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## Article

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# How Digital Twins Impact Responsiveness: A Dynamic Fit Approach to Information Processing for High-Involvement Product Demand Management

Dominik Oehlschläger · Andreas H. Glas · Michael Eßig

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**Abstract** In an era of rapidly evolving customer demands and technological advancements, organisations face mounting pressure to enhance their responsiveness. Digital Twins offer novel capabilities by providing comprehensive transparency on customer demands through dynamic and interactive links between real-world entities and their digital counterparts. As a result, Digital Twins have the potential to enable organisations to respond more swiftly and effectively to fluctuating customer demands across volume, process, and product dimensions. However, Digital Twins still lack empirical explorations and theoretical embedment, leading to conceptual ambiguity. Through a case study approach, the study integrates Digital Twins into the framework of Organisational Information Processing Theory (OIPT). Empirical evidence proposes that Digital Twins offer a spectrum of capabilities rather than a one-size-fits-all solution. The findings further emphasise the need for aligning Digital Twin sophistication levels with Information Processing Needs and Constraints, highlighting that the dynamic interplay between Digital Twin advancements, Information Processing Constraints, and Information Processing Capabilities creates a dynamic cycle of adaptation and optimisation. On the whole, the study presents four key implications: (1) Awareness about the versatile application areas of Digital Twins is created. (2) The positive impact of Digital Twins on volume, process, and product responsiveness is outlined. (3) The concept of Information Processing Constraints is introduced to OIPT. And (4) a dynamic cycle of aligning Digital Twin sophistication with Information Processing Capabilities and Constraints is suggested. Therefore, the study contributes not only to a deeper understanding of Digital Twins in demand management but also proposes a new dynamic fit perspective on OIPT.

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## 1 Introduction

Ever since Darwin's *Origin of Species*, scholars are aware that the ability of an entity to thrive depends foremost on its capability to respond to uncertain and dynamic environmental circumstances (Megginson 1963; Holweg 2005; Santos Bernardes and Hanna 2009). In the business realm, customer demands constitute a major source of environmental dynamism (Srinivasan and Swink 2018). Customer demands are not only fluctuating, based on trends or technological and competitive pressures, they are also becoming increasingly idiosyncratic (Lanzolla et al. 2020). Consequently, a company's ability to effectively manage and respond to these uncertain demands became a crucial competitive factor (Shashi et al. 2020; Jacobs 2006; Walters 2008). The fashion retailer *Zara*, for instance, is known for its ability to design, produce, and distribute a new garment in as little as 15 days, enabling it to quickly respond to changing customer preferences (Caro and Gallien 2007). This responsiveness has allowed *Zara* to achieve a significantly higher inventory turnover ratio than the industry average (Taplin 2014).

The capabilities that enable effective demand management are typically provided by digitalisation technologies such as big data (Yu et al. 2021; Roßmann et al. 2018), cloud computing (Cegielski et al. 2012), internet of things (Birkel and Hartmann 2020), or blockchain (Martinez et al. 2019). A vivid example of how digitalisation-enabled capabilities shape organisational demand management is beverage giant *Coca-Cola*, who converts data about customer preferences obtained by its numerous touch screen soda fountains into updating its shelf-ready flavours (WARC 2018).

Among these digital advancements, the Digital Twin (DT) phenomenon has recently gained substantial scholarly attention (Ivanov 2020; Ivanov and Das 2020; Bhandal et al. 2022; Ríos et al. 2020). DTs implicate the capability to digitally replicate and engage with reality through contemporary information exchanges between physical entities and their digital counterparts (Tao et al. 2018; Kritzinger et al. 2018). DTs are not a single technology; rather they represent an interactive methodology that integrates a suite of management processes and technologies, collectively creating a dynamic and holistic replication of, and interaction with, reality (Grieves and Vickers 2017). Conceptually, a holistic replication of reality would eliminate uncertainty (Patil et al. 2024), establishing a definitive threshold for transparency with no further enhancement possible. Therefore, we argue that DTs are the ultimate enabler of transparency. Empirically, however, DTs are predominantly analysed from a technological standpoint (Bhandal et al. 2022; Kritzinger et al. 2018). Extant literature primarily focuses on providing a detailed view of their technical underpinnings (e.g. Ríos et al. 2020). From a management perspective, DTs remain notably ambiguous. The overwhelming application areas relate to manufacturing process monitoring (e.g. Negri et al. 2017) and life-cycle management of isolated

and unattached assets such as spacecrafts (e.g. Glaessgen and Stargel 2012) or wind turbines (e.g. Sivalingam et al. 2018). This results in a limited understanding of DT implications (Bhandal et al. 2022), especially as real-world application cases transcend towards all sorts of devices, systems, or even people (Bolton et al. 2018; Bhandal et al. 2022). Despite Datta's (2017) assertion that the potential applications of DTs are only limited by human imagination, their versatility is not yet reflected by the scholarly landscape. Therefore, this study examines DT applications beyond manufacturing and asset management and thereby seeks to broaden the discussion on DTs to customer demand management.

In this light, high-involvement products require meticulous responsiveness to individual customer needs (Martin 1998; Radder and Huang 2008) and thus stand to benefit particularly from the unique capabilities offered by DTs to replicate reality and create thorough transparency (Grieves and Vickers 2017). According to Martin (1998), high-involvement products are characterised by a psychological attachment between customer and products due to attributes such as uniqueness, quality, sensory appeal, interactivity, or facilitation. Types of high-involvement products are: (1) safety-critical products, where functionality directly impacts customer well-being (e.g. protective gear, assistive devices, or pacemakers); (2) emotional/symbolic products, where personalisation fosters brand loyalty; and (3) interactive products, where customer engagement drives effectiveness (e.g. wearables like fitness trackers). This study will focus on safety-critical high-involvement products, as they necessitate a particularly deep understanding of individual needs and active customer engagement to ensure effectiveness of both utilisation and demand management (Oehlschläger et al. 2024). A firefighter's helmet, for instance, must not only ensure precise fit and comfort but also offer critical protection under extreme and dynamic conditions. Similarly, modular protective clothing systems must accommodate diverse body types while maintaining performance integrity in high-risk environments. By integrating DTs with these products, organisations could unlock new levels of responsiveness, aligning operational processes with the dynamic needs of individual customers (Bolton et al. 2018).

To understand how DTs can impact the demand management responsiveness of high-involvement products, it is essential to frame their potential within a theoretical context that accounts for the interplay between customer-specific needs and an organisation's capabilities to effectively process information. Against this backdrop, Organisational Information Processing Theory (OIPT) (Galbraith 1973; Tushman and Nadler 1978) established itself as the primary framework to examine the interplay between Information Processing Needs (IPN) and Information Processing Capabilities (IPC). Adopting OIPT for this study's research approach, helps define responsiveness as the outcome achieved when an organisation's prevalent IPN are perfectly accounted for (Williams et al. 2013). To successfully manage customer demands, IPN relate to insights on factors such as individual needs and product life cycles, particularly including the utilisation phase, but also on manufacturing activities, material qualities, and the general flow of goods. IPC, on the other hand, are enabled by an organisation's ability to establish distinct internal (Rauniar et al. 2019) and interorganisational (Premkumar et al. 2005) mechanisms to gather, process, and exploit information (Daft and Lengel 1986; Bensaou and Venkatraman

1995). Against this backdrop DTs represent a method with substantial potential to augment IPC. However, while the technical enhancements of DTs are necessary, they are insufficient on their own to fully exploit IPC. That is why investigations from a management perspective are vital, yet absent. Consequently, this study fills this gap by building on the OIPT framework to shed light on the tangible impacts of DTs across key dimensions of demand management responsiveness. Building on this, the study further investigates the underlying mechanisms by which these impacts unfold, specifically examining the interaction of DTs with IPC. This leads to the following research questions:

**RQ1:**

***How do Digital Twins impact responsiveness to customer demands?***

**RQ2:**

***How is the impact of Digital Twins related to its interaction with information processing capabilities?***

By exploring these dynamics this study contributes to the existing literature on theoretical embedment of digitalisation methods and -capabilities such as Gunasekaran and Ngai (2004), Jharkharia and Shankar (2005), Prajogo and Olhager (2012), or Rai et al. (2006). But also extends research that connects integration pursuits with the widespread presence of transparency (e.g. Zhu et al. 2018; Williams et al. 2013), and organisational responsiveness (e.g. Williams et al. 2013; Wang et al. 2006; Gunasekaran et al. 2008; Swafford et al. 2008). As DT research is still mainly at the conceptual stage (Schleich et al. 2019; Klostermeier et al. 2019), the research questions are addressed through an exploratory approach built on an in-depth case study. By analysing and discussing empirical findings in light of OIPT, this work formulates five propositions on the manner how DT impacts demand management responsiveness. By introducing a dynamic fit, that complements the traditional IPN-IPC fit, the study also extends the present perspective on OIPT. Theoretical elaborations suggest that effective DT utilisation should involve a coordinated approach between IPN, IPC, and Information Processing Constraints, potentially eliminating the need for costly, ultimate transparency solutions.

## 2 Theoretical Background

### 2.1 Digital Twin Conceptualisation

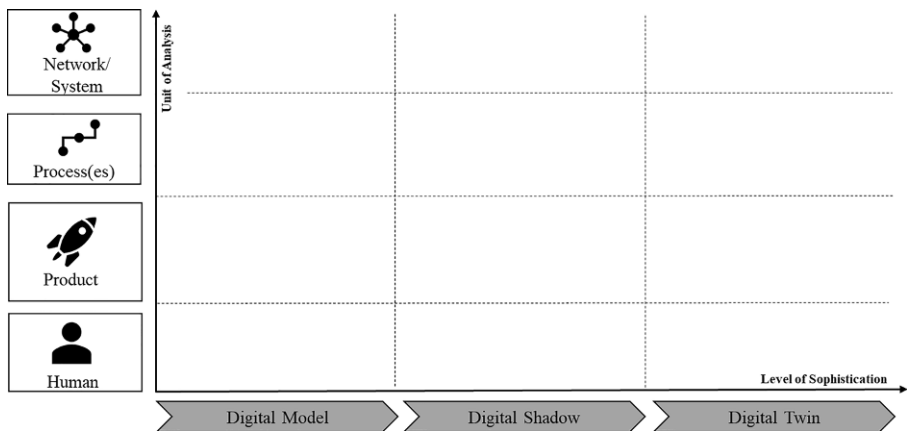
This work defines DT as the integration of distinct management and technological processes designed to holistically replicate and interact with reality, consisting of an original entity, its digital counterpart, and the flow of information that ties both together (Tao et al. 2018; Eigner et al. 2021; Gartner 2022; Kritzing et al. 2018). DT is conceptualised with respect to two dimensions:

- (1) *Unit of analysis* of the entity the DT is virtually replicating (Aheleroff et al. 2021). This is highly linked with the DT's scope and purpose. Four types of original counterparts are present in the extant literature: (a) *Human* (e.g. a virtual mannequin of a real person) (Kim and Forsythe 2008; Oehlschläger et al. 2024). (b) *Product*, a specific tangible object (Bolton et al. 2018; Olivotti et al. 2019; Parmar et al. 2020; Aheleroff et al. 2021). Examples range from complex goods (e.g. aircrafts) (Mandolla et al. 2019), modules (e.g. engines) (Liu et al. 2019), to components (e.g. engine discs) (Liu et al. 2019). (c) *Process*—a specific intangible object (Olivotti et al. 2019; Errandonea et al. 2020; Peruzzini et al. 2020; Aheleroff et al. 2021). Examples could be physical up-and downstream flows of specific goods (Brenner and Hummel 2017). (d) *Network or System*—a compound of several tangible or intangible entities (Bolton et al. 2018; Greif et al. 2020; Peruzzini et al. 2020; Fan et al. 2019; Ivanov 2020). By analysing demand management for high-involvement products as contextual setting, this study will explore DTs that interact with customer demands across the human, product, and process units. This approach allows for an in-depth exploration of a unique type of DT, distinctly different from traditional use cases.
- (2) *Level of sophistication* defines the nature of the DT's constituting characteristics, namely connectivity, simulation enablement, and dynamic interaction (Tao et al. 2018; Cimino et al. 2019; Ríos et al. 2020; Aheleroff et al. 2021; Agrawal et al. 2022). These characteristics manifest themselves in a spectrum, depending on factors such as velocity, data flow direction, or analytical capabilities (Kritzinger et al. 2018; Oehlschläger et al. 2024; Cimino et al. 2019). With respect to the characteristics' combined levels, a tripartite notation has been established by the extant literature (Kritzinger et al. 2018; Cimino et al. 2019; Errandonea et al. 2020; Aheleroff et al. 2021; Ríos et al. 2020; Oehlschläger et al. 2024): *Digital Model*—A basic DT construct or a DT Level I (e.g. a 3D model of a firefighter's helmet used for design and visualisation); *Digital Shadow*—An intermediate version of the DT construct or a DT Level II (e.g. sensor data from the helmet tracking parameters during a live operation); and *Digital Twin*—The strictest and most advanced version of the DT construct or a DT Level III (e.g. a real-time, interactive, and predictive replica of the helmet with bi-directional information flow).

Please note that the terminology refers to a continuum of sophistication within the broader Digital Twin framework, rather than distinct, standalone constructs: Each level builds upon the previous one, progressively incorporating more advanced capabilities. In this light, the term *Digital Twin* serves dual purposes: it can describe the overarching concept of virtual representations (including Digital Models and Shadows) and also denote the most advanced tier within this conceptualisation. Conceptually, the Digital Twin in its strictest form embodies the ultimate level of sophistication across all its characteristics. However, real-world use cases are not always as distinct as this classification suggests; a DT implementation may incorporate features from various levels—some advanced, others more basic, continuously evolving as technologies and their applications mature. To account for this gradient-like nature, the presence of these characteristics, even in their simplest forms, is sufficient to classify a construct as a *Digital Twin*. Therefore, 'DT' will be used

**Table 1** Constituting characteristics of a Digital Twin and its levels of sophistication

Characteristic	Definition	Level of sophistication		
		Level 1 <i>Digital Model</i>	Level 2 <i>Digital Shadow</i>	Level 3 <i>Digital Twin (s.str.)</i>
<b>Connectivity</b>	Values of one system converge with the respective values of its counterpart and remain in step with each other (Pecora and Carroll 1990)	Data is transferred manually and monodirectional	Data is transferred with medium automation and monodirectional	Data is transferred with full automation and bidirectional
<b>Simulation enablement</b>	Multi-physics, multi-scale, probabilistic models (Tao et al. 2018; Cimino et al. 2019)	Basic simulation of a given entity	Simulations of interrelated entities	Overarching simulations including distantly related entities
<b>Dynamic interaction</b>	Actively engage with and respond to the physical counterpart and other integrated system (Agrawal et al. 2022)	Descriptive: Detailing what is happening	Diagnostic: Explaining why something happens	Predictive and prescriptive: Forecasting what will and recommending what should happen

**Fig. 1** Digital Twin conceptualisation matrix

as a general term for the overarching construct, while ‘*Digital Twin (s.str.)*’ (sensu stricto) will specifically refer to the most advanced level of the DT framework.

Table 1 outlines and defines the key characteristics of a DT along with their corresponding levels of sophistication. Furthermore, Fig. 1 illustrates both dimensions of the DT conceptualisation. The vertical axis visualises the realm in which DT application cases could be located. The horizontal axis indicates the DT’s levels of sophistication, as explained in Table 1. Given the heterogeneous interpretations of the DT phenomenon, this proposed conceptualisation represents just one of many



possible approaches (e.g. van der Valk et al. 2020; Aheleroff et al. 2021; Freese and Ludwig 2024). Typically, these frameworks capture a bandwidth between ‘basic’ and ‘exhaustive’ DT ‘archetypes’ (van der Valk et al. 2022). Here, the present study’s chose to follow the aforementioned tripartite differentiation.

With respect to Fig. 1, this work’s case study setting applies humans (customers), products, and processes as DT units of analysis. All interviewed cases incorporated a human DT of the customer, defined as the recipient of high-involvement products. The human DT was created by obtaining individual body-dimensions and respective fields of activity, as expressions of their particular demands—fitting the earlier introduced definition of high-involvement products. Furthermore, three different product DT types are contemplated in the case: (1) A surrogate for all products with the same specifics as those held in stock; (2) A specific product that is either in stock or distributed to the end customer and linked to the overall system; (3) An intangible prototype used for the development of a new product. Process DTs are present in the context of data transparency through virtual comprehension of manufacturing and delivery processes. While network DTs were absent from the discussions, the recurring theme of interorganisational data sharing suggests an implicit acknowledgment of network dynamics. Altogether, the case’s application fits the DT conceptualisation as introduced by Fig. 1.

It is noteworthy that the DT conceptualisation of Table 1 and Fig. 1 builds on studies that predominantly investigate DT from a technical point of view as managerial research is still in its infancy (Bhandal et al. 2022; Errandonea et al. 2020; Oehlschläger et al. 2024; Holopainen et al. 2024). Most contributions to this discipline address manufacturing topics (Bhandal et al. 2022) and are either conceptual explanations (e.g. Barykin et al. 2020) or simulation experiments on macro-level uncertainty (e.g. Ivanov and Dolgui 2021). As of 2024, only a small fraction of the SCOPUS-listed business science journal articles empirically investigates DT and address non-technical management issues. An overview of these studies is provided by Table 2. Please note that Table 2 explicitly lists empirical management studies only, omitting both management but conceptual and empirical but technical articles.

Most of these studies aim to identify drivers of DT adoption (e.g. Oehlschläger et al. 2024). Other major performance measures were resilience (e.g. Burgos and Ivanov 2021), innovation management (e.g. Holopainen et al. 2024), and process efficiency (e.g. Francisco et al. 2020). Notably, theory is almost completely absent from DT discussions. Customer demands, while frequently mentioned, are typically not the central focus of research. For example, Burgos and Ivanov (2021), Freese and Ludwig (2024) and Patil et al. (2024) view customers as passive supply chain components who benefit from overall efficiency gains, and would even be indirectly affected by enhanced supply chain transparency, but do not go into detail what that would explicitly mean for customers. D’Amico et al. (2023) name enhancing customer satisfaction as one of the indirect drivers for DT adoption, which gets fulfilled by enhancing process efficiency. A more concrete approach is used by Francisco et al. (2020), who quantitative customer energy demands as key parameter the DT keeps track of, and Oehlschläger et al. (2024) who make DT of customer demands their core construct and argue that without customer adoption willingness, DT adoption is impossible. Similarly, Korotkova et al. (2023) claim that DT value has to be



**Table 2** Review of Digital Twin management studies that are empirical and non-technical

Case context	Core concept	Method	Unit of analysis	Theory	Mentions customers?	Citation
Construction	Adoption & potential	Design science	Product	n. a.	No	Agrawal et al. (2022)
Retail	Resilience	Simulation	Supply chain	n. a.	Yes	Burgos and Ivanov (2021)
	Adoption & potential	Survey and interviews	Process	n. a.	Yes	D'Amico et al. (2023)
Infrastructure	Efficiency	Simulation	Process	n. a.	Yes	Francisco et al. (2020)
Logistics	Adoption	Interviews	Supply chain	n. a.	Yes	Freese and Ludwig (2024)
Infrastructure	Description	Interviews	Process/Product	n. a.	No	Broo and Schooling (2023)
Cross-case	Innovation	Interviews	Process	None	Yes	Holopainen et al. (2024)
Oil & gas	DT acceptance	Interviews	Supply chain	Innovation diffusion	Yes	Korotkova et al. (2023)
Textile	DT acceptance	Survey, Structural equation model	Human	Technology acceptance model	Yes	Oehlschläger et al. (2024)
Manufacturing	Sustainability	Survey, Structural equation model	Supply chain	Complex adaptive systems	Yes	Patil et al. (2024)
Manufacturing	Value creation	Interviews	Network	n. a.	Yes	Rantala et al. (2023)
Manufacturing	DT adoption	Delphi	Process	n. a.	No	Saporiti et al. (2023)
Manufacturing	Efficiency	Delphi	Process	n. a.	Yes	Timperi et al. (2023)
Manufacturing	Innovation	Delphi	Network	Cognitive load theory	No	Van Dyck et al. (2023)
Agriculture	DT adoption	Weighted influence non-linear gauge system	Supply chain	Technology-organization-environment	No	Yadav and Majumdar (2024)
Architecture	Decision making	Interviews	Process	n. a.	Yes	Yan et al. (2022)

explained to customers who should contribute to feeding it with data, as it is otherwise perceived as unnecessary burden. Different value creation modes of DTs for customers is touched upon by Rantala et al. (2023). These typically correspond to Yan et al. (2022), who argue that customers can use the DT to optimise their purchasing decisions, Holopainen et al. (2024), who found that DTs enhances customer interactions, helping customers to visualise products and companies to better understand customer demands, and Timperi et al. (2023) who explains DT-enabled customer collaboration and customer-driven configurations during manufacturing.

Altogether, most articles on DTs focus on technical aspects and even the managerial ones tend to be largely conceptual and lack theoretical grounding. While the relationship between DTs and demand management has been touched, it has not yet been comprehensively analysed. Furthermore, no study was identified that embedded the impact of DTs into OIPT or any other grand theory. Consequently, this work advances managerial research on DTs by integrating them into the larger OIPT framework and providing empirical insights beyond manufacturing process monitoring.

## 2.2 Demand Management Responsiveness in Light of OIPT

OIPT propagates that organisations process information to attenuate the adverse effects of uncertainty (Daft and Lengel 1986; Galbraith 1974), meaning that the respective uncertainty of a given context drives the organisation's IPN (Lorentz et al. 2020; Bode et al. 2011; Foerstl et al. 2018; Busse et al. 2017). In contrast to studies such as Burgos and Ivanov (2021) or Ivanov and Dolgui (2021), who investigate the role of DTs for dealing with macro level uncertainties (Flynn et al. 2016) that are uncontrollable by the focal organisation (e.g. natural disasters), this work emphasises on demand management IPN. This relates to uncertainties on the needs of individual customers as well as on management processes installed to satisfy these needs (Flynn et al. 2016). Furthermore, OIPT argues that organisations aim for a perfect alignment (or fit) between their IPN and IPC, which, in turn, enhances organisational performance (Galbraith 1973; Tushman and Nadler 1978).

In this light, a typical OIPT performance measure is responsiveness (Williams et al. 2013; Yu et al. 2019). Although responsiveness has been addressed by many studies, it is often poorly defined, and many scholars use it as a synonym for agility or flexibility (Santos Bernardes and Hanna 2009). In line with Holweg (2005), the present study perceives responsiveness as inherently customer-centric concept. However, to prevent any misunderstanding, the term demand management responsiveness will be used. For the sake of clarity, and following Reichhart and Holweg (2007)'s proposition, the responsiveness concept is defined with respect to three dimensions that collectively determine an organisation's ability to meet customer demands: (1) Volume responsiveness, the ability to react to the timeliness of the movement of goods and services (Choi and Krause 2006) and shifts in delivered quantities, (Williams et al. 2013; Vanpoucke et al. 2014; Yin et al. 2017; Handfield and Bechtel 2002). (2) Process responsiveness, the response capabilities of manufacturing and logistics operations (Choi and Krause 2006; Schonberger and Brown 2017; Parmigiani et al. 2011). (3) Product responsiveness, the ability to customise

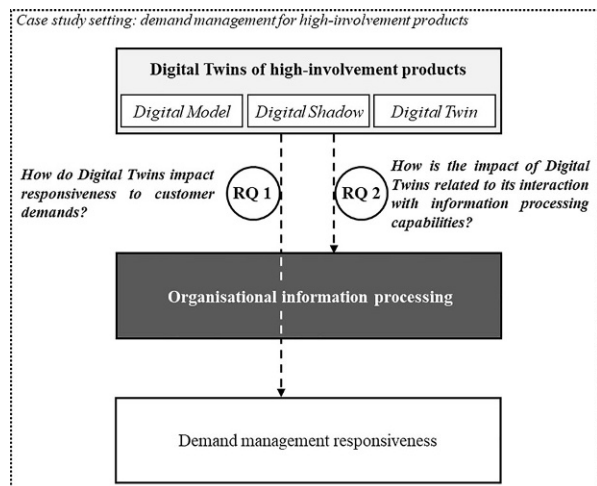
products (Yin et al. 2017; Collins et al. 1998), manage product lifecycles (Holweg 2005), and guarantee the quality of newly developed products (Martin and Grbac 2003; Klassen and Angell 1998).

To achieve an IPN-IPC fit, and ultimately responsiveness, the present study will follow Bartnik and Park (2018), who found that firms tend to prioritise investments that bolster their IPC over those aimed at diminishing their IPN. Similarly, most recent OIPT studies analyse how diverse digital technologies provide organisations with distinct IPC. Cegielski et al. (2012) demonstrates how cloud computing enables scalable and decentral information accessibility. Srinivasan and Swink (2018) or Schlegel et al. (2021) show how big data provides organisations with analytical capabilities on vast volumes of diverse data. Dubey et al. (2020) propagate secure data transfer and trust as IPC in the context of blockchain.

In contrast to these technologies, we consider DT as integrative and interactive method, that epitomises transparency and thus has the potential to engage with IPC in new and distinct ways. As previously described, empirical business science studies exploring this interaction are notably absent.

This work seeks to address that gap by exploring the relationship between DTs and IPC in the context of high-involvement product demand management, which is also visualised by Fig. 2. In the prevalent case study, OIPT is leveraged to explore DT as highly contemporary technological phenomenon whose capabilities are substantially impacting an organisation's IPC, in order to address the specific IPN associated with customer-specific demands of high-involvement products (Martin 1998). This not only enhances the general understanding of how demand management can become more responsive, but also delves into the black box of organisational information processing, providing scholars and managers with explanations on how the potential impact of DTs unfolds.

**Fig. 2** Research framework



### 3 Methodology: A Case Study Approach to Demand Management for High-Involvement Products

#### 3.1 Research Design

DT is a new and complex phenomenon that has been subject to scarce managerial research, requiring a deep conceptual understanding of its capabilities and interactions (Bhandal et al. 2022; Gupta et al. 2022). Thus, an in-depth case study approach was chosen (Eisenhardt 1989; Meredith 1998; Ketokivi and Choi 2014). It is reasoned that demand management for safety-critical high-involvement products, such as medical devices, protective equipment, and clothing (Martin 1998), provides an auspicious contextual setting to observe the nuanced capabilities of DTs. Effective demand management ensures high customer satisfaction through timely and high-quality product availability while maintaining overall operational efficiency (Jüttner et al. 2007; Treville et al. 2004). Furthermore, high-involvement products, which require a substantial understanding of individual needs, present unique challenges in information processing and require responsive managerial capabilities (Martin 1998; Radder and Huang 2008). Analysing the impact of DTs in this context allows for a deeper exploration of how they can enhance transparency, coordination, and adaptability within complex organisational environments. Thus, this setting is ideal for establishing in-depth knowledge on how DT-enabled capabilities can address the specific information needs of demand management and thereby improve responsiveness.

As shown in Table 3, issues relating to qualitative data subjectivity were addressed by taking measures to ensure construct validity, internal validity, external validity, and reliability.

#### 3.2 Sampling

To learn about the interaction between DTs, IPC, and responsiveness, a suitable case has to display two features: a contemporary demand management issue stemming from uncertainty, and a current consideration regarding the adequacy of DTs to solve this issue. The selected case is workwear for emergency service organisations (ESOs)—a quintessential example of a high-involvement product case (Martin 1998). ESOs, such as police, fire authorities, ambulance services, and the defence sector rely on specific clothing in the workplace to engage in challenging and critical situations (Carter 2008). Given these situations are highly distinct, each workwear product fulfils a specific purpose, tailored to its respective individual requirements, constituting workwear as high-involvement product. ESOs have an obligation to equip employees with fitting and appropriate garments. By gathering individual body-data of service members and virtually matching the data with product information, stakeholder along the ESO workwear supply chain recently began to apply DT approaches. Thus, this case allows for the empirical examination of a human DT as DT unit of analysis, addressing a hitherto unexplored empirical gap. On the whole, the formative reliance on operational accuracy makes safety-critical workwear for ESOs a prime example for a high-involvement case setting and thus enables

**Table 3** Case study validity measures, as adopted from Yin (2017)

Measure	Description	Employed Tactic
<i>Construct validity</i>	Identifying correct operational measures for the concepts being studied	An evidence chain was constructed as multiple informants were used for the same supply chain level. In total, 25 informants from multiple countries and different business functions across the supply chain contributed to the study Reviewing of 24 publicly available and internal documents (provided by interviewees) for triangulating codes obtained during interviews
<i>Internal validity</i>	Establishing causal relationships, whereby certain conditions are believed to lead to other conditions, as distinguished from spurious relationships	Relevant informants were located based on previously screened documents and mapping of relevant stakeholders Employing OIPT as guiding framework Matching of comparable patterns regarding IPC interactions, and product, process, and volume responsiveness
<i>External validity</i>	Defining the domain to which a study's findings can be generalised	Clearly defining the contextual setting of the case study: safety critical high-involvement products for ESOs, while carefully discussing the generalisability of findings
<i>Reliability</i>	Demonstrating that the operations of a study can be repeated with the same result	Case study protocols were used as guidelines for questions A case database was developed

a substantial opportunity to analyse a signature situation in rich depth (Dubois and Gadde 2014; Dyer and Wilkins 1991; Meredith 1998).

To choose theoretically useful interview candidates (Eisenhardt 1989), a theoretical sampling procedure was performed (Glaser and Strauss 1967; Bell et al. 2018). Sampling was controlled by OIPT as data collection, coding, and analysis were performed jointly and continuously compared to the theory's core concepts (Glaser and Strauss 1967). This particularly focuses on DT, IPC interaction, and responsiveness as performance metrics. Interviews were conducted sequentially over a nine-month period in 2021 and 2022 until theoretical saturation was achieved (Bell et al. 2018).

The interviewees were selected to represent key stakeholders across the ESO workwear supply chain, including representatives from ESOs, manufacturers, software suppliers, and external industry experts. The ESO was the focal entity, represented by its R&D department involved in new product development, product procurement parameter specification, and general product management. The horizon of an ESO's direct workwear supply chain consists of tier 1 suppliers (workwear manufacturers) and (internal) customers<sup>1</sup>. Each interviewee's role is connected to their organisation's specific function within the supply chain. For example, ESO representatives provided insights into procurement processes, product requirements, and end-customer feedback, while manufacturers and software suppliers elaborated on production, customisation, and technological integration. By interconnecting the in-

<sup>1</sup> The customer's role could also be classified as *user*, defined as 'members of the organisation who use the purchased products and services' Webster and Wind (1972, p. 17). For the sake of consistency with the extant literature (Flynn et al. 2016), the term *customer* is used.



**Fig. 3** Illustrative depiction of ESO workwear supply chain and interviewees

interviews accordingly, multiple perspectives ensured a comprehensive understanding of the overall dynamics of DTs.

Theoretical saturation was reached when meaningful topics were captured, and additional samples were redundant (Bell et al. 2018; Eisenhardt 1989). This involved iterative coding and sampling, aligning with research questions and OIPT (Corbin and Strauss 1990). Naturally, theoretical saturation is influenced by data complexity and researcher experience (Guest et al. 2006; Ryan and Bernard 2003). To still guarantee comprehensiveness, at least two different entities were interviewed for each supply chain node. In case the unified coding of this work's researchers led to repetitions that adhere to the previously described perception of theoretical saturation, no additional interview was pursued for the respective supply chain node. Figure 3 illustrates the supply chain for ESO workwear and positions the interviewees (indicated by bracketed digits).

To create a thorough understanding of the scale and complexity of demand management for high-involvement products, ensure construct validity, and ultimately enrich the empirical findings, interviewees in the case companies were encouraged to share any public or internal documents they would consider beneficial to comprehend their respective case context. Fortunately, the case companies were highly cooperative and provided this study's researchers with a total of 24 documents. These documents, ranging from 5 to 131 pages each (1233 pages in total), were produced between 2018 and 2022 and include service regulations, regulatory documents, feasibility studies, technical reports, meeting presentations, white paper, annual report, and advertisement brochures. These archival documents gave details on organisational sizes, procurement records, current demand management activities and issues, as well as on future strategies and how these could be achieved with help of DTs. They were analysed alongside interview transcripts to triangulate the findings, ensuring that data interpretations were grounded in multiple sources, creating an evidence chain that ensured a robust understanding of the interplay between DTs and demand management responsiveness, ultimately enhancing construct validity.

The interviewees originate from Germany, the Netherlands, and Switzerland. Three ESOs (with 50,000–200,000 active personnel) feature in the sample. Procured volumes for workwear products are within the same range as the number of active staff members, plus safety buffers. For example, ESO 1 recently procured 228,000 helmets, while ESO 2 ordered 53,000 coveralls. Financial data has only been disclosed by ESO 1 which spent more than €500m on workwear in 2021. While Manufacturers 1 has more than 1000 employees and creates an annual revenue of

more than €1 bn through its global operations, Manufacturer 2 and 3 are medium sized family run enterprises specialising in distinct niches of workwear production. Instead of using retailers as intermediaries, all manufacturers sell their products directly to customers. To account for the diverse set of circumstances ESOs operate in, manufacturers offer a wide range of products. For instance, Manufacturer 2 offers more than 2100 different product variants. Thus, companies operate with minimum stock and often fabricate products made-to-order. Both software suppliers are German start-ups that provide service solutions for manufacturers, retailers, and commercial customers to digitise end-customers and leverage these data primarily for outfitting processes. Software Supplier 1 has a performance-based business case building on returned good reduction, purchasing volume, and order value. Both industry experts have a technical background related to digitisation in the management of functional clothing and are independent external advisors to multiple ESOs and manufacturers. Table 4 provides an overview of the conducted interviews as well as of the reviewed documents.

### 3.3 Data Collection and Analysis

Semi-structured interviews were chosen for their ability to capture a range of perspectives while allowing flexibility for participants to express themselves naturally (Bell et al. 2018). Interview guidelines were inspired by the seminal works on OIPT (Daft and Lengel 1986; Galbraith 1974) and designed to probe DT, demand management responsiveness, and IPC interaction. As afore mentioned, there was so-far no precedent that gathered empirical data on DTs to enshrine their managerial impact in the extant theoretical landscape. Thus, guiding questions for all informants were kept rather open and continually refined to accommodate emerging themes, making them capable of eliciting insightful responses. Interview themes included descriptions on the current usage of DTs, reasons for adopting them (prevalent IPN), challenges during implementation and usage, capabilities brought by DTs, and their impact on demand management responsiveness. The questions' emphasis was slightly adapted for each stakeholder group to ensure relevance and depth in responses. Questions for ESOs as well as manufacturers stressed on the operational and strategic impacts of DTs. Customers were queried about their perceptions of DT-driven improvements in service and responsiveness, reflecting on organisational performance from a demand-side perspective. Software suppliers were asked about the technological advancements and IPC mechanisms embedded in DT applications. Industry experts provided insights into the adoption trends, challenges, and strategic fit of DTs for high-involvement products. Additionally, the documents described in Table 4 were collated alongside interview transcripts to triangulate the findings, ensuring that data interpretations were grounded in multiple sources. For example, service regulations and regulatory documents provided insights into operational benchmarks and compliance requirements, while feasibility studies and technical reports offered a detailed understanding of technical constraints and performance metrics.

All interviews were conducted remotely using video conferencing technology. Each interview session involved three interviewers, with one primarily posing ques-



**Table 4** Outline of informants

Role in the supply chain	Country	Interviewee	Reviewed internal documents (no. of pages)	Date range	Document content & relevance to the study
<i>Emergency Service Organisation 1</i>	Germany	Product Developer Process Owner Department Head	Service regulation 1 (109)	2018–2022	Operational benchmarks, compliance with standards, feasibility of DT applications, and technical performance
			Service regulation 2 (131)		
			Service regulation 3 (81)		
			Regulatory document 1 (59)		
			Feasibility study 1 (93)		
<i>Emergency Service Organisation 2</i>	Netherlands	Department Head Product Developer Process Owner	Feasibility study 2 (106)	2018–2019	Legal compliance, interoperability requirements, and performance evaluation for DT prototypes
			Technical report 1 (57)		
			Regulatory document 2 (44)		
			Technical report 2 (37)		
			Technical report 3 (26)		
<i>Emergency Service Organisation 3</i>	Switzerland	Process Owner	Technical report 4 (56)	2018–2021	Data transparency initiatives, integration challenges, and project outcomes
			Technical report 5 (8)		
			Meeting presentation 1 (17)		
			White paper 1 (70)		
			Annual report 1 (89)		
<i>Manufacturer 1</i>	Germany	Product Developer Product Developer Chief Executive Officer Head of Marketing and Distribution	Technical report 6 (17)	2019  2021	Market positioning and operational integration strategies for DTs Strategic insights on DT-enabled product development and marketing applications
			Annual report 2 (37)		
			Technical report 7 (97)		
			Annual report 3 (37)		
			Technical report 8 (97)		
<i>Manufacturer 2</i>	Germany	Chief Executive Officer Head of Production and R&D Management Assistant Head of Marketing and Distribution	Annual report 4 (37)	2019–2020	Organisational use cases for DTs, customisation processes, and operational improvements
			Technical report 9 (97)		
			Annual report 5 (37)		
			Technical report 10 (97)		
			Annual report 6 (37)		

**Table 4** (Continued)

Role in the supply chain	Country	Interviewee	Reviewed internal documents (no. of pages)	Date range	Document content & relevance to the study
<i>Software Company 1</i>	Germany	Customer Manager	Advertisement brochure 1 (9) Advertisement brochure 2 (5) White paper 2 (56) Technical report 8 (12) Technical report 9 (7) Meeting presentation 2 (10)	2021–2022	Customer-focused applications of DTs and software integration capabilities
<i>Software Company 2</i>	Switzerland	Chief Executive Officer		2021–2022	Software advancements in DT simulations and customer interaction tools
<i>Customer 1, Customer 2, ..., Customer 6</i>	Germany	Workwear User	n. a.	n. a.	Feedback on product usability and customisation preferences
<i>Industry Expert 1</i>	Netherlands	Researcher	n. a.	n. a.	Expert insights on industry trends and DT adoption challenges
<i>Industry Expert 2</i>	Germany	Researcher	n. a.	n. a.	Academic perspectives on DT frameworks and scalability

tions while the others took notes and occasionally interjected for clarification purposes. The duration of interviews ranged from 45 to 130 min, resulting in over 20 h of recorded dialogue. Subsequent to the interview phase, all recorded interviews were transcribed verbatim, ensuring an accurate representation of the participants' responses. These transcripts were transferred to the *MAXQDA* software tool for coding, following Corbin and Strauss (1990), Rädiker and Kuckartz (2019) as well as Mayring (2015). Open and axial coding were selected as they align with the study's goal to uncover patterns and relationships between DT capabilities and demand management responsiveness. Open coding allowed for the identification of diverse themes from the data without predefined categories, ensuring that the findings emerged inductively from the empirical evidence (Mayring 2015). Axial coding was then employed to organise these themes into coherent categories, facilitating a deeper understanding of the interplay between DTs and OIPT dimensions (Corbin and Strauss 1990). Alternative coding strategies, such as template analysis or deductive coding, were considered (King et al. 2017). However, these approaches rely on predefined structures that may constrain the emergence of novel insights (King et al. 2017). Given the nascent state of managerial research on DT, open and axial coding were deemed more suitable for capturing the complexity and richness of the data.

During the open coding process, each transcript was systematically reviewed and quotes containing significant themes or ideas were identified and labelled as individual codes (Corbin and Strauss 1990). This initial phase yielded more than 350 quotes and numerous unstructured codes capturing diverse aspects of the participants' discussions related to DTs and how they impact demand management responsiveness. The next step was axial coding, where the open codes were organised into coherent categories (Corbin and Strauss 1990; Mayring 2015). The goal was to establish meaningful connections which could be analysed in relation to the major dimensions of OIPT, allowing for a systematic alignment between empirical findings and theoretical framework (Corbin and Strauss 1990; Mayring 2015). Key themes identified in the interviews were cross-validated with information from the provided documents to ensure that the final set of codes was robust and reflective of both interview data and documentary evidence. For instance, regulatory documents helped to validate findings on compliance challenges in DT adoption, while technical reports informed the development of codes related to simulation enablement and dynamic interactions. Interestingly, when delving deeper into DTs, their interaction with IPC, and the specific nature of IPC exploitability, an intriguing theme emerged that extended beyond the original OIPT framework: interviewees discussed various considerations that are crucial during both the implementation and usage phases of DTs to successfully exploit them and their enabled IPC. These additional insights were clustered into five distinct codes suggesting barriers that prevent organisations from fully leveraging IPC. Consequently, this emergent concept was labelled *Information Processing Constraint* (IP Constraint—not to be confused with IPC for Information Processing Capabilities).

Altogether, the categorisation of dimensions and associated codes was informed by a combination of theoretical constructs from OIPT and emergent patterns from the data. For instance, codes related to 'connectivity,' 'simulation,' and 'dynamic

**Table 5** Investigated theoretical dimensions and their associated codes which emerged in the empirical data

Dimension inspired by OIPT	Number of quotes	Content of associated codes
<b>Demand management responsiveness</b> ( <i>Performance metric</i> )	186	Rate of returned goods
		Product variety
		Warehousing efficiency & effectiveness
		Logistics efficiency and effectiveness
		Monitoring
		Process lead-time
		Customisation
		Standardisation
<b>Information Processing Capabilities</b> ( <i>DT enabled</i> )	91	Product quality control
		Product development processes
		Connectivity
		Simulations
		Dynamic interactions
<b>Information Processing Constraint</b>	85	Integration ( <i>Internal, Customer, Supplier</i> )
		Strategic alignment
		Operational alignment
		Technical alignment
		Psychosocial alignment
		Economic alignment

interaction’ were aligned with IPC, while themes such as ‘customisation’ and ‘lead-time reduction’ were categorised under demand management responsiveness. This hybrid approach ensured that the dimensions were both theoretically grounded and empirically relevant. Through this iterative process of coding and analysis, 19 core codes emerged that were deemed essential for understanding the role of DTs in impacting demand management responsiveness (Corbin and Strauss 1990). Table 5 provides an overview of the investigated dimensions and their associated core codes, which emerged from structuring the empirical data.

## 4 Findings

Analysing the findings in light of the previously introduced dimensions led to the development of six propositions (Cornelissen 2017). These propositions describe *what* impact DTs high-involvement products have on demand management responsiveness (addressing RQ 1) as well as *how* this impact is achieved (addressing RQ 2).

### 4.1 Impact of Digital Twin on Demand Management Responsiveness

The first research goal centred on the performance effects of DTs, essentially addressing the question of *what* impact they have. Specifically, the impact of DTs of high-involvement products on demand management responsiveness is explored. Empirical evidence suggests that successfully implemented DTs can positively influence the three previously outlined dimensions of demand management responsiveness: volume, process, and product (Holweg 2005). Detailed descriptions of the

**Table 6** Impact of Digital Twins on volume responsiveness

OIPT concept	Code	Application in case study	Example quote
<b>Volume responsiveness (Performance concept)</b>	Decrease rate of returned goods	Backwards flow of products returned by customers	Since we updated our sizing chart based on the procured database [of anonymised DTs], the number of returned goods decreased. (Product Developer, Manufacturer 1)
	Improvement of product variety	Difference within product types	What we did continuously was investigate if the sizes were actually fitting the people. If you have many sizes, I am pretty sure that there are many sizes that no one uses. But there are also sizes that people need that are not in stock. That is why it is so important to have a good database of body dimensions, so that you can get rid of the size no one wears anymore. So that is what we did for the pants. (Industry Expert 1)
	Increase of warehousing efficiency and effectiveness	Creating a high inventory turnover and strategically storing goods where they are needed the most	Having the data from each of our soldiers, what they look like, where they are stationed, and so forth, having all that in one spot digitally and accessible, certainly enables us to strategically improve at which location we need to store what types and what quantity of products. (Process Owner, R&D ESO 3)
	Increase logistics efficiency and effectiveness	Optimising the match between each product and the customer who demands it	We merged the DT of a customer's hand, created by a smartphone application, with our inventory system. This helps us to identify, pick, and distribute the required product efficiently. (CEO, Manufacturer 2)

Table 7 Impact of Digital Twins on process responsiveness

OIPT concept	Code	Application in case study	Example quote
Process responsiveness (Performance concept)	Monitoring	Tracking of key processes to identify situations that require intervention	We could pick out every soldier with the 3D copy and virtually fit the pants. Here you have a soldier. You can see that his pants are too tight. Even though we haven't seen him, it was completely obvious. We gave him a phone call. We said: 'You took an 80/90 but that is not corresponding to your body size. So please return your pants and take another pair'. So, this shows what you could do. You have virtual control over the sizing process (Industry Expert 1)
	Process lead-time	Time it takes to convert customer demands into a successful product delivery	Imagine the sensor spots a malfunctioning, a crack in a vest, a tear in a protective suit, or similar. Something you wouldn't necessarily see yourself. We could reequip them instantly and have a suitable replacement at the ready and, who knows, maybe use a drone to deliver it (Process Owner, R&D ESO 1)

**Table 8** Impact of Digital Twins on product responsiveness

OIPT concept	Code	Application in case study	Example quote
<b>Product responsiveness (Performance concept)</b>	<b>Customisation</b>	Suiting a product specifically to an individual's needs	<i>If you have a guy who is actually a size 9, but his fingers are as long as a size 12, then it would make sense to individualise. So, with the DT, we are not only improving the system as a whole but also able to accommodate each person who does not fit in the system (CEO, Manufacturer 2)</i>
	<b>Standardisation</b>	Employing the same standards across the entire system	<i>At the moment, we are in the middle of introducing a modular and consistent clothing system. In the future, if soldiers are wearing underpants in size M, they will also receive ballistic equipment in size M. That was a major accomplishment of the DT. (Process Owner, ESO 3)</i>
	<b>Product quality control</b>	Guaranteeing that products adhere to the required quality standards	<i>We find huge differences between how close to the body trousers are, depending on if the trouser is from supplier A, B, or C. It is not possible to find these differences by our quality inspectors, because these tables of finished products are all uniform. Therefore, we desperately need a digital and transparent way of quality control. (Product Manager, R&amp;D ESO 1)</i>
	<b>Product development processes</b>	Creating and modifying products from design to marketing	<i>We are able to meet 70% of the requirements with the prototype we send, but it is a very complex procedure that is very labour intensive. If we would be able to use DTs of the product and the customer's hand, we would be able to digitise several aspects of NPD. It would save us a lot of time and money. Maybe we would even be able to meet 95% of the requirements with the first real prototype. (CEO, Manufacturer 2)</i>



findings are provided below, with overviews of the identified factors presented in Table 6, 7 and 8.

#### *4.1.1 Impact of Digital Twins on Volume Responsiveness.*

Manufacturers mentioned that poor product fit accounts for 50% of all returns which is a particular issue in the workwear context, because products are often made-to-order with a lack of capacity to manage returned goods in bulk. The interview data implies that a DT that accurately predicts customers' correct size, substantially decreases the rate of returns. Furthermore, all ESOs reported that a lack in intelligence regarding their population prevents purposive manufacturing. ESO 1 has three times more product sizes than does ESO 2. Interviewed affiliates of these two ESOs confirmed that DTs enable ESO 2 to equip service members much more efficiently and effectively. This was because they had more appropriate products than ESO 1 who did not use DTs for this kind of process. Industry Expert 1 explained how a DT-based principal component analysis not only enabled an improvement of the overall fit, but also streamlined the required number of product variants.

Product storage for ESO 1 used to be decentralised across roughly 80 warehouses within close proximity to the service members' deployment location. Owing to the lack of data, warehouses operated on a 'rule of thumb' basis. As a result, the quantity of many sizes was often suboptimal, and warehouses frequently had to distribute products that were too wide or small, which seriously impacted members' performance abilities and safety. By providing demand information regarding product types and volume per location, DTs enhance warehousing efficiency and effectiveness.

Given the perilous working environment, matching ESO members with their optimal clothing product takes considerable effort. The three ESOs reported that the ultimate goal of DTs introduction, was to fully equip recruits before their first official day of training. All informants saw the benefit of DTs to make their operational activities more targeted.

**P1a.** *Digital Twins positively affect volume responsiveness.*

#### *4.1.2 Impact of Digital Twins on Process Responsiveness.*

Industry Expert 2 discussed an increase in monitoring manufacturing process through virtual replicas of machinery and comprehending fabrication, allowing for virtual retracing of machine parameter settings and sewing processes, and ultimately predictive quality management. DTs also help to monitor issued equipment, the overall population, as well as internal and external circumstances, so it enables the ESO to act if any factor change necessitates intervention.

One key issue of the traditional processes of managing workwear is the substantial time-span between emergence of a customer demand and its satisfaction via a product delivery. Travel distances to warehouses could be extensive and it is not unusual for trial fitting to take several hours. Moreover, and as mentioned before, imperfect warehousing and planning leads to inadequate stock. All customers reported that it

used to be quite common to wait several months for specific products. The ESOs were aware of that, but lacked the necessary information to make a change. DTs provide continuous insights regarding contemporary customer demands. This not only optimises operational deliveries, but also impacts planning activities and provides procurement and manufacturing functions a time and information advantage. As a result, DTs reduce process lead-time substantially.

**P1b.** *Digital Twins positively affects process responsiveness.*

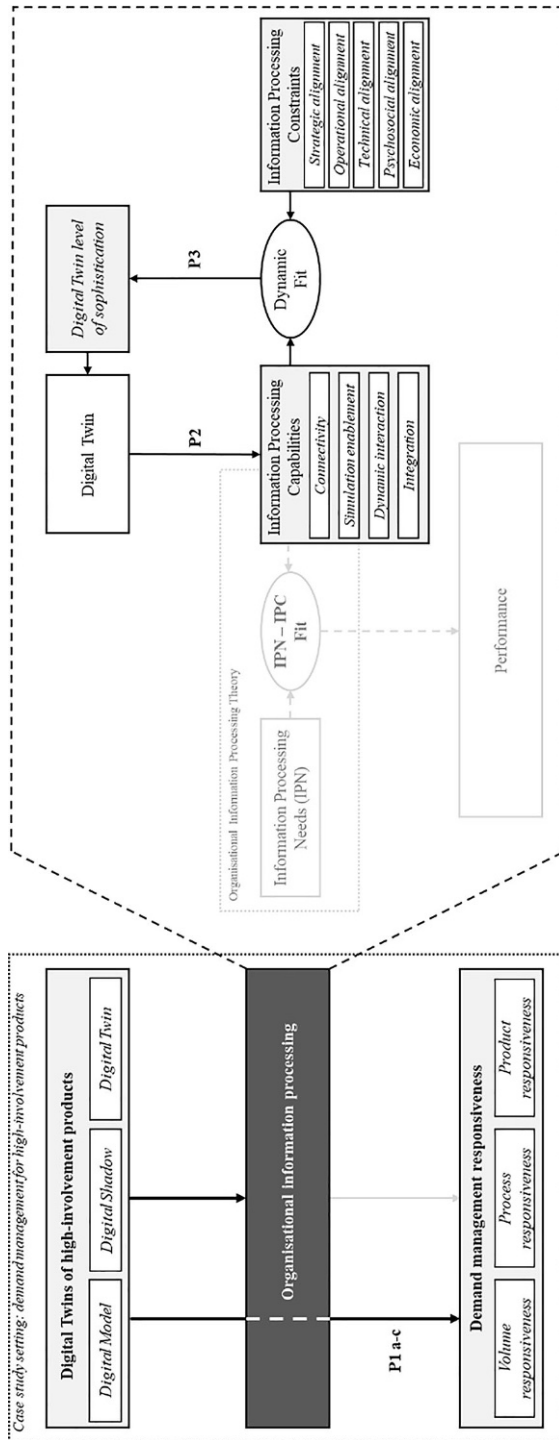
#### 4.1.3 Impact of Digital Twins on Product Responsiveness.

DTs make it possible to efficiently tailor a pattern from individual body dimensions. The importance of personalisation increases with population heterogeneity and individual tasks specificity—typical characteristics of high-involvement products. One measurable benefit was created by ESO 2: Instead of providing standard products for the entire population, it is able to effectively target outliers and equip them with individualised products. Thus, the fit for the overall population improves, while the number of generic and voluminous variants decreases. The value of DTs lies in detecting and decoupling outliers, while simultaneously streamlining the system for the remaining population. Moreover, ESO 3 reported that they are preparing to launch a modular clothing system, and ESO 2 stated that one is currently in development. In both cases, the use of DTs for research purposes has been a cornerstone for this accomplishment. Given large volumes, holistic quality control is often infeasible. However, as the recipient's well-being is at stake, impeccable quality must be guaranteed. Therefore, ESO 1 claimed that DTs enhance transparency and provide quality control departments with a new powerful tool. Manufacturers and ESOs are optimistic that the ability of DTs to simulate specific elements and digitally share elements intra- and inter-organisationally, will lead to improvements in product development processes. Manufacturer 1 discussed the possibility of gaining customer feedback for prototypes, and thus hoping for higher chances of commercial success. The same interviewee also complained about how tiresome and dull internal review phases during product development used to be. Substituting this work with DTs frees up resources that can be used for creative activities. Furthermore, human DTs can be used to design new products specifically to the end-customer's requirements, as reported by Industry Expert 1.

**P1c.** *Digital Twins positively affects product responsiveness.*

## 4.2 Digital Twins and Information Processing Capabilities

The second research goal aimed at exploring the manner *how* DTs impact demand management responsiveness. Thereby, more light is shed on (a) the IPC enabled by DTs and (b) the interaction between IPC, IP Constraints, and DT levels of sophistication. Figure 4 depicts the extended research framework and positions the suggested propositions within it by opening the black box of Organisational Information Processing. Thereby, the findings not only extend the OIPT framework through the



**Fig. 4** Depiction of propositions within the extended research framework

**Table 9** Information Processing Capabilities enabled by Digital Twins

IPC	Example quote	Level	Concrete technical/operational application in case
<b>Connectivity</b>	<i>It's quite fascinating because suddenly you can integrate data from disparate sources. I mean machines, people, functions and so forth. So instead of searching here and there for specific information, we have everything at the same spot. (Head of Production and R&amp;D, Manufacturer 3)</i>	Model	3D body scanner Virtual product parameters Radio-frequency identification for stock
		Shadow	Smartphone scanner Digital register of issued and required products
		Twin (s.str.)	Sensors in smart textile
<b>Simulation enablement</b>	<i>If we have the data in 3D, the suppliers can simulate their activities. That saves us a lot of work. We say, this is your basic pattern, it is the frame you have to work with, please provide us with a finer cut. Once we receive that, we have to format it, sew it, and simulate it. (Product Manager, Manufacturer 1)</i>	Model	Simulate prototypes
		Shadow	Simulate products in use Simulate customers
		Twin (s.str.)	Full-scale, real-time simulation of products within their operational environment, allowing for the prediction of wear, tear, and future needs
<b>Dynamic interaction</b>	<i>Imagine how many datapoints we have on a single hand. Now we have one person who needs a sniper-glove, who needs protection against cold climate, and who wants to absceil down from a helicopter. This means that the same hand requires completely different types of gloves. All of this means that we have to interpret the same hand in lots of different ways, depending on what type of pattern we are going to create. (Head of Marketing and Distribution, Manufacturer 2)</i> <i>If we have connected, software-based machinery and merged it with the DT of the respective product and customer, the machine will give you a pattern in the blink of an eye. From a technical perspective this is not an issue at all! (Industry Expert 2)</i>	Model	Monitoring of customer requirements Testing of fit and function for specific scenarios
		Shadow	Rapid and dynamic adjustment of patterns as new requirements emerge
		Twin (s.str.)	System self-improvement and intelligent assistance: Automated generation and adjustment of product designs through interconnected systems

**Table 9** (Continued)

IPC	Example quote	Level	Concrete technical/operational application in case
<b>Internal and external integration</b>			
<b>Internal</b>	<i>By having Digital Twins of both products and soldiers, every issue, every complaint, every comment is recorded comprehensively accessible to all parties. We are not separated entities any longer. We can work together. (Process Owner, ESO 1)</i>	Model	Centralised database for logs and comments accessible to all departments
		Shadow	Digital collaboration tools with automatic alerts for issues detected across multiple departments
		Twin (s.str.)	Instantaneous updates and proactive issue resolution across all departments
		Model	Virtual prototypes shared with customers for feedback
		Shadow	Digital platforms enabling customers to visualise and customise products based on 3D models of their specific needs
<b>Customer</b>	<i>The customer tells us, 'This is our problem'. Based on this, we started to develop 2 to 3 prototypes and send the best one to the customer. By using DTs of the product and the customer's hand, we were able to digitise several aspects of NPD: namely sharing more data in a faster way with our customer and asking questions from an early stage on. (CEO, Manufacturer 2)</i>		interactive digital tools that simulate product use in the customer's specific environment
		Twin (s.str.)	Real-time adaptation of product features based on continuous data flows from the customer's environment, allowing the product to evolve according to needs and usage patterns
		Model	Digital specifications and 3D models shared with suppliers
<b>Supplier</b>	<i>It is ping-pong. [...] We communicate with the supplier through simulations. (Product Manager, Manufacturer 1)</i>	Shadow	Integrated supplier platforms that use digital shadows of products and components to simulate processes and anticipate outcomes
		Twin (s.str.)	Autonomous adjustments in supplier processes, enabling seamless coordination

introduction of IP Constraints but also by introducing a dynamic fit approach (P3) which constitutes a dynamic cycle between DT, capabilities and constraints.

#### 4.2.1 *Digital Twins and Information Processing Capability Enablement.*

Four DT-enabled IPC advancements were identified in the empirical data: connectivity, simulation enablement, dynamic interaction, and integration. A holistic overview, including the concrete technical and operational application of each IPC in the present case study is provided by Table 9. Subsequently, proposition P2 is made.

**Connectivity** According to Manufacturer 3, DTs enhance the integration of data from various sources, providing a single platform where information from machines, people, and functions is readily accessible. This allows ESOs to monitor customer demands more efficiently by tracking product fit, usage, and inventory. For example, ESO 1 reported that before missions, they check individual inventories and ensure that the correct items are available. Representatives from this ESO also reported that DTs enable the monitoring of changes in tasks, body dimensions, or product quality, allowing for timely responses such as replacing defective equipment (e.g. through sensors that track garment condition). Additionally, Customer 2 reflected that, although DTs admittedly suffer from the limitation that they cannot be touched, they provide customers with detailed digital information about product texture, material, and functions. This can even be more informative than traditional physical channels. Moreover, Manufacturer 3 uses RFID chips to support this connectivity by enabling the tracking activities and inventories.

**Simulations** All manufacturers emphasised that having 3D data allows suppliers to simulate their activities, which significantly reduces the workload involved in product development. According to them, the process begins by providing suppliers with a basic pattern and frame to work with. Suppliers then refine the design and return it for further processing, including formatting, sewing, and simulating the final product. This approach not only streamlines the development process but also ensures that the end product meets the necessary specifications before physical production begins. The ability to simulate prototypes in this manner helps to identify potential issues early on, allowing for adjustments that save time and resources. Furthermore, manufacturers, suppliers, and industry experts agree that timely simulation capabilities extend beyond initial prototypes; they enable full-scale simulations of products within their operational environments, which allows for the prediction of wear, tear, and future needs. This provides valuable insights into product durability and performance under various conditions.

**Dynamic Interaction** Manufacturer 2 highlighted the complexity involved in designing products that meet diverse customer needs, such as creating different types of gloves for a single hand based on varying operational requirements. This scenario underscores the necessity of interpreting and adapting patterns to suit specific use cases, which can be efficiently managed through dynamic interaction capabilities.

By integrating connected, software-based machinery with the DT of both the product and the customer, manufacturers can rapidly generate and adjust patterns to match precise requirements. The industry for protective equipment was generally characterised as still driven by pen, paper, and physical labour. However, Manufacturer 1 declared a major motive for implementing DTs to enable more automation. In contrast to the laborious outfitting process employed by the other ESOs, ESO 2 (who has the longest successful DT concept in place) was able to convert this procedure into an automatised allocation of sizes that could avoid physical product try-ons. The manufacturers agreed that DTs could help in substituting manual activities. Industry Expert 2 also explained that processes, which once required significant manual effort, can now be executed almost instantaneously, as machinery provides optimised patterns in real time. This capability extends to monitoring customer requirements and testing fit and function for specific scenarios, ensuring that the final product meets the exact needs of the user. Furthermore, suppliers reported that DT enable rapid adjustments as new requirements emerge, allowing for continuous refinement of designs. The ESOs contemplated that at the most advanced level, these systems could potentially facilitate self-improvement and intelligent assistance, where interconnected systems autonomously generate and adjust product designs. However, this remains a conceptual idea, and they are currently satisfied with the DT's ability to make informed recommendations.

**Internal and External Integration** Interviews revealed an increase in the ease of collaborative business practices across functional units. Organisational tailors, for instance, gain a clear understanding of the patterns they are provided by the R&D department and are able to use the same method to express their opinion. The opportunity to articulate their needs through DTs is also mentioned by all customers. More collaboration among different R&D branches is possible, as a merged representation of customers and their equipment has proved helpful for designating distantly related products such as vehicle interiors. Furthermore, monitoring service members allows for the customer's individual circumstances to be integrated into the supply management activities. Customers could also report needs themselves and thus actively provide the ESO with their respective requirements. One example of merging such self-reports with DT data was mentioned by Industry Expert 1: because multiple customers complained about foot pain, customers received insoles based on recorded body data without any need of physical interaction. Collaboration between manufacturers and ESOs was considered a fundamental benefit of DT, as demands are clearly explained, and ideas could be exchanged rapidly and tested immediately. Additionally, end-customer feedback is integrated into manufacturers' work from an early stage. Manufacturers proclaimed that this translates to more dynamic communication channels with suppliers. Hence, DTs provide integrative IPC that entail inexpensive loops between involved supply chain nodes.

Beyond these explanations, all interviewees provided in-depth insights into the technical applications of DT within the case environment. These applications illustrate the dynamic spectrum of the Digital Model, Shadow, and Twin distinction—demonstrating that there is no universal 'one size fits all solution' for a DT. This leads to the following proposition:



**Table 10** Identified Information Processing Constraints

IP Constraint	Explanation in case study	Example quote
<b>Strategic alignment</b>	Consistency between DT capabilities and strategic objectives of demand management	<i>It's not enough to simply invest in the latest technologies; they must also integrate with our strategic objectives to drive meaningful outcomes. Without this alignment, we risk operating in silos. Digital Twins actually help us to connect our efforts and reach our goals. Given this, the investment in Digital Twins serves a strategic purpose (Department Head ESO 1)</i>
<b>Operational alignment</b>	Alignment of DT systems with existing workflows	<i>There will only be an improvement if the data is embedded in our process landscape and shared. If the data is not integrated in our processes and if suppliers are not fully integrated, then what is the point of collecting data in the first place? (Chief Executive Officer, Manufacturer 3)</i>
<b>Technical alignment</b>	Cross-functional and interorganisational compatibility of DT infrastructure	<i>By using Digital Twins, we are able to speak the same language. This does not only apply to the compatibility of the software packages the suppliers and ourselves use. We can actually work together. (Chief Executive Officer, Manufacturer 3)</i>
<b>Psychosocial alignment</b>	Compatibility of organisational culture and DTs	<i>To be honest, we have a general preference for paper-based processes. [...] For instance, there is a little book that all recruits get in which everything they receive is documented. [...] This book is sacred [...]. The recruits carry it with them at all times. We tried to digitise it, but no chance! And it is really the case that the recruits write down their equipment by hand and cross out what they have returned. [...]. My grandfather still has his, although his service time ended a long time ago. The book is his pride. (Process Owner, R&amp;D ESO 3)</i>
	User attitudes towards DT	<i>Look at us; no one has an ideal body. Would you be comfortable with the thought that unfamiliar people would look at it in such a detailed manner? (Managerial Assistant, Manufacturer 3)</i>
	Employee attitudes towards DT	<i>I am convinced that because of DTs, no one would have lost their job. They would have gotten different tasks. And I think these tasks would have even been more exciting than what they are doing right now. But we haven't integrated them sufficiently in the project. And suddenly, the backlash became too immense, and we had to terminate it. In hindsight, not integrating employees from an early stage on has been our biggest mistake. (Process Owner, R&amp;D ESO 3)</i>
<b>Economic alignment</b>	Consideration how investments in DT infrastructure create business value	<i>The scanner is expensive. The software is expensive. Skilled personnel is expensive [...]. But look at an ESO! I am talking about tens of thousands of uniforms. If you would be able increase the system efficiency by 3 to 4 percentage points, the savings would be significant. (Industry Expert 2)</i>

**P2.** *In the demand management context, Digital Twins enable distinct IPC along a dynamic spectrum.*

#### 4.2.2 Digital Twins and Information Processing Constraints.

As afore explained, an inductively captured concept has been identified. More specifically, informants discussed five constraints that limit the IPC exploitability and was thus labelled as IP Constraint. The sub-constraints are introduced in the following and an overview is provided in Table 10.

**Strategic Alignment** According to Department Head at ESO 1, simply investing in the latest technologies without ensuring their integration with strategic goals can lead to fragmented efforts and missed opportunities. This alignment is particularly vital when deploying DTs, which are designed not only to enhance operational efficiency but also to support the broader strategic vision of the organisation. The informant highlighted that DTs help connect efforts across various departments, ensuring that everyone is working toward common goals rather than in isolated silos. This sentiment was echoed by Manufacturer 2, who noted that DTs enable a more coherent approach to product development and customer engagement, aligning technical capabilities with market-driven objectives. Similarly, Industry Expert 1 emphasised that when DTs are strategically aligned, they facilitate better communication and collaboration across the supply chain, from R&D to customer service. This strategic alignment ensures that the organisation is not just adopting new technologies for their own sake but is using them to drive meaningful outcomes that are in line with its long-term objectives.

**Operational Alignment** The necessity of aligning technological systems with existing organisational workflows emerged as a crucial factor in realising the full potential of DTs. According to the CEO of Manufacturer 3, the value of DTs is significantly diminished if the data they generate is not embedded within the company's process landscape. This integration is essential for ensuring that the information collected is not just stored but actively used to enhance operations. The informant stressed that without seamless integration into processes and full supplier involvement, the collection of data serves little purpose. This perspective was shared by ESO 1's Process Owner, who highlighted the challenges of incorporating new technologies into established workflows. The informant pointed out that for DTs to deliver meaningful improvements, they must be aligned with the day-to-day operations of the organisation, ensuring that the data is not only accessible but also actionable. Industry Expert 2 further noted that DTs should be designed to complement and enhance existing workflows rather than requiring a complete overhaul of current practices. Similarly, Manufacturer 2's underscored the importance of integrating DT data with existing process landscapes. They observed that when DTs are aligned with operational workflows, they facilitate better coordination between departments and suppliers.

**Technical Alignment** The importance of ensuring that technological solutions are compatible across different functions and organisations was consistently highlighted by all informants. Industry Expert 1 argued that technical alignment is the absolute baseline for any kind of interorganisational exchange. The informant pointed out that only when DTs are technically aligned with the systems used by all parties, it creates a shared platform for communication and coordination. This alignment reduces the risk of miscommunication and ensures that everyone involved in the demand management has access to the same accurate and up-to-date information. The CEO of Manufacturer 3 described it more vividly by stating that DTs enable different entities within and outside the organisation to ‘speak the same language’. This alignment goes beyond merely ensuring that software packages are compatible; it fundamentally enables organisations to work together more effectively.

**Psychosocial Alignment** Successfully leveraging DTs in an organisation also requires careful consideration of the psychosocial aspects, including the attitudes and shared ways of working among employees. The Process Owner at ESO 3 highlighted a deep-rooted preference for traditional, paper-based processes within their organisation, using the example of a ‘sacred book’ that all employees receive. This book, in which service personnel document their issued and returned equipment by hand, is not just a tool but a symbol of pride and tradition. Despite attempts to digitise this process, the cultural attachment to the physical book proved too strong, demonstrating the challenges of shifting long-standing practices towards digital alternatives. This is a typical testimony for the psychological attachment between customers and high-involvement products (Martin 1998). Similarly, the Managerial Assistant at Manufacturer 3 pointed out the personal discomfort that can arise from the detailed data DTs can reveal, particularly in contexts involving physical measurements and body scans. The informant noted that not everyone has an ‘ideal body’, and the idea of strangers analysing this data in such detail can be unsettling for some employees. This highlights the need for sensitivity and transparency when introducing DTs that require personal data, as resistance can emerge from concerns over privacy and dignity. Moreover, the Process Owner at ESO 3 recounted a significant lesson learned during the attempted implementation of DTs. Despite their conviction that DTs would not result in job losses but rather in the reallocation of tasks to more engaging roles, the project faced significant backlash due to insufficient early integration of employees in the process. This misstep underscores the importance of involving employees from the outset when introducing new technological methods like DTs. By failing to do so, the organisation encountered resistance strong enough to terminate the project, demonstrating how crucial psychosocial alignment is to the success of technological initiatives.

**Economic Alignment** Finally, it is essential to align investments with the potential for creating business value. Industry Expert 2 highlighted the significant costs associated with DTs, noting that not only are the scanners and software expensive, but the skilled personnel required to operate these systems also come at a high cost. Despite these upfront expenses, the expert emphasised that in large-scale operations, such as those of an ESO, managing tens of thousands of uniforms, even a modest

improvement in system efficiency could lead to substantial financial savings. This perspective underscores the importance of economic alignment in the deployment of DTs—investments must be strategically planned to ensure that they yield measurable returns. Organisations must carefully evaluate how DTs can enhance operational efficiency and, consequently, contribute to overall cost savings.

In summary, the informants emphasised the critical importance of alignment, highlighting that capability enablers must be attuned not only to IPN but also to IP Constraints—dispelling the notion that ‘more is always better’. Drawing on Fisher’s (1997) seminal question, ‘*What is the right supply chain for your product?*’ one could similarly ask: ‘*What is the right Digital Twin for your organisation’s information processing environment?*’—defined by the combination of prevalent IPN, IPC, and IP Constraints. As proposed in P2, DTs manifest along a spectrum, creating a corresponding range of capabilities that introduces dynamism; there is no static fit, but rather an evolving state influenced by technological progress, increasing IPN, and shifting constraints. As depicted in Fig. 4, this dynamism forms a cycle in which these concepts continuously interact: advancements in DTs enhance IPC, while rising IPN also demand greater IPC. These capabilities can only be fully exploited when aligned with environmental IP Constraints, which impact the cycle externally. The IP Capability-Constraint alignment, in turn, determines the most appropriate level of DT adoption, influencing IPC, and the dynamic cycle begins anew. This implies two aspects: First, that leveraging IPC is not only subject to technological methods but also prevalent circumstances inherent in the organisational environment. And second, that IPC—IP Constraint alignment feeds back towards the DT’s level of sophistication, as advancing DT levels is subject to greater repercussion. This leads to the following proposition:

**P3.** *Pursuing the appropriate Digital Twin level of sophistication is subject to the dynamic fit between Information Processing Capabilities and Information Processing Constraints.*

## 5 Discussion and Implications

### 5.1 Reflections on Digital Twin Impact on Responsiveness

According to Reichhart and Holweg’s (2007), responsiveness is an explicitly customer-centric concept and therefore essential for effective demand management. The general need for more responsive demand management activities was echoed by all interviewees, who reported a continuous rise in customer demand heterogeneity attributed to an increase in individual task specificity and expediting diversity within the ESO workforce. Approaching this challenge necessitates a paradigm shift in the industry of high-involvement products, with an increased focus on individual rather than collective demands. First and foremost, the findings indicate that by timely capturing individual needs, DTs are creating transparency on customer demands by making them explicit and interactive. This corresponds to Graf-Drasch et al.’s (2022) work on proactive smart services, who leverage transparency on cus-

tomers' needs and behaviours to transform customer-interaction into anticipatory and personalised value offerings.

In this light, the findings suggest that DTs provide value across all responsiveness dimensions, which is crucial as Holweg's (2005) research stresses that overall demand management responsiveness depends on coherence among these three dimensions. The interviews stressed that DT impact affects both intra- and interorganisational demand management processes, creating operations that respond quickly to needs of volume and process alteration (Lowson et al. 1999; Christopher et al. 2004). By successfully providing transparency on the micro- and meso-level (Flynn et al. 2016), generic strategies against unaccounted uncertainty, such as general inventory buffers, decrease in significance; or as phrased by Oliveira and Handfield (2023, p. 1837): 'information replaces inventory and capacity'. Thus, DTs allow for the focus on strategic inventories that specifically hedge against unpredictable macro-level disruptions (Ivanov 2023). Moreover, DT facilitate efficient customisation procedures and thereby transform configurations from push to pull (Gunasekaran and Ngai 2005). This aligns with findings by Aheleroff et al. (2021) and Kritzinger et al. (2018) who highlighted DT influence on mass customisation—the ability to produce individualised goods in high volumes at an acceptable cost (Da Silveira et al. 2001). Corresponding to Oehlschläger et al. (2023), the interviews revealed that full customisation solutions are often unnecessary if a demand management system is provided with adequate insights to optimise and redesigns standards in a customer-driven manner.

The second research goal was to explore the manner *how* DT impact demand management responsiveness. Hereby, four DT-enabled IPC were identified: connectivity, simulation enablement, dynamic interaction, and integration. These are by and large congruent with the extant literature's definition of DTs (van der Horn and Mahadevan 2021; Bhandal et al. 2022). Albeit this might seem unsurprising, it is nonetheless noteworthy as the present study analysed a quite idiosyncratic use case for DTs: while the prevalent understanding of DTs builds on large-scale assets (e.g. power plants, vehicles, or machinery) or manufacturing processes, this work leveraged the application of high-involvement products. This finding therefore substantiated the earlier made claim that DT is not a narrow technology that is fixed to a specific activity, but rather a method consisting of different technologies and management processes which together create a dynamic and holistic replication of and exchange with reality within a dynamic spectrum. Consequently, we also need a dynamic approach in understanding DT exploitability. While the logic that DT relates to a spectrum was already defined by the extant literature (Kritzinger et al. 2018), the present study vividly described this spectrum by means of a novel, concrete, unprecedented, and in-depth case study. This spectrum positions DTs as catalyst for dynamism within the cycle depicted in Fig. 4. Accordingly, DTs continuously reshape the dynamic fit presented here and demand organisations to adapt accordingly.

## 5.2 Case-Specificities and Generalisability of Findings

As the findings are embedded within a specific case context, focusing on products that are characterised by psychological attachment, personalisation, and operational accuracy required by customers, they are particularly suited to scenarios where these attributes play a central role. The influence of DTs on IPC, however, extends beyond safety-critical high-involvement products. The capability of DTs to enhance connectivity, simulation, dynamic interaction, and integration could readily be adapted to industries with diverse requirements for responsiveness towards customer demands, such as aerospace, healthcare, or customised consumer goods (Bhandal et al. 2022). These industries can leverage the demonstrated capabilities to improve demand management responsiveness, albeit with sector-specific adjustments. For example, while high-involvement products may prioritise individualisation, other industries might focus on scalability or cost efficiency.

Moreover, the study highlights the importance of psychosocial and cultural alignment when adopting DTs—factors that are universally relevant across industries, though their manifestations may differ. For instance, in sectors with less emphasis on individualisation, the resistance to adopting DTs might stem from cost concerns or lack of technical expertise, rather than cultural attachment or psychological resistance. These nuances emphasise the flexibility of the framework while underscoring the need for careful contextual adaptation. Often, DT is depicted as data collection and simulation tool (NASA, for instance, originally defined the DT as ‘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.’ (Glaessgen and Stargel 2012, p. 7)). This widely accepted definition, however, falls short on the DT’s capability to not only integrate technical assets but also facilitate meaningful interactions across organisations, departments, and individuals. These entities, however, have to allow for integration not only from a technological but also from an organisational perspective—even an advanced DT does not create value if it is not usable. Consequently, the dynamic fit between IPC and IP Constraints proposed in this study is not limited to high-involvement product contexts and provides a conceptual foundation for future studies. These could explore how this dynamic fit manifest in different sectors and industries, offering a broader perspective on the role of DTs in aligning organisational capabilities with environmental constraints.

## 5.3 Proposition of a Dynamic IP Capability-Constraint Fit

Hence, the findings indicate that technology alone is not a remedy to uncertainty issues when IP Constraints are neglected. Technically, this has already been recognised by the OIPT literature as many studies discriminate between structural and technological mechanisms as IPC providers. Interestingly, Lorentz et al.’s (2020) understanding of structural mechanisms excludes technology altogether and focus on interpersonal mechanisms. In the same vain, Sheng et al. (2021) differentiate between IPC arising from technology, management, and organisational culture, but also treat these factors in isolation without exploring their interdependencies. This

clear distinction is surprising and omits the findings of the well-established literature stream on IT integration, which demonstrated that technology success and organisational structure are intertwined factors, often presupposing and promoting each other (Nadkarni and Prügl 2021; Liu et al. 2016; Venkatesh et al. 2003). The discussion has indirectly been acknowledged by the OIPT literature as multiple studies observed specific influential factors for IPC such as human-related capabilities (Schlegel et al. 2021), the establishment of an analytics culture (Oliveira and Handfield 2023), or more generic organisational design features (Bartnik and Park 2018; Egelhoff 1991). Still, Tiwari et al. (2024) recently complained that the extant literature on digital IPC is overly focused on technical abilities, neglecting the organisation's role in developing IPC.

We develop these existing perceptions further by making them explicit and tangible in form of introducing the concept of IP Constraints to the OIPT framework. Specifically, five constraints were identified: strategic, operational, technical, psychosocial, and economic. None of these five constraints individually is new to the scientific community. For instance, and in addition to the previously mentioned examples, Guo et al. (2024) tested that the adoption of blockchain depends first and foremost on technical infrastructure and technical compatibility while its performance effect of thereby enabled IPC is moderated by leadership characteristics. Lämmermann et al. (2024) reason that the capabilities of an organisation's personnel and the interaction between various teams is just as important as the capabilities of the technology in place. Yet, despite these assurances, a formal integration of IP Constraints into the broader OIPT framework has not been achieved. This implies that while scholars applying OIPT acknowledge, observe, and measure influential factors affecting IPC exploitability, these factors have been treated as exogenous rather than as part of a reciprocal relationship, akin to the alignment of IPN and IPC. Consequently, a corresponding extension of OIPT would imply the coexistence of two fits: While the IPN–IPC fit has been a prolonged feature of previous research (Tushman and Nadler 1978), the dynamic IP Capability–Constraint fit is proposed by this research and engenders a new perspective on information processing within OIPT. This is in line with Stahl et al. (2023), who argues that the prioritisation of technology IPC over organisational capabilities or vice versa should be dynamic and highly context-specific.

This implication is therefore twofold: (a) environmental IP Constraints define the exploitability of IPC; (b) the dynamic IP Capabilities–Constraints fit feeds back towards the DT itself. This creates the dynamic cycle depicted by Fig. 4: DT advancements enhance IPC, which can only be fully exploited through alignment with environmental IP Constraints. This alignment, in turn, determines the most appropriate level of DT adoption, perpetuating the dynamic cycle.

#### 5.4 Implications for OIPT and Managers who Contemplate Digital Twin Adoption

A Digital Twin in the strictest sense is based on real-time data and interoperability between digital and real world (Oehlschläger et al. 2024). Given that it is impossible to surpass the level of IPC created by holistically and promptly replicating

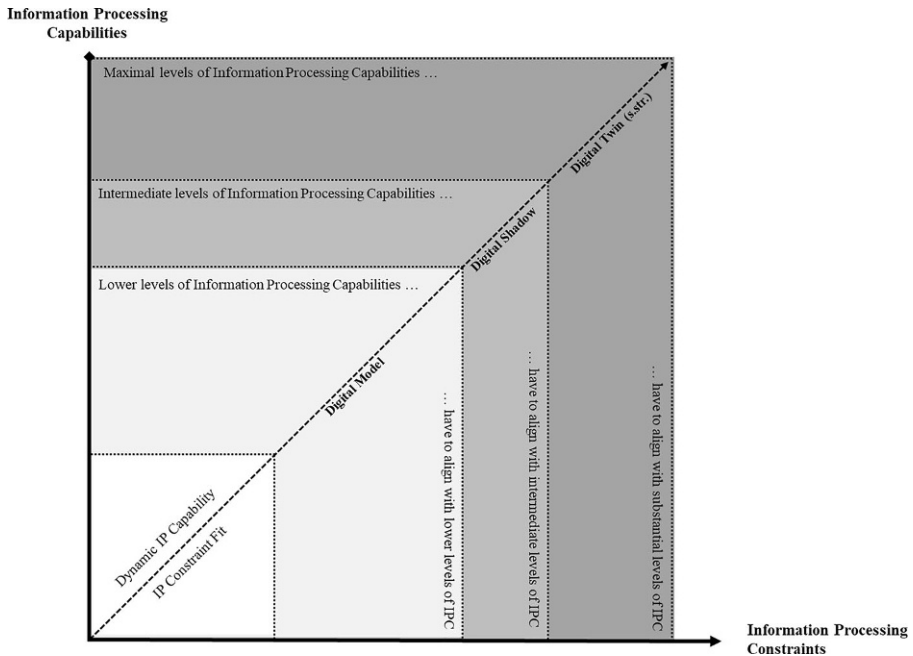
**Table 11** Overview of presumed IP Constraint relevance for each identified IP Capability and DT level

IP Capabilities/DT Level		IP Constraints				
		Strategic	Technical	Operational	Economic	Psychosocial
<i>IP Capabilities</i>	<b>Connectivity</b>	Supportive	Critical	Supportive	Critical	Peripheral
	<b>Simulation enablement</b>	Supportive	Critical	Critical	Critical	Peripheral
	<b>Dynamic interaction</b>	Critical	Critical	Critical	Supportive	Critical
	<b>Integration</b>	Critical	Supportive	Critical	Peripheral	Critical
<i>DT Level</i>	<b>Digital Model</b>	Peripheral	Critical	Supportive	Supportive	Peripheral
	<b>Digital Shadow</b>	Supportive	Critical	Critical	Supportive	Supportive
	<b>Digital Twin (s.str.)</b>	Critical	Critical	Critical	Critical	Critical

every entity of interest, DTs fabricate a conceptual limit for IPC. It is notable, that these highly advanced DTs are already technologically feasible (Tao et al. 2019). As mentioned before, however, technology alone, even if potent, is insufficient to overcome a deficit in structural mechanisms (Nadkarni and Prügl 2021). Hereby, the empirical data revealed not only a reluctance to implement DTs on the most advanced levels but also that informants were largely satisfied with their chosen DT sophistication levels, as the corresponding effects aligned with both their IPN and their IP Constraints. Increasing DT advancement does not only translate into higher performance potential but also to a substantial and non-linear increase in expenses (West and Blackburn 2017; Salvador et al. 2014; Bolton et al. 2018). This means that the identified IP Constraints intensify in severity as DT sophistication increases, meaning that higher DT levels are more challenging to align with corporate strategies and operations, demand greater technical interoperability, may necessitate cultural shifts for adoption, and involve more substantial financial investments. Due to these constraints, the highest degree of responsiveness in a system, created by the most advanced DT type, is not by default the optimal choice for a given organisation. A DT that enhances demand management responsiveness but simultaneously increases coordination complexity, faces adoption resistance, or incurs accelerated investment costs, may result in adverse effects that could potentially outweigh its benefits (Ivanov et al. 2019; Salvador et al. 2014). Or, as Williams et al. (2013, p. 544) write: ‘Managers often note that they are awash in data, yet lacking in valuable information’. In line with the conceptualisation of fit in strategic management (Venkatraman 1989; Venkatraman and Camillus 1984), a higher DT level is only superior to a lower one if a fit between IPC and IP Constraints is created.

This leads to two major considerations that managers are facing. First, what level of IPC is needed to satisfy my IPN (IPN-IPC fit)? And second, what IPC level fits the IP Constraints prevalent in my direct organisational environment? Based on the answers to these questions, managers can identify their respective optimal state of fit in which IPN, IPC and IP Constraints correspond perfectly to each other. Each DT level corresponds to a local optimum, with Digital Model offering limited transparency, Digital Shadow providing high transparency, and Digital Twin (s.str.) achieving ultimate transparency. Furthermore, it is deduced that each of these optima inherit a certain degree of responsiveness (tackling a different degree of IPN) that





**Fig. 5** Visualisation of dynamic IP Capability-IP Constraint fit

could be advanced by moving to the next optimum. Nevertheless, IPC could still be enhanced by implementing higher level DTs, even if it would offset the equilibrium. The consequential increase in effect size would, however, be limited. A change in IPN should thus be offset by adjusting both: IPC as well as the IP Constraints that limit IPC exploitability. Table 11 provides an overview of the presumed IP Constraint relevance for each identified IP Capability and DT level. While the empirical findings did not explicitly differentiate DT levels, this conceptual framework provides a structured lens for understanding how IP Constraints evolve across levels of sophistication. Thus, Table 11 serves as a conceptual tool to bridge the empirical insights on understanding which IP Constraint has particular relevance for each of the DT enabled IP Capabilities in the studied case. Figure 5 illustrate this reasoning by visualising the dynamic IPC-IP Constraint fit.

## 6 Conclusion

This study widens the general understanding of DTs in demand management by providing empirical evidence on their impact on responsiveness in the context of high-involvement products by embedding DTs in the theoretical framework of OIPT. The findings highlight that DTs are not a one-size-fits-all solution but instead offer a spectrum of capabilities that must be aligned with both needs and constraints of information processing. The dynamic interplay between DT advancements, IPC, and

IP Constraints forms a dynamic cycle that continuously shapes and reshapes the fit between these elements.

Implications are fourfold. First, awareness of a novel technological method in an unprecedented case setting is created. Second, insights regarding the effects of DTs are given to enhance volume, process, and product responsiveness. Third, the concept of IP Constraints is introduced. And fourth, the importance of establishing a dynamic fit is outlined. This should sensitise decision makers to prioritise adopting the DT level of sophistication that adheres best to the given IPN and IP Constraints rather than simply the most advanced one.

Overall, this research offers theoretically grounded insights into the value of DTs for demand management, contributing to a deeper understanding of their multifaceted nature (Bhandal et al. 2022; Kritzinger et al. 2018). By elucidating the complex interplay between DTs and demand management responsiveness, this study lays a foundation for further exploration in this area. There remains much to be discovered, and future research could build upon the propositions presented here by testing them through cross-case studies, thereby validating and extending the findings across different industries and contexts. Additionally, longitudinal studies could explore the evolving role of DTs over time, particularly as technology and organisational processes continue to advance. Furthermore, future research could address this study's limitations, such as the specific case setting of high-involvement products. Moreover, focusing on central Europe as case-region could also have influenced the findings as Bartnik and Park (2018) show different national preferences in information processing among Germany, Japan, and China. Additionally, research could shed more light on the relationship between DTs and IP Constraints which we considered as external factors. For instance, studies could explore how DTs shape organisational cultures towards responsiveness-drivenness by embracing real-time capabilities (Oliveira and Handfield 2023). To overcome a potential shortage of use cases, simulations and experiments based on real-world data could be promising methods to conduct these studies.

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## Declarations

**Conflict of interest** D. Oehlschläger, A.H. Glas and M. Eßig declare that they have no competing interests.

**Ethical standards** Participants to the empirical work have agreed consent to participate. This work is compliant with Ethical Standards.

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