophies in supply management

Table 10. Description of distinct customer integration philosophies in supply management

Philosophy	Product-driven	Market-driven	Customer-driven
Performance factors	▪ Delivery ▪ Process reliability ▪ Economies of scale ▪ Quality assurance ▪ Stock turn ▪ Operational costs	▪ Flexibility ▪ Uncertainty ▪ Sales ▪ Market penetration and share ▪ Lead-time ▪ Minimal disruption	▪ Cultivating distinct capabilities ▪ Value added ▪ Personalisation ▪ Novel business models ▪ Servitisation ▪ Customer retention
Segmentation	▪ Undifferentiated ▪ Mass market	▪ Differentiated ▪ Market segments	▪ Relationships ▪ Segments of one
Supply chain type	Functional	Agile	Customised
Impact type	Efficiency	Effectiveness	Transformational
Resultant	Output	Output	Outcome

At the initial stage, product-driven supply management activities are likely to be traditional and transactional (Saldanha et al., 2013). The themes of reliability, quality assurance, and delivery are fundamental at this level, emphasising the importance of meeting customer expectations at high processual efficiency (Reyes et al., 2023). Customer information is typically quantitative to combat adverse effects such as the infamous bullwhip effect (Dominguez et al., 2014; Lee et al., 1997). Hence, supply management can concentrate on managing a functional supply chain that generates reliable output for a generalised market in which customers are passive recipients (Ta et al., 2015).

When progressing to a (sales) market-driven philosophy, flexibility, responsiveness and effectively addressing uncertainties gain in importance (Shashi et al., 2020). supply management needs to focus on agile supply chain activities that emphasise on the effective creation of output at minimal disruptions (Shashi et al., 2020). Through basic digitalisation technologies, product development is refined and the initiation of servitisation efforts become more feasible (Holmström and Partanen, 2014; Vargo and Lusch, 2004). Performance factors include lead-time reduction, market penetration, and customer satisfaction, impacting loyalty, sales, and retention (Dadzie et al., 2005), contributing to the refinement of business cases.

Finally, in the advanced digitalisation stage of high customer integration, supply management activities undergo a profound transformation towards a customer-driven philosophy. Notably, insights transcend merely sharing quantitative information and encompass the creation of a qualitive understanding of demands; thus, impacting supply management on a strategic level. The emphasis on servitisation becomes a central theme, with a shift from output to outcome (Martinelli and Tunisini, 2019). This transition is aligned with cultivating distinct capabilities (Herhausen et al., 2020; Marcon et al., 2022), collaborating rather than transacting (Saldanha et al., 2013), exploring novel business models (Aspara et al., 2021; Bogers et al., 2016; Stahl et al., 2023), and creating value beyond traditional product offerings (Holmström and Partanen, 2014). Hence, supply chain activities have to be managed customised to the prevalent circumstances (Hsieh et al., 2008). This allows to maximise customer satisfaction, loyalty, and retention (Herhausen et al., 2020; Purmonen et al., 2023), contributing substantially to the competitive position of the procuring organisation (Rai et al., 2006). It should be noted that there are also critics of a customer-driven supply management philosophy, as narrowly adjusting value solutions to customer preferences, especially in long-term relationships, bears the hazard of excessive commitment which could limit an organisation’s operational flexibility (Christensen and Bower, 1996; Håkansson and Ford, 2002; Hsieh et al., 2008). Nonetheless, the customer centric level would fulfil Tunisini and Sebastiani’s (2015) desire that supply management’s responsibility is extended to all activities directed at creating and delivering customer value, a current void that was also observed by Jääskeläinen and Heikkilä (2019) as well as Kähkönen and Lintukangas (2012). Consequently, supply management should be inspired to think outside its prevailing box and extend the research scope on information system integration (e.g. Gunasekaran and Ngai, 2004; Kauremaa and Tanskanen, 2016; Korpela et al., 2013) which presently predominantly concentrates on upstream flows (e.g. Shou et al., 2018) and process automation (e.g. Glas and Kleemann 2016) with the downstream side as well.

3.5 Conclusion of the Literature Review on Digital Customer-Driven Supply Management

The present study constitutes a critical reflection on the inclusivity and openness of supply management research to up- and downstream perspectives. Hereby, the question was raised if supply management, in its current state, is embracing an ambilateral approach, as suggested Ellram et al. (2020), or is it, to some extent, blind on one eye? The metaphorical blindness refers to an imbalance in focus, with an exclusive concentration on upstream activities and a neglect of downstream aspects.

The findings of this work suggest that supply management, as discrete discipline, may indeed possess a monocular vision. The absence of articles from core supply management journals, the observed disconnect between academic discussions advocating for ambilateral focus against the actual mainstream discourse, and the historical inclination towards upstream considerations all contribute to the notion that supply management might not be fully embracing the importance of integrating downstream perspectives. While it might be too categorical to state that supply management is entirely blind on one eye, as a school of interdisciplinary studies on customer integration in supply management activities has been identified, there is a need for the discipline to further enhance its focus on digital customer integration.

Hence, this work initiates a discourse on customer-driven supply management as novel supply management philosophy. Evidently, organisations are progressively advancing towards higher levels of digital maturity (Bibby and Dehe, 2018; Glas and Kleemann, 2016; Porter and Heppelmann, 2015; Seyedghorban et al., 2020; Srai and Lorentz, 2019). Therefore, there is huge potential for supply management to leverage enhanced digital customer integration capabilities for its core activities. Since supply management's vision would then comprise actual end-customer demands and not distorted demands reported by the presently focalised internal functions or internal customers, customer-driven supply management could result in an enhanced management of order pipelines which will reduce supply chain volatility and strengthen supply pipelines (Purvis et al., 2014; Springer and Kim, 2010). Considering the fact that supply management considers itself strategic rather than functional (van Weele and van Raaij, 2014), it becomes essential to adopt a customer-driven philosophy and thereby do justice to its own ambitions (Chen et al., 2004).

Naturally, the literature review is not without limitations that particularly relate to the biases inherent to sampling, screening, and selecting literature (Durach et al., 2017). For instance, the rigidly defined inclusion and exclusion criteria may lead to the exclusion of relevant studies that do not precisely fit the predetermined criteria. Moreover, the present work is subject to the discussion concerning the very identity of supply management and its demarcation to SCM. One could argue that the conceptual blindness that this work accused supply management to possess, is an inherent characteristic of supply management, because supply management is originally construed on dyadic buyer-supplier relationships (Webster and Wind, 1972). Consequently, incorporating customer integration would turn this dyad into a triad, the smallest number of entities necessary for a network (Choi and Wu, 2009), and therefore, transcend the research domain from supply management to SCM (van

Weele and van Raaij, 2014), where the debate on customer integration is much more vivid and established (Marty, 2022). Nevertheless, this research was able to demonstrate that there is a need as well as great potential for supply management to reconsider the role of customers as critical drivers for its activities and strategies without losing its distinct identity.

To further advance the discourse on customer integration in supply management, there is a need for deliberate efforts to bridge this gap between the broader academic dialogue and contributions to the core journals of the discipline. This could involve fostering interdisciplinary collaboration, encouraging scholars to contribute to both mainstream supply management outlets and journals focused on downstream considerations, and revisiting the criteria for what is deemed publishable within the core supply management research community. Only through such endeavours can the field overcome potential blind spots and evolve towards the more holistic and ambilateral perspective of customer-driven supply management.

Altogether, the presented literature review not only scrutinises the existing state of downstream matters in the supply management literature but also proposes an indication for the multifaceted nature of digitalisation maturity in customer integration. Therefore, the present dissertation’s research topic is determined to be both relevant and still theoretically uncovered. Hence, this work will help optimising supply management activities and ensuring that the discipline, like Janus, gazes in both directions – upstream and downstream – fostering a truly ambilateral and customer-centric supply management philosophy.

4 Research Approach of the Dissertation

4.1 Introduction to the Dissertation's Research Approach

In the following, the research purpose and research questions are contoured, based on the previously identified research gap. Furthermore, delimitations are established and a synopsis of studies conducted to answer the research question is presented. By specifying focus, content, and depth about what the research will and will not cover expectations should be managed and misinterpretations avoided.

4.2 Research Gap

As it was thoroughly ascertained in the previous chapter, the existence of a customer-driven supply management philosophy is both pending and auspicious. Therefore, and in line with the calls on more academic debate on customer integration in supply management (Martinelli and Tunisini, 2019; Reaidy et al., 2020; Santos and D'Antone, 2014), this work aims to fill this conceptual void. At the same time, DTCDs are a novel technological method that promises to create an unprecedent and maximal level of integration and interaction in the supply chain, hence providing the necessary tools for customer-driven supply management.

This conceptual void calls for the development of a basic theorisation of the subject. By contemplating DTCDs as a capability or tool to improve interorganisational interaction and satisfy information processing needs, the theorised conceptualisation of DTCD will be theoretically embedded. This corresponds to Martinelli and Tunisini (2019, p. 29), who describe 'customer integration as a source of capabilities' and suggest that these capabilities constitute the alignment between supply and demand management – a topic that chapter 3 determined, still requires further research. This view is also shared by scholars like Flechsig et al. (2022),Hilletofth et al. (2009), Jüttner et al. (2006), Lorentz et al. (2020), Santos and D'Antone (2014), Walters and Rainbird (2004), or van Hoek et al. (2020, p. 3) who argue that 'while technology can enable progress in supply management, the question is how to use this to create meaningful new capabilities'.

4.3 Dissertation's Research Purpose and Research Questions

The purpose of this work is to fill the delineated blank space by anchoring DTCD in the theoretical landscape of supply management research, or in other words:

Explore the effects of customer-driven supply management facilitated by Digital Twins of Customer Demands

It is vital to begin with the establishment of a structured knowledge base regarding the theoretical conceptualisation of DTCD as facilitator of customer-driven supply management. This will allow for comprehending the customer-driven supply management as novel philosophical approach and link digital twins as its facilitator. Furthermore, a deeper understanding of DTCD usability is obtained. Hereby, value enablers are identified and evaluated. Finally, investigations regarding the impact of DTCD on various aspects of supply management are conducted. Accordingly, this dissertation raises the following three research questions which has been visualised by Figure 13 and will successively approach the overarching research goal.

RQ 1: *How could Digital Twin of Customer Demands enabled customer-driven supply management be conceptualised?*

RQ 2: *What are prerequisites for utilising Digital Twins of Customer Demands in supply management?*

RQ 3: *How are Digital Twins of Customer Demands impacting supply management's evolution towards customer-drivenness?*

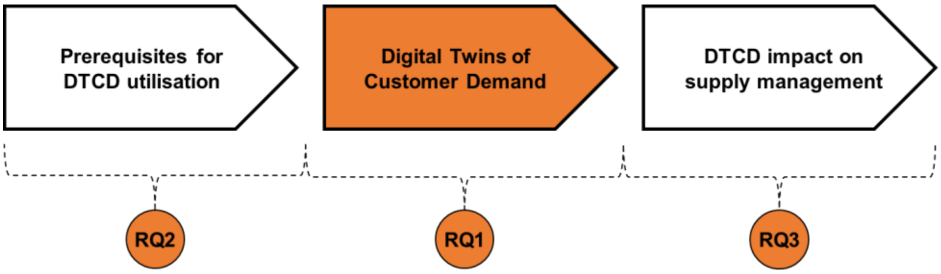

Figure 13. Overall dissertation research framework

4.4 Research Philosophical Principles of the Dissertation

The principles underpinning business science recognise the influence of key fundamentals on research endeavours. These principles, as articulated by Bell et al. (2018) and Easterby-Smith et al. (2012), shape the perception and examination of social reality in each research undertaking. They encompass considerations on the nature of constructs of interest, exploring issues of underlying objectivity (ontology), and what constitutes acceptable knowledge (epistemology) (Bell et al., 2018; Easterby-Smith et al., 2012; Saunders et al., 2019). When examining the impact of DTCDs on supply management, the investigation's complexity is apparent, with variations arising from contextual factors such as industry, customer base, and the social environment. Recognising these variations challenges the notion of defining reality as universally solid and treating research phenomena as independent constructs (Saunders et al., 2019). In this work, an ontological perspective influenced by social constructionism is embraced, emphasising the role of social actors in the accomplishment and sense-making of social phenomena (Bell et al., 2018). Despite this influence, from an axiological standpoint, the researcher endeavours to maintain objectivity, minimising biases and errors to facilitate the proposition of generalizable contributions (Bell et al., 2018; Saunders et al., 2019).

This approach aligns with the general case study setting of the dissertation, allowing for an inductive and in-depth analysis within a predefined context (Saunders et al., 2019). The complex and multidisciplinary nature of DTCD necessitates an acknowledgment of multiple meanings, interpretations, and realities within a dynamic setting of processes, experiences, and practices (Easterby-Smith et al., 2012; Saunders et al., 2019). Consequently, a mixed method of exploration is adopted, merging various types of knowledge, including but not limited to numerical, textual, and qualitative data. This approach entails the incorporation of multiple epistemologies, blending measurable facts and causal predictions with perceptions and interpretations (Saunders et al., 2019).

4.5 Delimitations and Scope of the Dissertation

Digital Twins are multifarious phenomena that could relate to different levels of analysis – from a single component to an entire network of systems (Dohrman et al., 2019). For the sake of an in-depth analysis without the need to compromise for width, this work will particularly emphasise on discrete Digital Twins. This means that the foremost object of analysis will be Digital Twins of tangible entities that have been created purposefully for managing customer demands. While these types of Digital Twins constitute self-dependent entities, they could also be interpreted as subset of a potentially larger 'system of systems' (Dietz and Pernul, 2020).

Furthermore, supply management is construed as a strategic field related to coordinating and overseeing the various flows between buyers and suppliers while aligning these with customer demand from an organisational perspective (Ellram et al., 2020). Please note that this work will therefore neither take an overall supply chain network perspective (as supply chain management does (Mentzer et al., 2001)) nor strive to optimise this network as such. Rather, emphasis is put on the activities and interactions of the focal organisation whose supply management gets affected through the Digital Twin of its (end-) customers' demand.

With business science being an applied field of study (Golden Pryor and Taneja, 2010), this dissertation intends to uphold its academic integrity and credibility, while simultaneously combining theoretical insights with managerial applications. Given the previously described contextual idiosyncrasies of Digital Twins, embedding the dissertation in a case study setting was reasoned to optimally balance rigor and relevance (Toffel, 2016).

In that regard, the clothing sector will be utilised as setting for empirical groundwork. Clothing is particularly affected by the continuously growing importance of e-commerce (Blázquez, 2014). In fact, the total volume of apparel sold online in the European Union grew by 93% in the previous five years from USD 78 billion in 2017 to USD 150 billion in 2022 (Eurostat, 2022). Moreover, in many EU countries the fraction of clothing items ordered online surpassed the share bought in physical stores (Eurostat, 2022). Technically, clothing products are a decent example for a good that should be easy to vend online, as the fact that the basic attributes of a particular clothing article can be researched prior to purchase, categorizes them as classical search good (Nelson, 1970). On the other hand, it can be argued that e-commerce transforms clothing from a purely search good to an experience good (Nelson, 1970; Ofek et al., 2011), or at least adds an experiential element to the purchasing process (Balaram et al., 2022). In an e-commerce setting, customers are unable to physically interact with the products before purchasing and thus rely heavily on product descriptions, images, and size charts to make purchasing decisions (Balakrishnan et al., 2014; Balaram et al., 2022; Su, 2009). This can introduce a level of uncertainty and subjective interpretation and thus, customers may not be able to fully assess attributes like the fit of the clothing item before buying (Balakrishnan et al., 2014; Su, 2009). Moreover, market leaders set standards for rapid order fulfilments while willingly accepting high return ratios if particular customer requirements cannot be accurately captured (Choi et al., 2004; Griffis et al., 2012; Hong and Pavlou, 2014). Consequently, many customers are ex post unsatisfied with their ex ante purchasing choice which explains why the return ratio of online ordered apparel is substantial (Su, 2009). According to some sources, more than half of all clothes bought online are returned (Asdecker, 2022; Ivanova,

2020) and could even loom to 70 – 80 per cent in the case of fashion (Asdecker, 2022). Generally, clothing articles bought online are three times more likely to be returned than clothes bought in-stores (Buhler, 2018).

Estimations for the German market reckon that every single product return that stems from e-commerce involves average costs of EUR 15.18 (EUR 7.25 in product value loss plus EUR 7.93 in process costs) (Asdecker, 2022). But also the total environmental impact of online returns is immense as each returned article is estimated to cause a medial emission of 849 g CO_2 (Asdecker, 2023). Studies suggest that the CO_2 emission of all returns in the US in 2019 was equal to that of 3 million cars driving for one year (Ivanova, 2020). Here, clothing has the lion share, as at least one-third of all returned articles bought online relate to apparel (Narvar, 2022). While other types of goods are typically returned due to the product being defect (Ahsan and Rahman, 2016; Buhler, 2018), size uncertainty is the major driver for apparel returns in e-commerce (some studies speak of more than 40% (Narvar, 2021)).

Hence, the clothing sector is a prime example for experiencing extant supply chain challenges such as the continuously growing importance of e-commerce (Blázquez, 2014), economic and ecological costs through product returns (Hjort and Lantz, 2016), and heterogenous and quickly changing customer demands (Jacobs, 2006; Walters, 2006a, 2006b). These challenges are not only inherent to fashion but also to workwear and protective clothing. In this regard, emergency service organisations such as police, fire authorities, ambulance services, and the defence sector (Carter, 2008), rely on specific clothing in the workplace to engage in challenging and critical situations. Since these situations are highly distinctive, each workwear product fulfils a specific purpose tailored to the respective individual requirements.

Altogether, the protective clothing sector was chosen as overall setting for this dissertation as its prevalent supply chain challenges are highly relevant, empirically observable, and could potentially be approached through DTCD (Gustafsson et al., 2021).

4.6 Synopsis of Studies that Compile the Dissertation

The research goal of exploring the effects of customer-driven supply management facilitated by a DTCD is approached through a concert of multiple theoretical and empirical studies. An overview of the research approach’s outline is given in Table 11.

Table 11. Outline of the dissertation's research approach

	Research Question	Purpose	Methodological Approach	Theoretical Contribution
1	How could Digital Twin enabled customer-driven supply management be conceptualised?	Conceptualise DTCD	*Conceptual*	*Conceptual*
2	What are prerequisites for utilising DTCD in supply management?	Explain DTCD utilisation	*Empirical*	*Theory Testing*
3	How are DTCD impacting supply management?	Explain DTCD impact	*Empirical*	*Theory Building*

4.6.1 RQ 1: Conceptualisation of Digital Twin enabled Customer-Driven Supply Management

The purpose of research question 1 is to elucidate and contextualise the central phenomenon. This will be achieved in form of a foundational framework for comprehending and characterising the role of Digital Twins in representing customer demands within supply management. This research question functions as groundwork for the preceding ones.

The first research question will be answered through a multi-method approach. Initially, a literature review, following the guidelines of Durach et al. (2017) and Webster and Watson (2002) will be performed. This literature review will build on the conceptual arcs and limits of customer integration and demand centricity concepts, that have been identified in chapter 3. The goal is to carve out the abilities provided by DTCD and clearly define their scope of application. Potential role models for structuring the findings could be the supply management digitalisation grid by Srai and Lorentz (2019), also adopted by Flechsig et al. (2022).

Due to the conceptual infancy of advanced digitalisation technologies in supply management research (Bhandal et al., 2022; Srai and Lorentz, 2019; van Hoek et al., 2020), a sound conceptualisation model can probably not be constructed on previous publications alone. Thus, a look at the contemporary industry perspective regarding DTCD might be necessary. Following Flechsig et al.'s (2022) example, a selection of case studies might help to identify drivers and application areas for pursuing DTCD in supply management. Thereby, the literature review's findings are enhanced by empirical insights. Table 12 adumbrates the presumed attributes of DTCD, as introduced in chapter 2.3.7, and how DTCD could enable customer-driven supply management.

Table 12. Digital Twin attributes and impact on customer-driven supply management

Digital Twin Attributes	Presumed Impact on Customer-Driven Supply Management
Timely collection and analysis of data	Swift adaptation to changing customer demands and market trends
Precise representation of entities	Enhanced decision-making by providing accurate insights on customer preferences
Continuously reception of feedback	Iterative and agile procedures
Connection of analytical and predictive methods	Proactive planning and resource allocation
Virtual involvement	Potential to customise value offerings
Ongoing monitoring, analysis, and optimisation	Identification of inefficiencies and allowing for continual refinement of the supply chain to effectively meet evolving customer needs

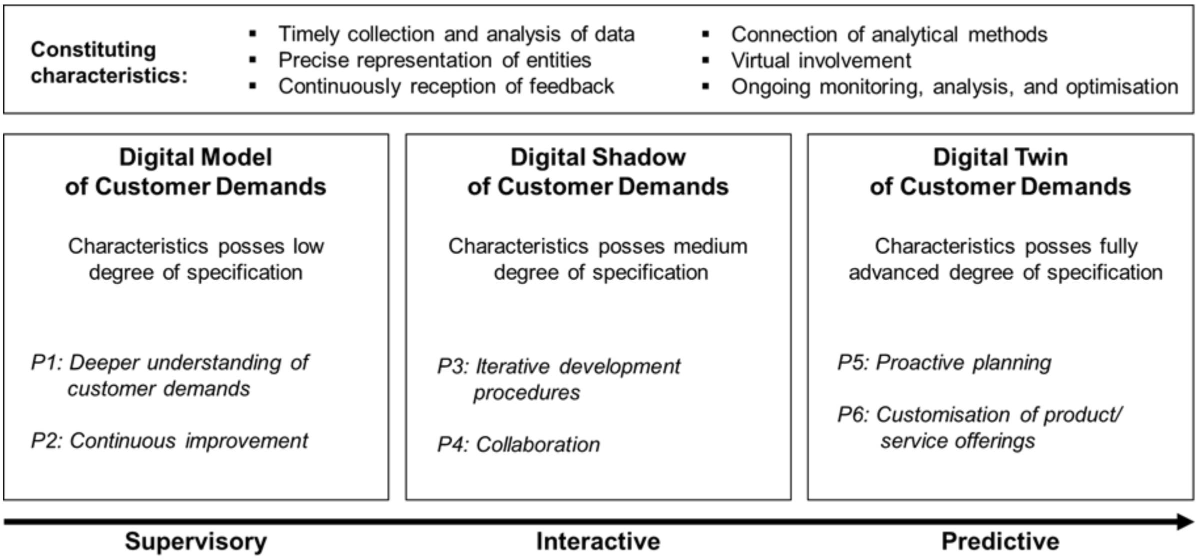

Figure 14. Prospect of the design of a potential DTCD framework

Building on the assumptions made in Table 12 as well as works such as Kritzinger et al. (2018) or Oehlschläger et al. (2021), Figure 14 gives a first prospect of a potential framework that illustrates how Digital Twins could enable customer demand integration in supply management.

4.6.2 RQ 2: DTCD Utilisation Prerequisites

The second research question engages in the usability of DTCD. This will be achieved through empirical work that identifies determinants that are crucial for DTCD establishment. These determinants will be adopted from extant theories and tested for transferability to the present circumstances. Table 13 gives an overview of the four determinants which are expected to be analysed for answering this research question. Each of these prerequisites has been already featured in a study conducted by this dissertation's author.

Table 13. Overview of DTCD prerequisites presumably investigated for RQ2

Prerequisite	Method	Publication Status	Outlet
Technical Proof of Concept	Experiment (n=63)	Published	3D body.tech 2022
Technology Acceptance	Survey (n=185)	Published	Industrial Management & Data Systems
Capabilities	Case Study (n=25)	Major Revision	Schmalenbach Business Review
Data Quality	World Café (n=16)	Published	IPSERA 2023
		Under review	Journal of Purchasing & Supply Management

Technical Proof of Concept

This study explores a smartphone application's feasibility to enable virtual human-product matchmaking within the context of organisational outfitting procedures, building on an experiment conducted in February 2021 with 63 participants. The experiment's data has been published in different outlets, for instance in the conference article Oehlschläger et al. (2022b). Results show that smartphone camera based 'scanners' supported by sophisticated algorithms provide a powerful tool for the creation of a DTCD.

Technology Acceptance

Successful implementation of DTCD necessitates users' technology acceptance. Building on the research stream on technology acceptance like the Technology Acceptance Model (Davis, 1993, 1989) or its subsequent extension the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003), an already conducted and published study (Oehlschläger et al., 2022a) contrasted three hierarchical DTCD with different degrees of user integration and examined determinants for their respective acceptance. Results show harmonious effects across Digital Twin levels. This indicates that technological radicality plays only a subordinate role when assessing acceptance determinants such as user perception on ease of use, usefulness, trust, and risk.

Capabilities

Emphasis will be put on investigating distinct capabilities that are both created through DTCD and needed for their usage in the supply management context. A potential theory to structure this approach is the Organisational Information Processing Theory (Galbraith, 1974, 1973). To be in line with the principles of grounded theory based explanatory and exploratory research, case studies seem to be the most auspicious methodological choice. That means, that an interview series will be conducted in which interview partners are approached that have knowledge on which capabilities are required for DTCD usage as well as how their exploitation could lead to distinctive capabilities for supply management.

Acquisition of High Quality Data

A key prerequisite for Digital Twin establishment is the access to high quality data, especially when data sources are outside the boundaries of the focal organisation. Therefore, Oehlschläger et al.'s (2023a) study is leveraged that investigated incentive mechanisms for the acquisition of high-quality data to build DTCD. Hereby, a focus group was invited to meet in form of a world café to discuss and evaluate which plausible mechanisms could be used to procure necessary data.

4.6.3 RQ 3: DTCD Impact on Customer-Driven Supply Management

Research question three picks up the conceptual model of DTCD-enabled customer-driven supply management as introduced as a result of research question 1. This model will be substantiated with empirical evidence and thereby further expanded. In line with the claims made in chapter 2.2.2, which build on the reasoning of works such as Jaworski and Kohli (1993), Jüttner and Christopher (2013), or Kohli and Jaworski (1990), a customer-driven management philosophy ultimately leads to more market responsive business practices. Additionally, Digital Twins have the potential to generate pervasive interorganisational connectivity (Lanzolla et al., 2020), leading to supply chain visibility, which was declared to be a key enabler of responsiveness from a supply chain perspective (Williams et al., 2013). Therefore, a clear and predefined thread to approach the third research question on supply management performance from both sides, marketing and supply chain, is choosing Holweg's (2005) dimensions of responsiveness: product, volume and process responsiveness.

With respect to product responsiveness, and in accordance with the extant literature, this dimension incorporates abilities to customise products (Bernardes and Zsidisin, 2008; Collins et al., 1998; Eggers et al., 2014; Parmigiani et al., 2011; Tu et al., 2001; Vanpoucke et al., 2014a; Yin et al., 2017), manage product lifecycles (Holweg, 2005), and guarantee the quality of newly developed products (Klassen and Angell, 1998; Martin and Grbac, 2003; Williams et al., 2013). This goes in line with a study recently conducted by the dissertation author (Oehlschläger et al., 2023b). Here, an experimental setting was used to analyse the impact of a DTCD on product responsiveness – defined as effectively satisfying heterogenous and idiosyncratic customer demands. A theory originating in production economics built the foundation to identify the economic effects of a DTCD as enabler of a new cost-performance window, visualised by Figure 15.

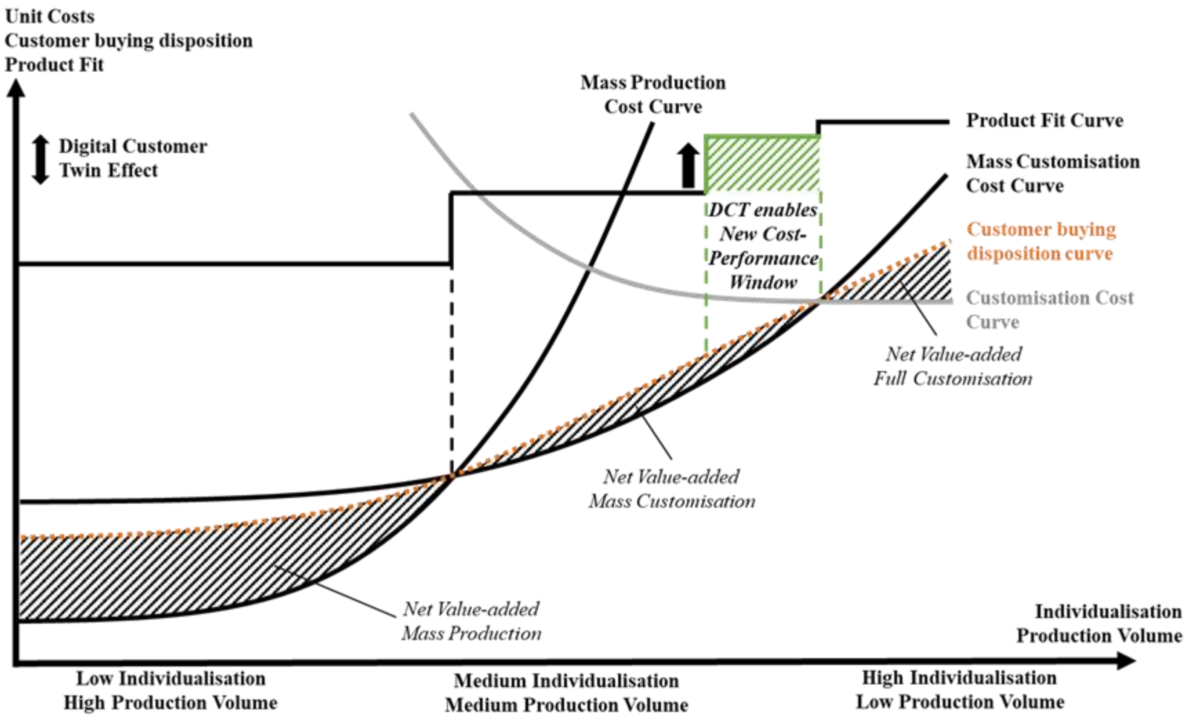

Figure 15. Economics of Digital twin based product responsiveness

Source Adopted from Oehlschläger et al., 2023b, p. 7

Volume responsiveness relates to the impact of DTCD on an organisation's ability to react to the timeliness of the movement of goods and services (Choi and Krause, 2006), shifts in delivered quantities, (Handfield and Bechtel, 2002; Vanpoucke et al., 2014a; Williams et al., 2013; Yin et al., 2017), product varieties (Bernardes and Zsidisin, 2008; Klassen and Angell, 1998; Williams et al., 2013), as well as the number of markets served (Klassen and Angell, 1998). Process responsiveness would emphasises on a DTCD's ability to alter processes in times of changing external circumstances (Choi and Krause, 2006; Gunasekaran and Ngai, 2005; Handfield and Bechtel, 2002; Klassen and Angell, 1998; Parmigiani et al., 2011; Schonberger and Brown, 2017; Vanpoucke et al., 2014a; Williams et al., 2013).

A simulation will be performed to investigate the impact of DTCD on process and volume responsiveness. Hereby, empirical data will be collected to compute a model that represents supply management processes with and without the usage of a DTCD.

This could provide insights into how DTCD could help to deal with fluctuations in demand, tackle product returns, and optimise order fulfilment times. Figure 16 gives a first glimpse on the anticipated findings regarding the impact of DTCD maturity on supply management performance.

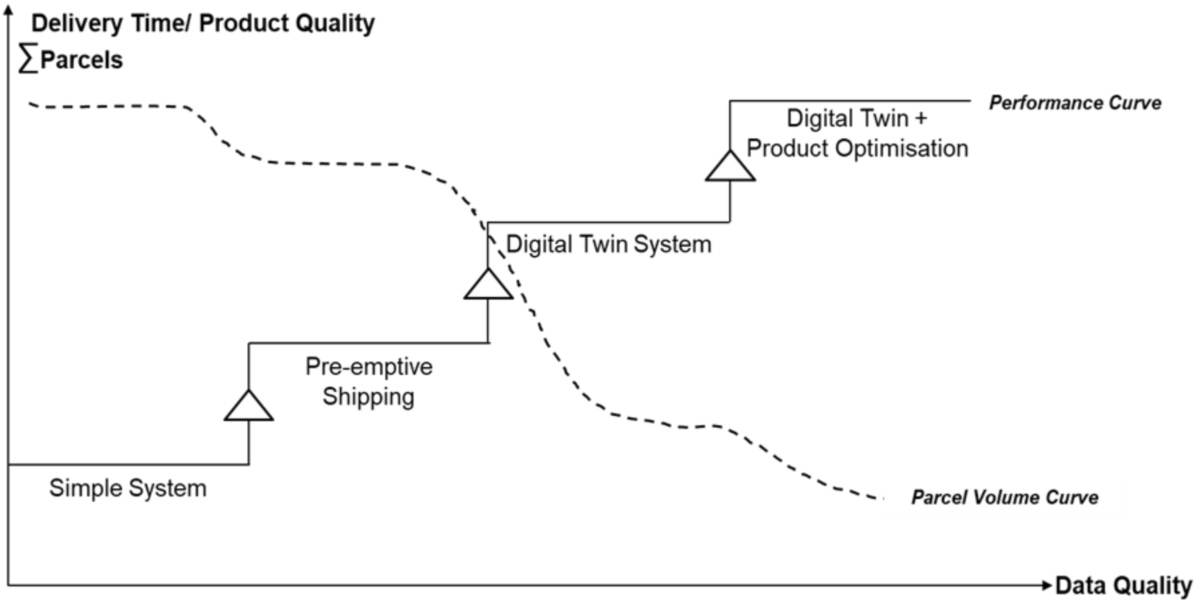

Figure 16. Anticipated findings regarding the impact of DTCD maturity on supply management performance

5 Overall Dissertation Structure

The dissertation is organised in six chapters as illustrated in Figure 17.

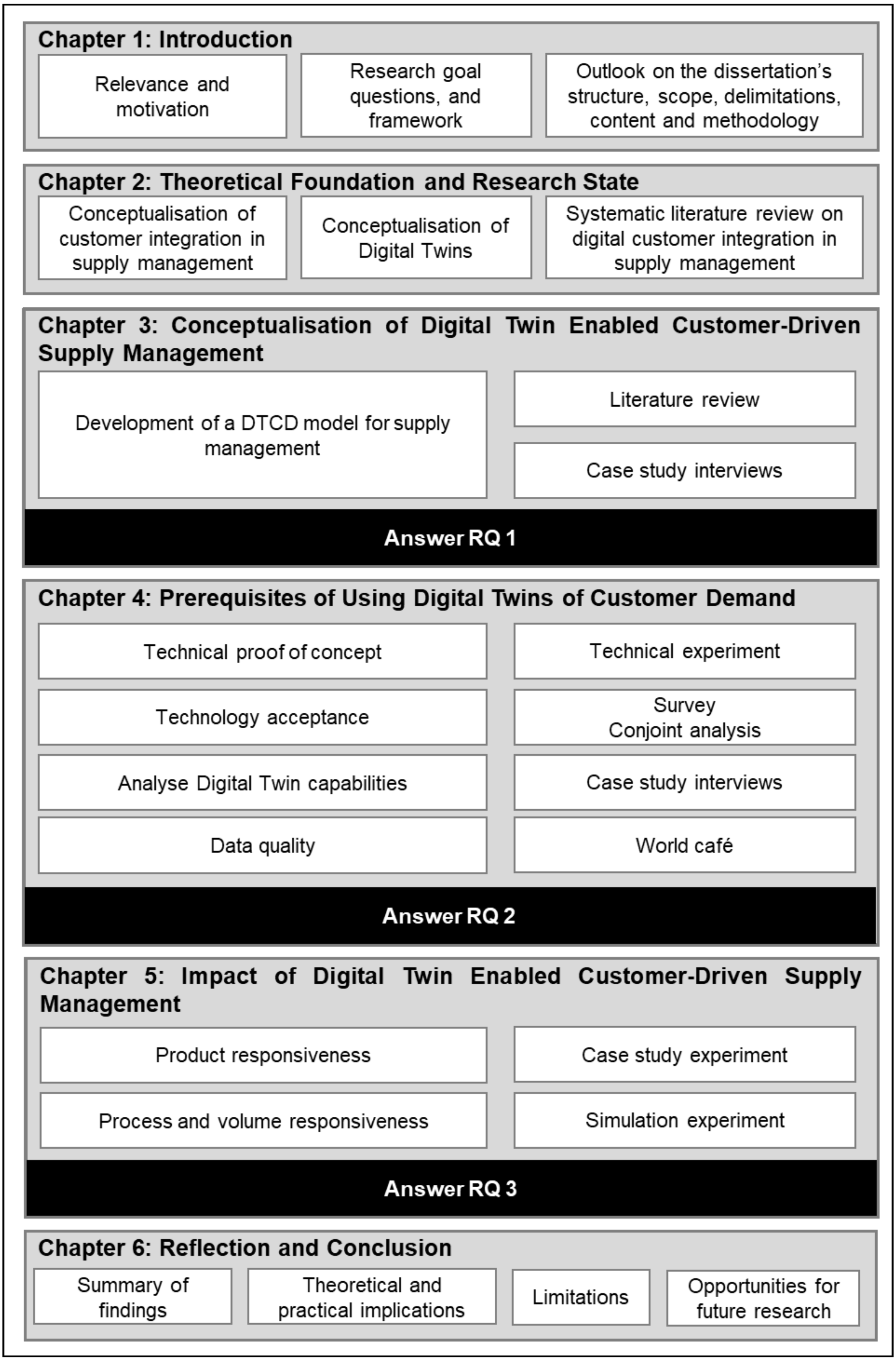

Figure 17. Dissertation structure

Analogue to the content of this working paper, the first chapter will describe the managerial and theoretical relevance by highlighting gaps in the extant research and potentials to enrich managerial understanding on DTCD. Research questions and the associated research framework are developed, and this work's scope and methodology are illustrated. In Chapter 2, a structured knowledge base is established through defining key concepts and describing the current state of the extant literature. In chapter 3, a DTCD model for supply management is developed through combining a systematic literature review with empirical data. Chapter 4 and 5 will contain empirical investigations. The fourth chapter will identify, analyse, and discuss value enabler for DTCD usability in the supply management context, while Chapter 5 illuminates how DTCD create value in supply management through demand satisfaction and supply chain performance. Finally, Chapter 6 reflects upon the empirical findings and discusses overall theoretical and managerial contributions of the dissertation.

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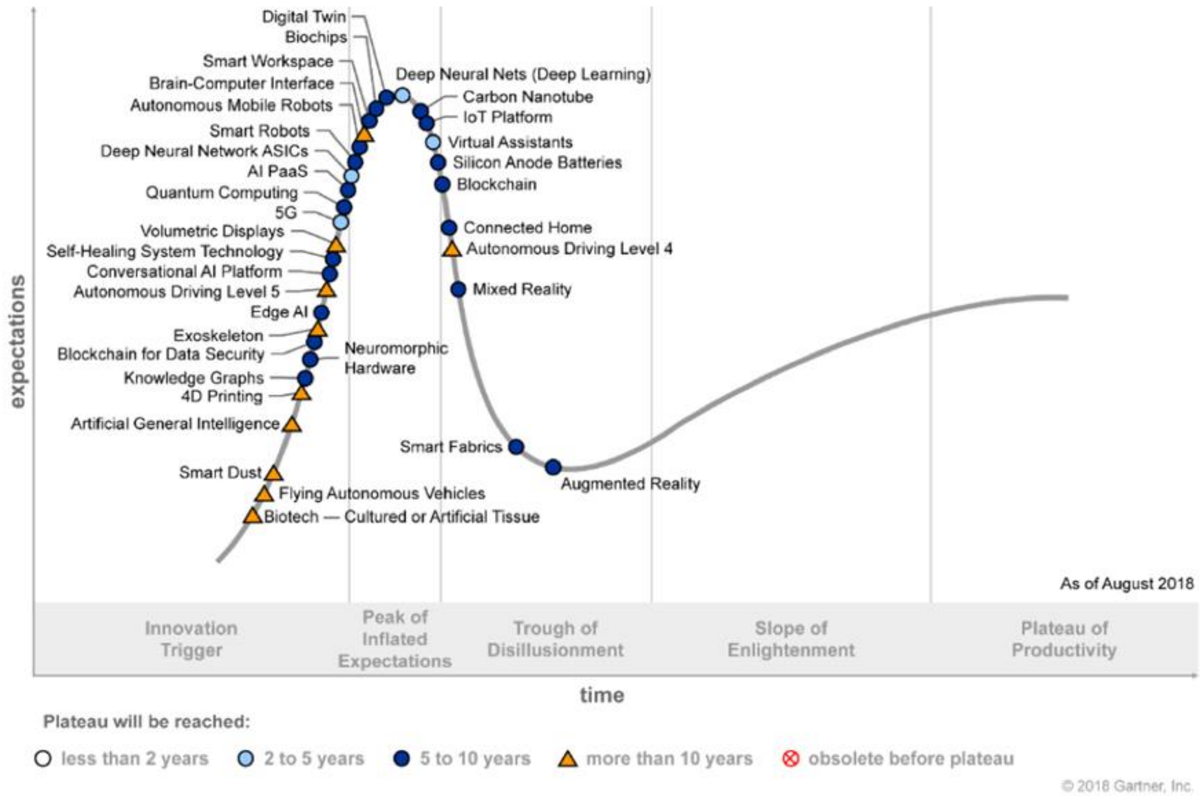
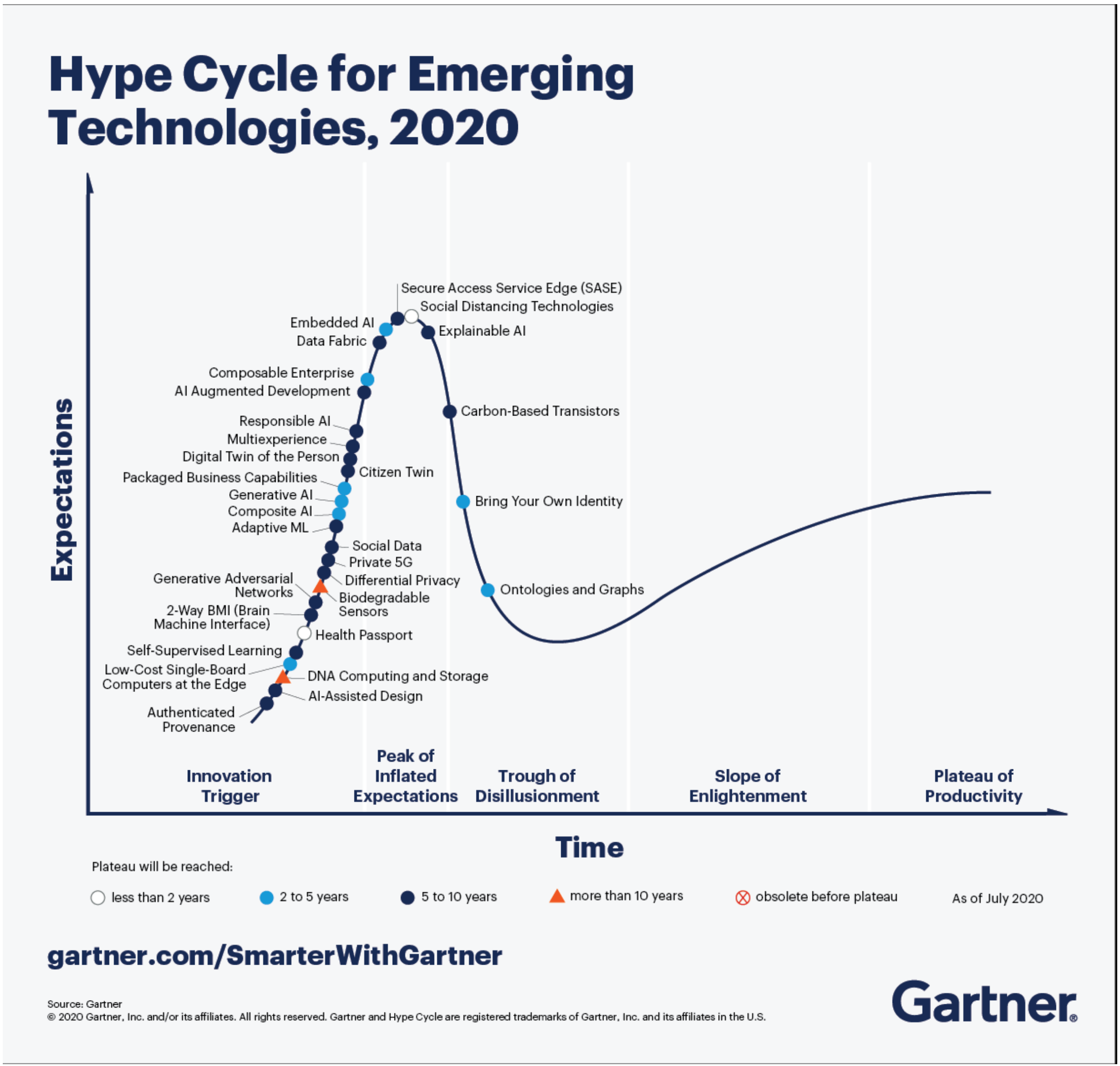
Appendix

A1 Hype Cycle for Emerging Technologies 2018



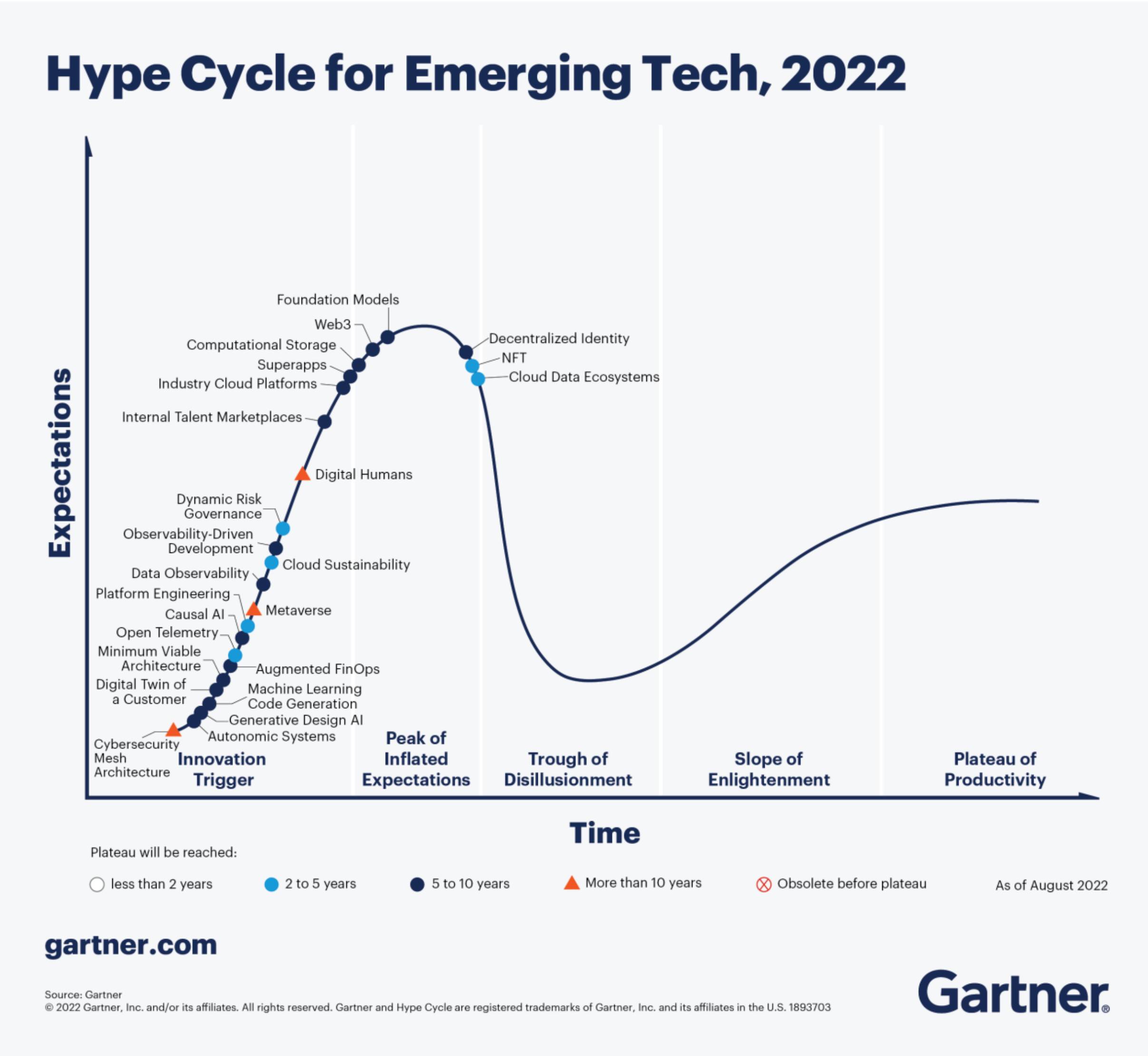
Source: Adopted from Costello and van der Meulen (2018)

A2 Hype Cycle for Emerging Technologies 2020



Source: Adopted from Gartner (2021)

A3 Hype Cycle for Emerging Technologies 2022



Source: Adopted from Gartner (2022b)

A4 Number of articles per journal in the refined sample

Journal	Refined sample
Industrial Marketing Management	16
Supply Chain Management: An International Journal	4
International Journal of Physical Distribution & Logistics Management	3
International Journal of Production Research	3
Journal of Business and Industrial Marketing	3
Business Process Management Journal	2
International Journal of Operations and Production Management	2
International Journal of Production Economics	2
International Journal of Productivity and Performance Management	2
Supply Chain Forum: An International Journal	2
Transportation Research Part E: Logistics and Transportation Review	2
Corporate Social Responsibility and Environmental Management	1
International Journal of Logistics Management	1
Journal of Business Logistics	1
Journal of Business Research	1
Journal of Manufacturing Technology Management	1
Journal of Supply Chain Management	1
Management Research Review	1
Manufacturing and Service Operations Management	1
MIS Quarterly	1
Production Planning and Control	1
Research Technology Management	1
Technological Forecasting and Social Change	1

A5 Comprehensive list of identified socio-technical prerequisites of digital customer integration

Terms		Definition	References
Social	**Collaboration**	Cooperative effort in which indi2viduals or groups work together to achieve a common goal or solve a shared problem	Agrawal et al., 2022; Agrawal and Narain, 2023; Aspara et al., 2021; Attaran and Attaran, 2004; Chong and Zhou, 2014; Dolgui and Ivanov, 2023; Feng et al., 2022; Gustafsson et al., 2019; Herhausen et al., 2020; Hsieh et al., 2008; Huikkola et al., 2020; Kamalaldin et al., 2020; Kazantsev et al., 2022; Marcon et al., 2022; Martinelli and Tunisini, 2019; Marzi et al., 2023; Piercy, 2009; Purmonen et al., 2023; Reaidy et al., 2020; Reyes et al., 2023; Santos and D'Antone, 2014; Shashi et al., 2020; Sjödin et al., 2018; Truong et al., 2012; Tunisini and Sebastiani, 2015
	Customer orientation	Business philosophy that places the customer's needs, satisfaction, and experience at the forefront of all decision-making and operations	Bai et al., 2021; Hsieh et al., 2008; Jääskeläinen and Heikkilä, 2019; Marcon et al., 2022; Martinelli and Tunisini, 2019; Purmonen et al., 2023; Sheth et al., 2009; Steward et al., 2019; Truong et al., 2012
	Technology acceptance	Willingness and readiness of individuals or organisations to adopt and use a new technological means	Boldosova, 2020; Chong and Zhou, 2014; Hasija and Esper, 2022; Mahlamäki et al., 2020
	Trust	Belief in the reliability, integrity, and honesty of a person, organisation, or system, leading to a confident and positive expectation of their actions and behaviours	Agrawal et al., 2022; Agrawal and Narain, 2023; Chong and Zhou, 2014; Hasija and Esper, 2022; Holmström and Partanen, 2014; Kazantsev et al., 2022; Martinelli and Tunisini, 2019
Technical	**Data gathering/ Information sharing**	Process of exchanging or disseminating data, knowledge, or insights between individuals, organisations, devices, or systems.	Agrawal and Narain, 2023; Agrawal et al., 2022; Andersson and Jonsson, 2018; Ardito et al., 2019; Aspara et al., 2021; Attaran and Attaran, 2004; Burgos and Ivanov, 2021; Dolgui and Ivanov, 2023; Feng et al., 2022; Gallear et al., 2008; Gallino and Moreno, 2018; Gawankar et al., 2020; Gustafsson et al., 2019; Gustafsson et al., 2021; Huynh, 2022; Kamalaldin et al., 2020; Lau and Lee, 2000; Maheshwari et al., 2023; Marcon et al., 2022; Martinelli and Tunisini, 2019; Martinez et al., 2019; Marty et al., 2023; Marzi et al., 2023; Rai et al., 2006; Reaidy et al., 2020 Reyes et al., 2023; Shashi et al., 2020; Thun, 2010
	Data processing/ Pattern detection	The act of organising, and manipulating data to produce meaningful information or insights including the identification of recurring or significant patterns, trends, or regularities within data or information	Agrawal and Narain, 2023; Agrawal et al., 2022; Akmal et al., 2022; Andersson and Jonsson, 2018; Ardito et al., 2019; Burgos and Ivanov, 2021; Dolgui and Ivanov, 2023; Feng et al., 2022; Gallino and Moreno, 2018; Huynh, 2022; Rai et al., 2006; Reyes et al., 2023
	Data quality	Level of accuracy, consistency, reliability, and completeness of data, ensuring that it is fit for its intended purpose and can be trusted	Agrawal et al., 2022; Gustafsson et al., 2019; Rai et al., 2006
	Digital representation/ Data visualisation/ Simulations	Graphical representations of data and information, such as charts, graphs, maps, and dashboards, designed to make complex datasets more understandable and accessible. Simulations are computer-based or mathematical models that mimic real-world processes, systems, or scenarios.	Agrawal and Narain, 2023; Agrawal et al., 2022; Burgos and Ivanov, 2021; Dolgui and Ivanov, 2023; Gallino and Moreno, 2018; Gustafsson et al., 2019; Gustafsson et al., 2021; Huynh, 2022; Reyes et al., 2023

Terms		Definition	References
	Decentral data access	A data management approach where data is distributed across various locations or nodes within a network, and authorised users or applications can access and retrieve data from these decentralised sources without relying on a central repository	Agrawal and Narain, 2023; Agrawal et al., 2022; Ardito et al., 2019; Lau and Lee, 2000; Marcon et al., 2022; Marty et al., 2023; Marzi et al., 2023; Reyes et al., 2023
	Distinct capabilities	unique and specific abilities and resources that enable a company to effectively collaborate with or meet the unique needs and requirements of its customers	Agrawal and Narain, 2023; Akmal et al., 2022; Bogers et al., 2016; Gustafsson et al., 2019: Holmström and Partanen, 2014; Huikkola et al., 2020; Huynh, 2022; Marcon et al., 2022; Marzi et al., 2023; Reyes et al., 2023; Sjödin et al., 2018; Tunisini and Sebastiani, 2015; Veile et al., 2022
	Interaction	Mutual communication, engagement, or influence that occurs between two or more individuals, entities, or elements, typically involving the exchange of information, actions, or reactions between the parties involved.	Agrawal and Narain, 2023; Agrawal et al., 2022; Ardito et al., 2019; Dolgui and Ivanov, 2023; Gustafsson et al., 2019; Gustafsson et al., 2021; Herhausen et al. 2020; Marcon et al., 2022; Truong et al., 2012: Veile et al., 2022
	System integration	Process of combining different software, hardware, or data systems and ensuring that they function together as a unified and cohesive whole, allowing seamless communication and data exchange between previously separate components or systems.	Akmal et al., 2022; Bai et al., 2021; Dolgui and Ivanov, 2023; Kamalaldin et al., 2020; Marcon et al., 2022; Piercy, 2009; Rai et al., 2006; Reaidy et al., 2020; Santos and D'Antone, 2014; Shashi et al., 2020; Sjödin et al., 2018; Thun, 2010; Tunisini and Sebastiani, 2015; Veile et al., 2022
	Behaviour monitoring/ Tracing/ Transparency	Visibility into the flow of goods, services, and information through systematic observation and analysis of customer interactions. This includes the ability to track the movement and status of objects.	Agrawal et al., 2022; Agrawal and Narain, 2023; Andersson and Jonsson, 2018; Ardito et al., 2019; Burgos and Ivanov, 2021; Choi et al., 2019; Dolgui and Ivanov, 2023; Feng et al., 2022; Gallear et al., 2008; Gallino and Moreno, 2018; Gawankar et al., 2020; Gustafsson et al., 2021; Huynh, 2022; Kazantsev et al., 2022; Lau and Lee, 2000; Maheshwari et al., 2023a; Martinelli and Tunisini, 2019; Martinez et al., 2019; Marty et al., 2023; Marty, 2022; Reyes et al., 2023; Shashi et al., 2020; Thun, 2010; Tunisini and Sebastiani, 2015

A6 Comprehensive list of identified performance themes of customer integration

Performance theme	Definition	Area	Share	References
Automation	Use of technology to perform tasks or processes without significant human intervention	PSM	0	/
		IM	1	Mahlamäki et al., 2020
		SCM	3	Agrawal and Narain, 2023; Hasija and Esper, 2022; Reyes et al., 2023
		Op.	1	Martinez et al., 2019
Business case development	Crafting a comprehensive and compelling rationale, supported by financial and non-financial evidence, to justify and guide the implementation of a specific business initiative or project.	PSM	5	Sheth et al., 2009; Sjödin et al., 2018; Steward et al., 2019; Truong et al., 2012; Tunisini and Sebastiani, 2015
		IM	3	Steward et al., 2019; Truong et al., 2012; Tunisini and Sebastiani, 2015
		SCM	2	Aspara et al., 2021; Veile et al., 2022
		Op.	2	Bogers et al., 2016; Gustafsson et al., 2019
Capability creation	Developing, acquiring, or enhancing the skills, resources, and competencies within an organisation to effectively address current and future challenges, enabling it to achieve strategic objectives and adapt to dynamic environments.	PSM	6	Jääskeläinen and Heikkilä, 2019; Marcon et al., 2022; Piercy, 2009; Sheth et al., 2009; Steward et al., 2019; Truong et al., 2012
		IM	5	Herhausen et al. 2020; Marcon et al., 2022: Piercy, 2009; Steward et al., 2019; Truong et al., 2012
		SCM	5	Agrawal et al., 2022; Bai et al., 2021; Hasija and Esper, 2022; Martinelli and Tunisini, 2019; Veile et al., 2022
		Op.	1	Martinez et al., 2019
Customer satisfaction	Positive perception, contentment, and fulfilment experienced by customers in response to their interactions with a product or service that intends to satisfy their demands.	PSM	2	Steward et al., 2019; Tunisini and Sebastiani, 2015
		IM	3	Boldosova, 2020: Steward et al., 2019; Tunisini and Sebastiani, 2015
		SCM	3	Agrawal et al., 2022; Bai et al., 2021; Reaidy et al., 2020
		Op.	4	Akmal et al., 2022; Gallino and Moreno, 2018; Gawankar et al., 2020; Gustafsson et al., 2019
Customisation	Tailoring products, services, or experiences to meet specific individual or customer group requirements.	PSM	0	/
		IM	0	/
		SCM	4	Agrawal and Narain, 2023; Aspara et al., 2021; Huynh, 2022; Reaidy et al., 2020
		Op.	2	Akmal et al., 2022; Bogers et al., 2016
Delivery	Managing the physical flows of goods from the point of origin to the final destination.	PSM	2	Gallear et al., 2008; Jääskeläinen and Heikkilä, 2019
		IM	0	/
		SCM	3	Aspara et al., 2021; Attaran and Attaran, 2004; Thun, 2010
		Op.	4	Gallino and Moreno, 2018; Gawankar et al., 2020; Gustafsson et al., 2019; Gustafsson et al., 2021

Performance theme	Definition	Area	Share	References
Flexibility	The ability of a system or process to adapt and respond promptly to changes, uncertainties, or varying demands, ensuring operational agility	PSM	3	Gallear et al., 2008; Jääskeläinen and Heikkilä, 2019; Marzi et al., 2023
		IM	1	Hsieh et al. 2008
		SCM	7	Agrawal and Narain, 2023; Agrawal et al., 2022; Bai et al., 2021; Huynh, 2022; Lau and Lee, 2000; Reyes et al., 2023; Santos and D'Antone, 2014
		Op.	4	Akmal et al., 2022; Andersson and Jonsson, 2018; Gawankar et al., 2020; Holmström and Partanen, 2014
Forecasting & Planning	The systematic analysis and projection of future trends, demands, or events, enabling organizations to make informed decisions and develop strategies for efficient resource allocation and operational preparedness	PSM	0	/
		IM	0	/
		SCM	7	Agrawal and Narain, 2023; Ardito et al., 2019; Attaran and Attaran, 2004; Dolgui and Ivanov, 2023; Hasija and Esper, 2022; Huynh, 2022; Maheshwari et al., 2023
		Op.	1	Andersson and Jonsson, 2018
Ideation / Product Development	Integrating customers in the creative process of generating refining, and implementing innovative ideas into tangible goods or services	PSM	1	Sjödin et al., 2018
		IM	0	/
		SCM	7	Agrawal and Narain, 2023; Ardito et al., 2019; Aspara et al., 2021; Bai et al., 2021; Chong and Zhou, 2014; Huynh, 2022; Santos and D'Antone, 2014
		Op.	1	Gawankar et al., 2020
Inventory management	Systematic control and oversight of a company's stock of goods, ensuring optimal levels are maintained to meet demand while minimizing holding costs and preventing stockouts	PSM	0	/
		IM	0	/
		SCM	2	Agrawal and Narain, 2023; Attaran and Attaran, 2004
		Op.	4	Andersson and Jonsson, 2018; Bogers et al., 2016; Gustafsson et al., 2019; Holmström and Partanen, 2014
Leaner Processes	Focuses on eliminating waste and optimising efficiency	PSM	0	/
		IM	0	/
		SCM	1	Reyes et al., 2023
		Op.	0	/
Loyalty/ Sales/ Retention	Ability of a business to maintain and foster ongoing relationships with its existing customers, encouraging their loyalty and repeat patronage over an extended period.	PSM	3	Marzi et al., 2023; Steward et al., 2019; Tunisini and Sebastiani, 2015
		IM	5	Boldosova, 2020; Herhausen et al. 2020; Purmonen et al., 2023; Steward et al., 2019; Tunisini and Sebastiani, 2015
		SCM	2	Aspara et al., 2021; Rai et al., 2006
		Op.	3	Gallino and Moreno, 2018; Gawankar et al., 2020; Gustafsson et al., 2019

Performance theme	Definition	Area	Share	References
Predictive analytics	Predict future outcomes, trends, or behaviour, providing valuable insights for decision-making and strategic planning.	PSM	0	/
		IM	0	/
		SCM	3	Agrawal and Narain, 2023; Ardito et al., 2019; Dolgui and Ivanov, 2023
		Op.	1	Andersson and Jonsson, 2018
Reliability	Consistent and dependable performance of a system, ensuring that processes are executed smoothly and efficiently with minimal variation or disruptions.	PSM	1	Jääskeläinen and Heikkilä, 2019
		IM	0	/
		SCM	2	Agrawal and Narain, 2023; Agrawal et al., 2022
		Op.	2	Akmal et al., 2022; Andersson and Jonsson, 2018
Risk management	Identification, assessment, and mitigation of potential uncertainties and threats to an organisation, aiming to minimise the impact of adverse events on its objectives and operations.	PSM	0	/
		IM	0	/
		SCM	4	Agrawal et al., 2022; Burgos and Ivanov, 2021; Choi et al., 2019: Reyes et al., 2023
		Op.	0	/
Servitisation enablement	The strategic transition of a product-centric business model towards one that emphasises the provision of integrated services, transforming the value proposition from selling products to delivering comprehensive solutions and customer-centric experiences.	PSM	6	Kamalaldin et al., 2020; Marcon et al., 2022; Piercy, 2009; Raddats et al., 2019; Sjödin et al., 2018; Tunisini and Sebastiani, 2015
		IM	6	Boldosova, 2020; Kamalaldin et al., 2020; Marcon et al., 2022; Piercy, 2009; Raddats et al., 2019; Tunisini and Sebastiani, 2015
		SCM	3	Chong and Zhou, 2014; Huikkola et al., 2020; Santos and D'Antone, 2014
		Op.	1	Holmström and Partanen, 2014
Speed/ Lead time	The total duration it takes for a product or service to move through a system, encompassing all processes from initiation to completion.	PSM	3	Gallear et al., 2008; Jääskeläinen and Heikkilä, 2019; Marzi et al., 2023
		IM	0	/
		SCM	6	Agrawal and Narain, 2023; Agrawal et al., 2022; Ardito et al., 2019; Bai et al., 2021; Choi et al., 2019; Santos and D'Antone, 2014
		Op.	3	Akmal et al., 2022; Gustafsson et al., 2019; Martinez et al., 2019
Sustainability	Maintaining ecological balance and meeting present needs without causing detrimental environmental, social, or economic effects.	PSM	2	Jääskeläinen and Heikkilä, 2019; Marzi et al., 2023
		IM	0	/
		SCM	5	Agrawal et al., 2022; Feng et al., 2022; Huynh, 2022; Marty et al., 2023; Reyes et al., 2023
		Op.	0	/

Performance theme	Definition	Area	Share	References
Uncertainty reduction	The process of minimising ambiguity and unpredictability in decision-making and operations	PSM	1	Gallear et al., 2008
		IM	0	/
		SCM	7	Agrawal and Narain, 2023; Bai et al., 2021; Choi et al., 2019; Chong and Zhou, 2014; Rai et al., 2006; Santos and D'Antone, 2014; Thun, 2010
		Op.	5	Akmal et al., 2022; Andersson and Jonsson, 2018; Gallino and Moreno, 2018; Gustafsson et al., 2019; Martinez et al., 2019