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Realizing zero-waste value chains through digital twin-driven S&OP: A case of grocery retail

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ABSTRACT

We posit that the zero-defect mindset from manufacturing is a crucial step in the direction of achieving zero-waste value chains. Using a reflective conversation approach within a food grocery retail case setting, we show how digital twin-supported sales and operations planning (S&OP) may be used as an intervention to predict and detect variabilities across the value chain to prevent and reallocate food surplus, allowing us to bring the zero-waste value chain concept to fruition. The contributions of this study include extending the zero-defect concept to value chains in grocery retail for addressing food waste and proposing the notion of digital twin-enabled planning as a means of improving upon the shortcomings of the traditional S&OP process.

1. Introduction

About a third of the world's food supply goes to waste because it never reaches customers before expiring. Global food waste is predicted at 1.6 billion tons per year, rising to 2.1 billion tons by 2030 (Morone et al., 2019; Aydin and Yildirim, 2021). Although food waste happens at all levels of the value chain, it is most preventable and controllable at the retail stage in developed countries (Parfitt et al., 2010; Brancoli et al., 2017; Teller et al., 2018). The economic and ethical implications of food surplus and food waste are foremost concerns in the food industry. Ironically, at a time when many people have been striving to survive on less than the bare minimum of food, the food system produces a surplus that results in massive waste generation. This reveals the paradox of *scarcity in abundance*, where abundance and scarcity coexist even in the most developed nations (Winne, 2008).

Food waste is an indication of an unsustainable food system that necessitates managerial interventions (Parfitt et al., 2010; Filimonau and Gherbin, 2017). We deem the paradox of scarcity in abundance as a demand–supply mismatch problem or, more specifically, a sales and operations planning (S&OP) problem, where managers tend to prioritize economic metrics such as cost and product availability over waste reduction. Availability of products is crucial and should remain so in the future. However, with increased concerns about food waste and its sustainability implications (Mena et al., 2014), organizations today must balance demand and supply with an additional emphasis on *zero waste*.

Theoretically, zero waste is the central pursuit of zero-defect manufacturing (ZDM). In ZDM literature, the notion of "zero" implies a disruptive quality management philosophy that supports zero tolerance for defects, errors, or variations. The impacts of ZDM are (a) reduced cost by not having to indulge in the treatment of defective products, (b) reduced waste, and (c) the elimination of all non-value-adding elements in the products or processes (Psarommatis et al., 2022). The ZDM mindset of proactive reduction of variations or errors has thus far been limited to manufacturing quality management challenges. We believe that the mindset has far-reaching implications throughout the value chain, and not just in manufacturing.

The "first time right" strategy of ZDM, especially in the food industry, is equally applicable for planning to pursue zero waste across the value chains (Taylor and Fearne, 2009; Papargyropoulou et al., 2014; Awasthi et al., 2021). The lead time, which is the time it takes to grow, produce, and sell food, is long and affects numerous links in the value chain (Dreyer et al., 2018). This, combined with the fact that food is perishable and has a limited shelf life (Mena et al., 2014), makes the proactive zero-waste mindset relevant. Planning and the ability to achieve a balance between the growth and production of food and demand in order to pursue zero-waste value chains becomes a critical management response to realize the first-time right strategy. As Industry 4.0 technologies are key enablers of ZDM strategies (Powell et al., 2022), and as planning effectiveness is largely dependent on complex scenario analysis and informed decision-making, we foresee the potential of digital twin-enabled planning to overcome the puzzling paradox of scarcity in abundance. The literature offers little understanding of the orchestration

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of resources for digital twin-enabled planning. Therefore, we explore this in the current research by asking *how can managers structure, bundle, and leverage resources for digital twin-enabled zero-waste value chain planning?* The goal of this study is to align S&OP with the ZDM mindset for zero variability along the value chain, and it is the first attempt to address research gaps at the crossroads of zero-defect manufacturing, zero-waste value chains, and digital twin technology.

2. Theoretical background

2.1. Zero-waste value chains and S&OP

The food industry deals with perishable products with limited shelf-life. Unlike durable products, the quality of food products continuously deteriorates as they make their way through the value chain from raw material grower to final consumer (Apaiah et al., 2005), leading to potential waste generation and food safety concerns (Ben-Daya et al., 2020; Ling and Wahab, 2020). In this study, we refer to waste as food that is unfit for sale and human consumption and has been discarded as a result of managerial action or inaction, or decisions made by consumers, value chain actors, and other stakeholders (Dreyer et al., 2019). In the food system, the value chain of grocery retailing in the developed world has great potential for waste reduction (Parfitt et al., 2010; Dora et al., 2021) and is very much related to variability in demand and supply (Germain et al., 2008). Variability causes the risk of overstocking or understocking in the value chain, which is particularly relevant for perishable food products. The overstocking of food products may cause surplus food and food waste, leading to monetary and environmental wastage and reduced performance (Kiil et al., 2018a). The consequences of understocking are low product availability and service levels, leading to lost sales and revenue reduction. Both situations cause efficiency/effectiveness losses in the value chain (Kaipia et al., 2013) and should be avoided.

Waste reduction and zero-waste strategies in conventional retailing are a dilemma and a compromise between product availability and high service levels, and waste reduction (Mena et al., 2014). Reducing assortments or availability of products, in fact, can result in customers switching to competitor stores (Corsten and Gruen, 2003). Strategies such as supply-driven and modified promotions (Mena et al., 2014; Huang et al., 2021) and surplus food donations (Devin and Richards, 2018) are employed to compensate for the supply variabilities resulting from poor demand and supply management (Taylor and Fearne, 2009). Variabilities in consumer demand and on-shelf availability are addressed by incentivizing consumers through discounting and dynamic pricing, promoting measures for household waste reduction (Huang et al., 2021), sharing demand information for improved forecasting (Mena et al., 2014), and ordering via automatic replenishment systems (Van Donselaar et al., 2010; Kiil et al., 2018b).

Automatic replenishment programmes are a known means to improve forecasting and decision making and, in turn, improve product availability (Avlijas et al., 2021) and reduce food waste (Kiil et al., 2018a) in retail. This increases transparency, improves coordination in replenishment decisions, and facilitates the synchronization of orders to balance product availability and waste. The extant research demonstrates how the order proposals from the automatic replenishment systems (ARS) could account for the current and minimum inventory levels, point of sale (POS) data for forecasting, batch size and lead time, ordering frequency, safety stock levels, delivery times, and also the remaining shelf life of perishable products (Kiil et al., 2018a, 2018b) while following predefined continuous or periodic replenishment policies (Kouki et al., 2015, 2016). Store managers can accept the proposals of ARS or can adjust the proposals to suit specific needs (Van Donselaar et al., 2010). Nonetheless, establishing good heuristic replenishment policies can be mathematically complicated, especially when including highly perishable products (Nahmias and Pierskalla, 1973). Also, such automated systems focus on the POS and other demand-influencing data for improved forecasting and not on addressing the overall value-chain variabilities for waste reduction. Such systems are rarely equipped to handle irregular demand fluctuations, cannibalization and halo effects from campaigns, seasonality, and product launches. To dampen variability, planning needs not only to *detect and predict* short-term changes in demand but also to include variability with a longer time horizon, such as seasonal demand patterns, campaigns and promotions activities, new product introductions, and yearly business plans, when negotiating with suppliers (Dreyer et al., 2018). Moreover, the ground rules for calculations and inputs for automatic ordering and operations for the next 6–12 months and the trade-offs are also determined at a tactical planning level (Dreyer et al., 2018).

While retail organizations conventionally seem to plan separately the "demand-driven category management and supply-oriented operations management", the S&OP process has been argued to improve retail tactical planning through an aligned and integrated set of demand and supply plans (Dreyer et al., 2018). On the supply side, several food products have long production lead times, such as crops, beef, and wild-caught fish, with uncertainties in both quality and yield (Taylor and Fearne, 2009). For such long-time horizon variability, S&OP may provide *reallocation* of food and stability in tactical planning and further operational planning decisions, and *prevent* food from being discarded (Dreyer et al., 2018). To manage variability, the demand (and supply) management mechanisms (Chopra and Meindl, 2007) applied should be carefully considered in S&OP in order to realize a zero-waste value chain.

2.2. Planning for zero waste and the role of digital twin technology

The core concept of ZDM, which is based on a "zero defect" or a "first time right" mindset realized through *detect, predict, prevent, and reallocate* (originally *repair*) strategies (Powell et al., 2022; Psarommatis and Kiritsis, 2022), is closely related to the S&OP process in the food value chain (Dreyer et al., 2018). Through the alignment of supply-facing and demand-facing activities (including alignment with suppliers and customers), the medium- to long-term supply chain planning process in S&OP coordinates cross-functional plans into a unified set of plans (Oliva and Watson, 2011). The cross-functional integration of plans supports the detection and prediction of anomalies and prevention by dampened process variability in the value chain caused by the classic demand amplification effect (Forrester, 1985). By utilizing and sharing demand information across functions and levels in a timely manner, operational reallocation (Dora et al., 2021) and adjustments such as changes to stock levels, production plans, and ordering systems can be made sooner to prevent inefficiencies and, in turn, variabilities causing waste. The traditional S&OP process, however, is more human-intensive and technologically constrained, and there is a pressing need to transform it to support technology-enabled planning.

ZDM, on the other hand, is also not a new concept, having origins dating back to the Cold War era (Psarommatis et al., 2020), but it has only lately re-emerged as a gamechanger due to the emergence of Industry 4.0 technologies (Powell et al., 2022).[1] The combination of core ZDM strategies of "detect and prevent", "detect and reallocate", "predict and prevent", and "predict and reallocate" all rely heavily on technological advancements, as does the S&OP for zero-waste value chains (see Fig. 1). In this study, among the many complementing Industry 4.0 technologies, we envision and explore in particular the potential of digital twin technology (DT) in S&OP in strengthening the link between planning and execution, and for realizing the "first time right" or pro-active "zero-waste" mindset of ZDM in the food value chain.

In recent years, DT has experienced unprecedented growth. Gartner

[1] We refrain from including a more detailed review of ZDM in the paper due to word limit constraints—the review of ZDM and the way forward is available in a recent issue of the journal (see Powell et al., 2022).

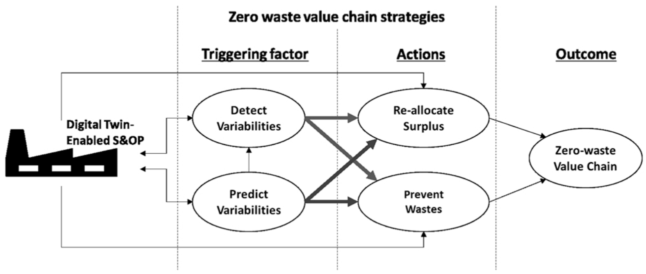

Fig. 1. Zero-waste value chain framework and strategies.

has ranked the technology among the top ten technology trends with strategic value.[2] Broadly accepted as a digital representation of a physical system, the precise definition varies across domains and applications such as in aircraft design (Glaessgen and Stargel, 2012) or in supply chains (Ivanov and Dolgui, 2021). DT allows for rendering the state and behaviour of a system in (close to) real time; it supports a two-way interchange of data and the possibility of physically interacting with the system through the digital model (Erikstad, 2017; Errandonea et al., 2020).

Digital twin-driven S&OP for executing the zero-waste strategies depicted in Fig. 1 is anticipated to benefit from the breadth of capabilities it enables: the *triggering factors*, such as the prediction and detection of variabilities, can be benefited by visualization aids, anomaly detection and alerting across the value chain, analysis of the continuously updated model of the physical system, multi-asset or actor synchronization, remaining life assessment, and so on. Moreover, planning *actions* such as waste prevention or reallocation can be aided by predicting future consequences and testing action plans, optimization, what-if and performance analysis, converting hindsight to foresight, and establishing ground rules for automated or autonomous systems (Erikstad, 2017; Barat et al., 2019; Burgos and Ivanov, 2021). In sum, digital twins are a leap-forward and provide functionalities beyond those provided by conventional simulation or historical data-driven decision models by switching from anticipated cases to sensor-based observations as the model's primary input and from simulated time to (near) real time (Erikstad, 2017; Errandonea et al., 2020; Burgos and Ivanov, 2021).

The term "digital twin" is often confused with "simulation-based digital model" or "digital shadow" (Kritzinger et al., 2018). In simulation-based digital models, all data are entered manually; there is no direct exchange of information between the physical system and its digital model. A digital shadow is an accurate digital model that is unidirectionally linked to the physical system and continuously updated in response to any changes in the system (Kritzinger et al., 2018). In addition, there are many types of digital twin models, such as "*data-driven digital twins*" (Erikstad, 2017; Friederich et al., 2022), "*physics-based digital twins*" (Erikstad, 2017; Kurvinen et al., 2022), and "*behaviour-based digital twins*" (Stary, 2021; Barat et al., 2022).

DT finds uses in a growing range of applications and situations within the manufacturing (Ding et al., 2019; Mandolla et al., 2019; Zhou et al., 2020; Li et al., 2021), operations (Min et al., 2019; Zhang et al., 2022; Serrano et al., 2021), and supply chain literature (Ivanov and Dolgui, 2021; Park et al., 2021). However, the possible uses of DT in S&OP or even more generally in (tactical level) planning, let alone for actualizing zero-waste value chains, are poorly understood. We address this research gap in the food retail context.

2.3. Resource orchestration perspective

As a critique of the resource-based view, it is well observed by now that mere possession of valuable, rare, inimitable, and non-substitutable (VRIN) resources does not result in superior performance or any competitive advantage (Ketchen et al., 2014). It is necessary to strategically accumulate and leverage the resources to develop specific capabilities and achieve the desired outcome (Gligor et al., 2022). Resource orchestration theory, as an extension of the resource-based view, explicitly addresses the role of managerial actions in effectively structuring, bundling, and leveraging firm resources for value creation (Sirmon et al., 2007, 2011). The structuring process involves accumulating, acquiring, and divesting organizational resources to manage their resource portfolio. The bundling process involves enhancing or creating new capabilities from the resources. The leveraging process enables exploiting the capabilities for performance and competitiveness.

Being a high-level theorization, the resource orchestration perspective provides the opportunity for more contextualized explanations for how resources are accumulated, combined, and exploited (Gligor et al., 2022). The research looks into digital twin driven planning for realizing zero-waste food value chains by contextualizing and reflecting on the managerial actions involved in the orchestration process.

3. Methodology

We adopted a reflective conversation approach (Walsh et al., 2015) to envision the role of DT in S&OP for zero-waste food value chains (Table 1 summarizes the data sources which is illustrated in Fig. 2). This involved first setting the case context within grocery food retailing. We interviewed four senior managers from the case company in addition to the secondary data from reports, and other internal publications, about the tactical planning process and the challenges of a grocery retail chain as well as the role of technology in their planning and replenishment.

The grocery retailer (we refer to them as Case X here onwards) is a Norwegian full assortment supplier of groceries to the consumer market. The assortment of approximately 8500 products is divided between the categories of dry, frozen, chilled, bread, and fruit/vegetables. The business model of Case X is integrated retailing and wholesaling, but the operations of the retailing and wholesaling are split into two different business units. The wholesaler unit is responsible for inbound, warehouse and inventory management, and outbound logistics to stores, while the retailer unit organizes the assortment, suppliers, sales, and stores. The company has a national network of multiple grocery stores. Avoiding surplus food and food waste is strategically important for Case X, which has targeted metrics for reducing food waste. However, as a full-range grocery retailer competing on price, availability, and service level, balancing supply and demand to reduce waste and surplus food is challenging.

Next, we synthesized the niche literature at the intersection of S&OP, the food retail industry, and waste in food value chains to identify the variabilities causing waste that could be addressed through digital twin enabled S&OP.

For exploring the potential of DTs, we recruited (1) an S&OP consultant (who we refer in the text as "SOX"), (2) a DT expert (who we refer in the text as "DGX") for reflections on the potential of DT in food S&OP, and (3) a group of three senior leaders from a replenishment and forecasting solutions provider who have been developing DT models to support S&OP (We refer to the solution provider as "SSP" in the text - we do not differentiate between the firm's participants as their comments are complementary and consensus based and not contradictory). The reflective conversations with them were based on their experiences and perspectives and our inputs on the case context and insights from the literature on food waste, planning, and DT capabilities. The approach is justified by two explicit reasons: (a) *triangulation* (the approach bridges the distinct knowledge gaps and supports making sense at a holistic level): DT experts have limited knowledge of the tactical planning specificities in food retail; S&OP consultants are less aware of the technicalities of digital twins; the literature misses the link between S&OP and digital twin technology, and (b) *the futuristic nature of the*

[2] https://www.gartner.com/en/newsroom/press-releases/2016–10–18-gartner-identifies-the-top-10-strategic-technology-trends-for-2017

Table 1
Knowledge sources and purpose.

Knowledge source	Description	Purpose
A Norwegian grocery retailer (as case context)	Secondary data and documents Interviews with four senior managers 1. Manager, responsible for replenishment 2. Senior project leader, logistics 3. Project manager, forecasting 4. Development manager, logistics	To understand the tactical planning process, challenges, state-of-the-art, and opportunities for improvement
S&OP consultant	Operates in the US region and has 20 + years of experience in supply chain and planning. He has been consulting for a major food producer among many other clients in other industries. The client has in place an advanced or mature S&OP process.	To reflect on the planning challenges in the food industry and how DT could support S&OP
DT expert	Principal scientist at the software research centre of a multinational information technology and consulting company. Specializes in digital twin technology and modelling and simulation, with 20 + years of experience in applied/industrial research.	To reflect on the technicalities, potential, and how DT can be implemented to support S&OP for zero waste
DT-based S&OP software solution provider	A team of three participants from a European planning, forecasting, and replenishment software solution firm with a global customer base and having clients from the retail, wholesale & distribution, and manufacturing industries 1. Head, CPG values chains focused product area 2. Senior product marketer focusing on CPG offering 3. Head, forecasting & replenishment product area	To understand the potential and future of the digital twin enabled supply chain/planning and its possible impact on zero-waste value chains
Literature	Literature crossing food waste and S&OP in food production and grocery retail	To guide and interpret the reflective conversations with regards to zero-waste value chains

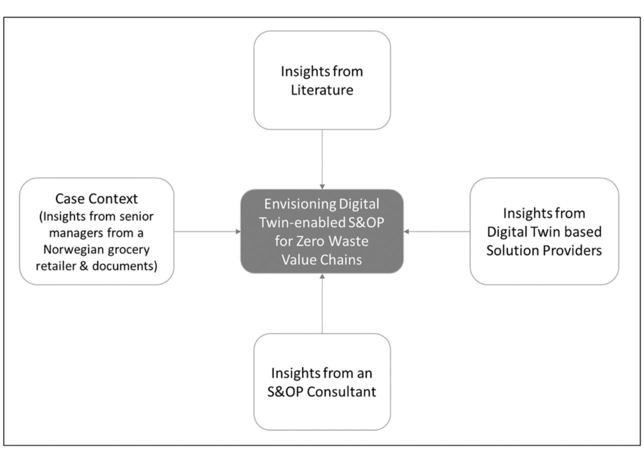

Fig. 2. Knowledge framework.

problem: the companies are curious but are not deeply aware of how DT may be leveraged in planning, and there exists a distinct void in research at this intersection of tactical planning and zero-waste value chains.

For rigour and transparency in data analysis, we followed the Gioia technique (Gioia et al., 2013). We developed a comprehensive narrative of all the interviews. We began with first-order analysis of the reflective interactions, which involved in vivo coding to capture the respondents' language. We then consolidated these codes into respondent-centric first-order empirical findings (see Figs. 4, 5, and 7 for the synthesis, and Appendix A1-A3 for the represntative quotes).

4. Findings

Fig. 3 shows an overarching framework of resource orchestration for DT-enabled planning for zero-waste. The figure illustrates the managerial actions involved in the structuring, bundling, and leveraging process. The findings reveal that orchestrating resources for the use of digital twin in S&OP is a potential solution to the retail food waste problem.

4.1. Structuring

In resource orchestration, structuring refers to the process by which organizations or managers, through accumulation, acquisition, and diversification, manage their resource portfolio (Sirmon et al., 2007). Unlike in other technologies, effective DT deployment relies heavily on a thorough understanding of the system in question, the complexities involved, and the purpose of the deployment. Thus, organizations need to adjust their resource portfolio through the *acquisition and accumulation of intellectual capital*—the specialized and intangible knowledge resources available internally (the knowledge of the domain and system complexities) and those incorporated into the resource portfolio from external sources (the deployment of DT would generally require expertise from outside). The *acquisition* and *accumulation* of intellectual capital emerge as the aggregate dimensions of the structuring process and are reflected through two managerial actions (second-order themes), namely, "assessing between the many models" and "sensing how detailed to model". Fig. 4 synthesizes the empirical findings to 2nd order themes and the bundling dimension.

4.1.1. Assessing between the many models

DT aid in the analysis of why a system is behaving in a particular way, why it is not achieving its goals, how could it behave differently, or what would be the impact of introducing specific changes for improvement. For example, with the war in Ukraine, supply lines of grain are disrupted [3] and organizations need to rethink how they want to operate differently—they might have to redesign their supply chains or replan demand and supply considering the changing geopolitical situation. Digital representation of the system could facilitate analysing and rethinking what could happen to arrive at a more informed and objective decision. Nonetheless, many of the parameters and factors used in the models are impacted by both the ERP systems (inputs such as batch sizes or inventory transactions) as well as by, for example.

- **AI analytics,** such as machine learning driven forecast
- **3D-modelling,** such store planograms and floor plans to accurate information of the physical space available in different stores for optimal replenishment decisions
- **Optimization**, such as probability-based optimization of fresh products' replenishment orders or optimization of main replenishment days (weekdays when each item is being replenished) using swarm intelligence

[3] https://www.faktisk.no/artikler/0vp5y/flere-medier-brukte-feil-tall-om-kornproduksjonen-i-ukraina

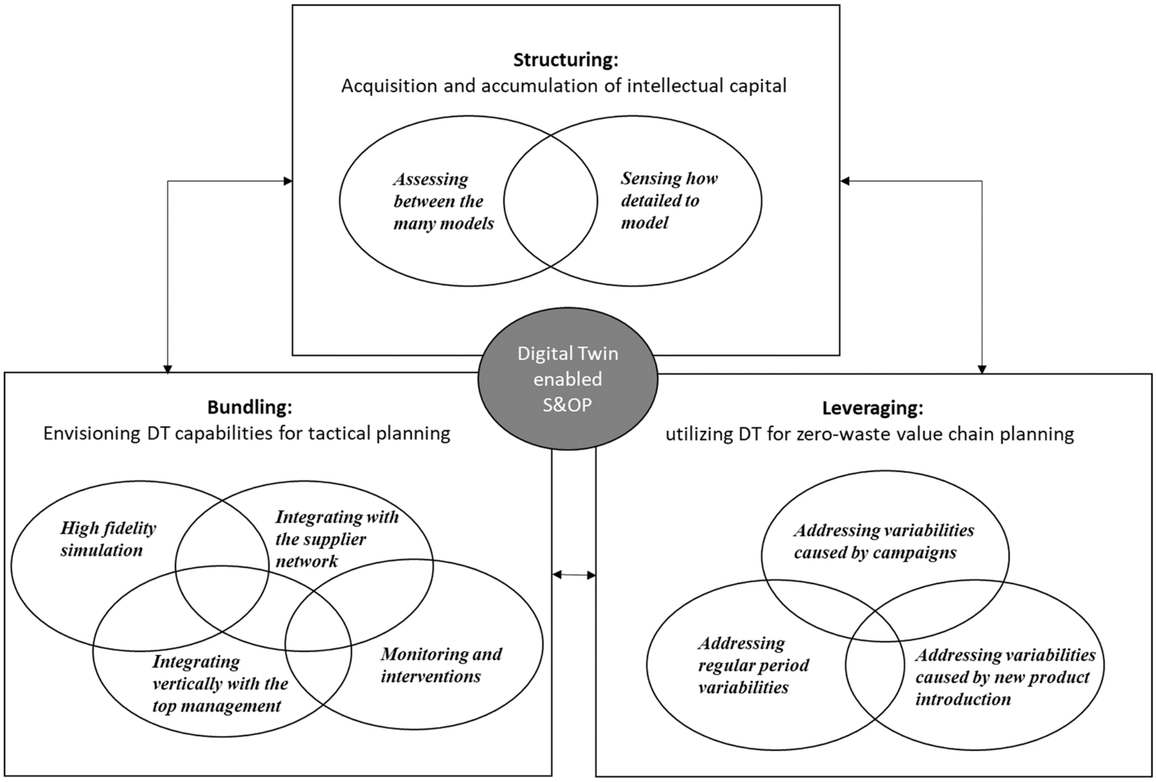

Fig. 3. Resource orchestration process for DT-enabled S&OP.

- **Statistical modelling**, such as modelling of fresh item consumption through First-In-First-Out rate
- **Rules & heuristics,** such as allocation of scarce inventory (caused by e.g. delayed shipments) in accordance with the inventory need and business importance of different sales channels

Historical data-driven models (using statistical or AI/ML-based approaches) (Min et al., 2019) can represent stable systems, but they need "relevant" data for accurate forecasts. That is, the data should not be affected by a new event, like a pandemic, that renders the past patterns of behaviour unreliable and potentially tampers with the integrity of the data. Survival bias (Hildebrandt, 2021) (as in considering only "surviving" observations and ignoring those missing), can also result in faulty forecasts. To cope with uncertainties and changes, it is necessary not just to rely on data and analytics but also to augment in the model the new behaviour that people are adapting (demand patterns/preferences). Data alone is not adequate to comprehend or anticipate the system behaviour, especially in dynamic environments (Barat et al., 2022). The behaviour of the entities within the system must also be modelled.

> Even if one has 10 years of data about consumers and how they behave, the data still won't suffice, or even be reliable after the pandemic, that has led to new patterns in behaviour and supply chain landscape. Digital twins essentially being models, by definition no model is perfect, but unless the model closely represents the reality, it is same as to garbage in and garbage out, and without any value. – DGX

> It is possible to have a calculation, on what will be waste if we have some assumption on the customer behaviour.- Case X

4.1.2. Sensing of how detailed to model

Coarse- or fine-grained simulation models may be developed depending on the purpose of the digital twin. A "coarse-grained" model simulates system behavior at a higher level of abstraction (Pourbafrani and Van Der Aalst, 2021). Stock and flow-based system dynamics model is an example. "Fine-grained" models, such as agent-based models (suited more for socio-economic or political systems) are ideal for capturing and understanding the system's heterogeneity and individualistic behaviours. By modelling the interactions between numerous individuals in the system, bottom-up approaches can capture micro-behavior and analyze the emergent and consequential macro-behavior (Macal and North, 2005; Barat et al., 2019). For example, when three people are in a room and two of them are friends, how the interactions will emerge will be very different compared to if none of them knew each other. Nonetheless, a fine-grained approach comes with its own limitations. Scaling beyond a limit (since the model could encompass a very high number of agents and their behaviours) demands very high computing power, in addition to its modelling complexity, which requires an extensive understanding of the application domain. Hybrid models can be used in such cases. This would require thorough domain or system knowledge and understanding (of what kind of concepts are there, how one may capture those concepts in a precise way, and what are the micro- and macro-behaviours and emerging behaviour that are seen in this domain) to assess where one does not need a level of detail and can adopt a coarse-grained approach and where one truly needs a fine-grained approach.

> I developed a digital twin of the city to predict COVID's spread using such a model. Viruses are unseen elements. People's movements and behaviour are unknown. How they interact with their community is also unknown. For the model to be accurate, it must incorporate demographic variations and related behaviors, such as taxi drivers meeting numerous individuals in one day. You must understand such things. You must also understand the virus's traits, how it spreads (air or contact), and what kind of contact is required. So, capture everything. – DGX

In sum, leveraging digital twins, especially in social systems, where the effectiveness of the models significantly depends on how one

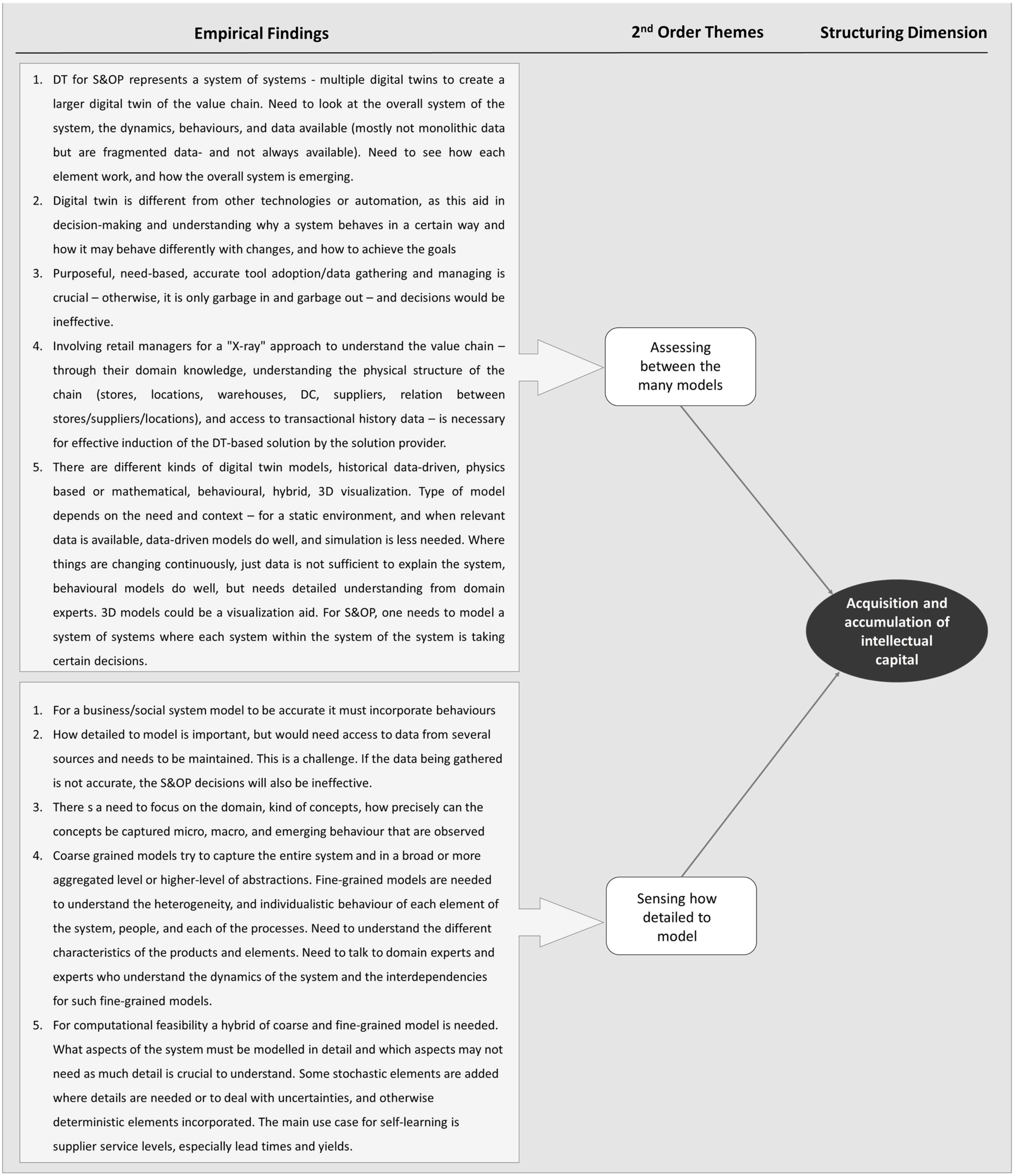

Fig. 4. Empirical findings on Structuring.

combines the approaches (such as data analytics as well as coarse- and fine-grained approaches or stochasticism and determinism) to provide a meaningful representation and assessment of the business, goes far beyond just acquiring the technology.

4.2. Bundling

Bundling refers to the process of improving or developing capabilities from a combination of unique resources. It could either involve improvements to an existing capability or creating a completely new capability (Sirmon et al., 2007). DT capabilities for planning point to the latter and is the aggregate dimension in the bundling process. We

Fig. 5. Empirical findings on Bundling.

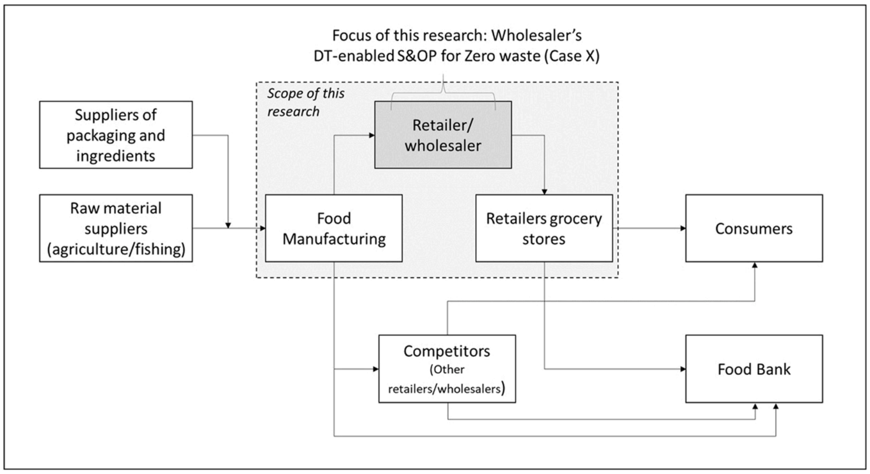

Fig. 6. Food value chain.

synthesize and present the empirical findings to 2nd order themes and the bundling dimension in Fig. 5.

4.2.1. High-fidelity simulation

DT enables *high-fidelity simulation*, which is one of the second-order themes, as illustrated in Fig. 5. It can be utilized in assessing the implications of the siloed decisions with respect to the overall goal of planning as well as to explore the many scenarios and options for deducing synchronized decisions to achieve the overall goal. In grocery retail, the complexities and the product-, supply-, and demand-related characteristics (Dreyer et al., 2018) of the planning environment (such as perishable items require faster delivery compared to others, some food items cannot be packaged together with others, some require special containers and packaging, etc.) require more of a fine-grained or hybrid approach to the digital twin model. Pure coarse-grained models will be inadequate in representing such systems that contain "multiple adaptable, self-organising, and uncertain entities (such as warehouses, trucks, products, and store), individualistic behaviour (such as product expiry), and exhibit emergent behaviours (such as availability, unavailability, and damages of products that are significantly influenced by several uncertain spatio-temporal aspects: transportation delay, inappropriate packaging with certain class of products, availability of other similar products, etc.)" (Barat et al., 2019).

> Through scenario planning, you can test out if it is actually a realistically executable plan because you can simulate that if we are doing these decisions, what are the implications on the supply chain? Will there be some bottlenecks? Do we have enough warehousing capacity to execute this plan? You can see other problems and you can decide if we need to add a new warehouse, or do we actually need to change the plan so that we can actually execute it? You don't need to guess and hope that you can do it, at a high level, but test this type of detail with the digital twin. – SSP

> As part of the S&OP process and other planning processes, it's for the planner to play around with different scenarios—what happens if your demand is higher than expected, and what happens if you don't get the materials as planned, and then thinking of the different scenarios and playing around with those and having a Plan B […] The key is to have one aligned plan. Of course, the organization is primary and then on an execution level you need to be able to quickly react to the changes when the plan doesn't go as you thought it would go. – SSP

4.2.2. Integrating with the supplier network

DT-driven planning capability facilitates *integrating with the supplier network* (or the suppliers' suppliers), a second-order theme in the bundling process that enables early warnings and adaptability in planning. S&OP has traditionally been inward looking with a focus on cross-functional coordination and perhaps maintaining contact with the first-tier suppliers and direct customers for improved demand–supply balancing (Jonsson et al., 2021). However, with rising uncertainties, changing customer needs, and supply chain disruptions, the need for assessment goes beyond these traditional planning considerations. It has become important to keep track of the suppliers' suppliers or their network and make decisions considering those. As SOX observes:

> Decisions they [suppliers' suppliers] make obviously impacts me; I must know early on whether or not I would get the delivery, or will be delayed, or if it is coming from, say, Ukraine or Russia during this war, or if there are other issues going on, so that I can deal with that. So, S&OP will start to look outward beyond the organizational walls, and to the end-to-end supply chain.

Likewise, customers and customers' data are also useful. For example, in the semiconductor industry, a manufacturer may want to follow the sales of automobiles, as they are the end users of the semiconductors. Incorporation of such information into the model can reduce the bullwhip effect and dependence on people's perceptions of demand. It could also support contingency planning of early warnings and predictions. Retailers want to engage with their suppliers because they are not getting the same service levels as before the pandemic. Suppliers may push near-expiry products to retailers. However, high automation and real-time product tracking can enable supplier network integration with digital twins. All functions may now assess the value chain effects of their actions, which may prevent siloed decisions and improve integrated planning.

> With DT, you know where and if an order will be late. Again, if there is a cause to anticipate that a shipment is late, the planner needs to be informed so that they can take preventive measures, such as adjusting the shorter-term plans beyond the agreed upon S&OP level plans. – SSP

Optimistic and pessimistic forecasts can be run through the system to plan for overtime, opening new distributions centres, and so on. As part of budgeting and at a slightly less frequent cadence, it can also support assessing extreme scenarios, such as a pandemic. The exceptions that emerge will need a follow-up on what are the root causes, how to reduce or manage them to balance demand and supply, and assess if they should bubble up in the S&OP process and involve more executives (such as the directors of demand and supply) to make broader decisions.

Fig. 7. Empirical findings on Leveraging.

4.2.3. Integrating vertically with the top management

DT capability in planning also supports *integrating vertically with the top management*, and this emerges as a second-order theme in the process. The S&OP literature largely neglects the commercial decisions involved in matching demand with supply. DT-driven planning can allow assessing and comparing between the commercial and budget implications for the demand and supply plans and could also provide inputs to strategic planning. The analysis could play a major role in the executive meeting of S&OP. Budget is what the CFO and the executives are keen about, tracking what they had agreed upon, the degree of divergence, and the causes of such divergence. Some divergences may even be considered acceptable or safe, or some could be the result of a major disruption, such as the pandemic.

With DT, the planners could be more objective in decision-making; it could be easier to run scenarios and anticipate the impacts of all of that and assess different trade-offs to see how to achieve the goals at the pre-S&OP meeting. At the executive meeting, any queries or suggestions could also be run and shown to the executives before deciding upon the plans. On the other hand, the financial plans, which are preceded by category-level planning for the upcoming years, include evaluating questions such as how much on which category, their implications on the stock or supply situations, and what is required to reach sales goals. However, these plans and assessments are at a high level, without sufficient knowledge about the actual products to be sold, how they will be distributed to the various stores and warehouses, and so on. The detailed planning for execution is often not well linked to high-level plans. This is an area where digital twin technologies can help translate the high-level plans into lower-level detailed and actionable plans for the future on individual SKUs in the store.

> We are using historical aggregated data and not aggregate what is in the system for every SKU. we are using pre-allocation, based on the data from aggregated forecast, and trying to manage the stores and the capacities at the warehouse and the transport during the process. In the future it could be nice to aggregate on micro-SKU and not from aggregated historical data- Case X

> If companies have had an S&OP process and plan in place, they still have had many point solutions that don't specifically talk to each other and then with the digital twin, I think, the main idea is really to connect everything both from a functional perspective and then from a time horizon from strategic to tactical to the operational type of planning. – SSP

4.2.4. Monitoring and interventions

Monitoring and interventions is the fourth DT capability for planning. Digital twins characterize synchronization as whatever state a real system is in, the virtual system should also be in the same state and enable data to flow in both directions between the real system and the digital representation. This not only allows monitoring in real-time but also interventions or corrective or adaptive actions.

Real-time inputs on the demand side include the different levels of aggregation based on location, items, or time at distribution centres (DCs), at the state or regional levels, country level, the forecasts and the lags (forecasted versus actual demand), which SKUs are performing, goals and divergences, and the causes behind these. One of the most important matrices on the supply side is inventory which includes inventory targets, location or levels, orders, SKUs in the DCs, plant level, location of the stock, and when or where out-of-stock occurs. The second major matrix could be demand supportability, which is the degree to which forecasts are achieved. The other important matrix is capacity and includes capacity utilization, which locations are out of capacity, which are running under capacity, whether the bottleneck lines are actually getting utilized to 100%, and so on. While real-time monitoring is not new to businesses, DT unlocks a higher potential for real-time monitoring. It integrates data from various sources into a model and incorporates historical data with real-time data, along with predicted data. Real-time monitoring with a digital twin is more than just a visualization of data and the physical object's state in real-time; mostly needed to quickly identify when things are not going as planned to re-adjust or optimize the execution – such as monitoring transit data and purchase orders' estimated time of arrival and provide near real-time e2e projections of the impacts of disruptions. It can also suggest responses to these disruptions based on demand, priorities, and alternatives such as scarcity allocation, the use of a substitute supplier, or the substitution of a product.

Planning decisions can be augmented, where the planner is responsible for assessing the system recommendations and alternatives and making the final decision. Alternatively, it may be automatic or autonomous, where the system generates the final optimal decision (while the planner may assess and override the decision if necessary). Kiil et al. (2018a) demonstrated the effectiveness of an automatic replenishment system and urged practitioners "to apply appropriate replenishment programs according to the product characteristics and especially the shelf life", which could suitably be assessed within a digital twin. Optimization techniques or a reinforcement learning or genetic algorithm work well in the autonomous space and can potentially minimize wastes while maximizing product availability (Barat et al., 2019).

> Although S&OP is a formal process where ideally in week one you do this, in week two you do that, and then in week three and week four, in reality, this is not the case. If I start in week one, it's not that everything is good and done, and I move on to week two without having to worry about what I did in week one. So in reality, this is where digital twin capability could support, where decisions are continuous and activities are iterative or dynamic. It's sort of homologous and sort of all done together. – SOX

4.3. Leveraging

Leveraging refers to the process of creating value by aligning the capabilities of the organization (Sirmon et al., 2007). In line with our research purpose, the aggregate dimension of the leveraging process in this study is *utilizing DT for zero-waste value chain planning* in the context of Case X (see Fig. 6) and is reflected through the managerial actions (second-order themes) to realize a zero-waste strategy. Fig. 7 synthesizes the empirical findings to 2nd order themes and the leveraging dimension.

Refer to Table 2 for a reflective analysis comparing and contrasting the causes that lead to waste with the benefits that could be gained through using digital twins.

4.3.1. Addressing regular period variabilities

The stores of Case X are replenished either by the automated replenishment system or by manual ordering by the store manager on a weekly and a daily basis at the SKU level. Automated replenishment programmes alone can reduce 20% of food waste (Kiil et al., 2018a). However, there still remain variabilities causing waste, which could be prevented. For example, demand for some products could be affected by *weather fluctuations or changes* that some automated replenishment systems may even factor in, but is usually not quite effective as Case X stated; weather changes quite rapidly from day to day, and the information is too late to process through the value chain and have that optimal amount of stock in store. This could cause overordering, leading to waste, and could be avoided through a better integration and visibility across the value chain.

DT in the context of S&OP is a detailed simulation model of an actual value chain (a system of systems), that uses real-time data and snapshots to forecast value chain dynamics. All relevant supply chain echelons, combining transparency into both pull and push-based item flows on the day-SKU-node level for several months, even a year ahead, largely driven by machine learning driven demand forecast, order proposals and

Table 2
Synthesis of the causes of food waste and the potential of digital twin-driven planning.

		Leveraging Digital Twin-driven planning for Zero Waste			
	Causes of wastes (from literature)	Effective integration	Monitoring & intervention	High fidelity simulation and predictions	Synthesis of the reflective conversations/interviews ZWV strategies Detect – Prevent | Detect - Reallocate Predict – Prevent | Predict - Reallocate
Uring Regular period variabilities	Weather fluctuations or seasonality affecting demand		✓		Detect-Prevent *Such variabilities could be detected and the decisions may be adjusted to the changing conditions for waste prevention. Mostly, at a store level considering the weather data may be too late as the supply chain may not be able to promptly react to cope with it. At a more tactical level such scenario planning can help set guidelines for more effective decisions at the execution level.*
	Cold chain infrastructure		✓		Detect-Prevent *Such variabilities could be detected to activate warning or maintenance alerts to prevent waste or surplus. Temperature conditions are measured and maintained during transport. But such applications/technologies are not commonly used as inputs to improve planning.*
	Short shelf-life		✓	✓	Predict-Reallocate *The model can predict spoilage of products based on the product type and other conditional information and schedule reallocation to food banks. Using batch level expiration dates and projected inventory requirements to predict spoilage and reallocation to stores is business as usual. Advanced models can also help in store-level spoilage predictions.*
	Information asymmetry	✓			Detect-Prevent *Real-time data acquisition and sharing can prevent information asymmetry and improve integration with the suppliers or customers. This could avoid miscommunication or misinformation, or misjudgement causing wastes. Systematic and timely data sharing (*e.g. *real sales, forecast, order plans, inventory levels, planned promotions, assortment and range changes, supplier availability and lead times and expiring inventory) and the 2-way collaboration of DT has big potential in reducing wastes in value chain. The retailers and suppliers are wanting better collaboration capabilities, and increased activity in implementing the capabilities.*
	Human errors in stock rotation, shelving, stacking, or handling		✓	✓	Detect-Prevent *Such variabilities could be detected to activate warning or maintenance alerts to prevent wastes. Nonetheless, practical use cases are still rather rare.* Predict-Prevent *The model can predict if such errors are more likely with new recruits or temporary staff or during peak or holiday seasons and activate early warnings to prevent wastes.*
	Forecasting error	✓		✓	Predict-Prevent *Better integration with the customers can provide a better understanding of their buying behaviour which could improve forecasting. Additionally, the associated conditions, such as sales or campaigns of competing outlets, inputs on weather changes for seasonal products etc., may improve forecast and reduce wastes. Systematic data sharing, (*e.g. *Point-of-sale, forecast, order plans, inventory levels, planned promotions, assortment and range changes, supplier availability & lead times, expiring inventory) combined with machine learning and demand sensing has big potential in reducing wastes in value chain through better forecast accuracy.*
	Mega-trends	✓		✓	Predict-Prevent *Consumer behaviour towards a new product could be predicted based on the assessment of the patterns in purchasing, social media activities, and also comparable/similar products* etc.*, that are indicative of any emerging trend and that could result in not purchasing a new product. Awareness to such assessments can improve planning effectiveness and prevent wastes. Nonetheless, this is still not very common in practice though relevant for customer insights.*
Variabilities caused by campaigns	Increased safety stock for high service levels	✓		✓	Predict-Prevent *High stock levels are a consequence of expectations, uncertainties and variabilities. Through better integration with suppliers and customers variabilities and uncertainties can be predicted. This helps in optimizing the safety stock levels and in turn prevent wastes.* *"I have seen even* e.g. *0,5 + pp forecast accuracy improvement and forecast bias by more than 20 pp for products with promotions using point-of-sales data and machine learning forecasting, which have been challenging or very manual for slow-moving products."*

(*continued on next page*)

Table 2 (*continued*)

	Causes of wastes (from literature)	Leveraging Digital Twin-driven planning for Zero Waste: Effective integration	Monitoring & intervention	High fidelity simulation and predictions	Synthesis of the reflective conversations/interviews ZWV strategies Detect – Prevent | Detect - Reallocate Predict – Prevent | Predict - Reallocate
	Forecasting accuracy	✓		✓	Predict-Prevent *Through better integration with the customers and also modelling the activities of the competitors and their campaigns, forecasting accuracy could be improved, thus preventing wastes. Forecasting in some form is done by every company and the development through AI and ML improvements has been quite rapid in the past years*
	Competitors' actions	✓			Detect-Prevent *Competitors'campaign inputs could have an impact on planning as some of the consumers might already have bought the products, thus preventing wastes. Competitors' actions and events can and are often modelled to understand implications on own sales.*
	Consumers forward buying behavior			✓	Predict-Prevent *Campaigns like "buy-one-get two-free" can lead to consumers buying more than they need and in turn household waste. Such concerns are usually not within the scope of planning. Digital twin-based planning could help in evaluating such trade-offs in food surplus handling such as between discounts on short shelf life products (pushing out the waste problem to consumers) and reallocating to the food banks. Nonetheless, in practice this is not the main driver behind retailers' or CPG companies' decision making.*
Variabilities caused by new product introductions	Impact on alternative products			✓	Predict-Prevent *New product introduction is affected by the alternative products/ cannibalisation. Through digital twin enabled planning the consumer buying patterns and their impact on both the new and the alternate products can be analyzed to predict the market response. Analysis of such usually overlooked aspects before launching the product in the market can prevent surprises and wastes. It takes into account cannibalisation and halo effects during planning of the new product launch.*
	Forecasting error			✓	Predict-Prevent *For new product information, historical data is unavailable. What if analysis on a fine-grained digital twin for planning, modelled to predict the behaviour of the targeted consumers could prepare the managers to plan better for unforeseen events, and thereby prevent wastes. In practice, however, totally new product innovations in fresh products are rather rare, meaning that data from existing products can be used to estimate the demand for the new.*

projections, considering transactions, parameters and factors that impact orders such as current and projected inventories, safety stocks, delivery schedules, lead times, store space etc. From this, planners can have end-to-end time-dependent visibility into impacts of business decisions (e.g. changes in supply chain, abnormal situations, disruptions, or inventory shortages), and work out action plans and contingencies. Once the plan is done, it is ready for automatic execution. It can automatically model the impacts of the restrictions and enables informed, automated decisions to mitigate the business impacts of new restrictions caused by disruptions such as late delivery or production line breakdown or integrate to external and third-party systems near-real time to enable quickest possible reaction.

Some imported products might have a longer lead time and, thus, a *shorter shelf-life*, or even failure in timely maintenance of *cold chain infrastructure* could emerge as a cause for early spoilage (Mena et al., 2011). Suppliers could be irresponsible or disinterested in engaging proactively in maintaining cold storage to reduce waste (Filimonau and Gherbin, 2017). Shelf-life, in particular, can vary depending on the product, packaging, and refrigeration quality. Such nuances are not considered in the conventional planning and forecasting process, leading to unwarranted wastage. Digital twins could monitor such variabilities through Internet-of-things-based infrastructures (Ben-Daya et al., 2020). Information asymmetry or *lack of information sharing* is a notable cause behind waste in food value chains. Digital twins could facilitate incorporating information of the suppliers and their capabilities and assessing the possible implications. Further, social media data today serves as an important source to inform of any supply chain disruptions or consumer demands and reactions in real time (Singh et al., 2018) that a DT could leverage to improve *planning and forecasting*. Such considerations could predict possible food wastage associated with what Mena et al. (2011) refer to as "*mega trends*"—that is, an increasing demand for fresh products and products out of season, and a move away from products with preservatives.

> How consumers or shoppers actually move around in stores and this kind of modelling, from a space perspective, where does it make sense to put certain products, to logically optimize the store experience for the consumer, thus enhancing service levels while not compromising waste. – SSP

Even with DT-enabled planning, uncertainties will inevitably remain, and there will be surplus food products nearing the end of their shelf-life. Case X donates all of the surplus to food banks. Nonetheless, such donations are more often ad hoc (Filimonau and Gherbin, 2017), and donors typically behave passively due to cost considerations (Sundgren, 2022). Given the various data points it evaluates, a digital twin could predict the possibility of food surplus and provide alerts to food banks well in advance for timely distribution.

> It's about 40% reduction in waste just by managing the supply chain better. Typically, we have also been able to increase sales at the same time, so it hasn't meant that we've just used inventories, but rather we've been able to have the right product in the right place and at the right time. The reasons being, for example, utilizing the weather

information; some products are weather reactive, and when there's good weather we have more availability, and when there's bad weather we have less, and all these drive supplies and reduction in the waste. – SSP

4.3.2. Addressing variabilities caused by campaigns

In week 10, the chain manager of Case X decides the specific campaigns in the different store chains specifying what, when, and the volume. On a yearly basis, the chain manager decides the number of campaigns in agreement with the suppliers. Case X organizes campaigns to drive sales and demand—campaign planning is, therefore, one of the significant planning processes, relying heavily on high forecasting accuracy in order to be profitable. Approximately 10–15 people (part of assortment and purchasing) are devoted to campaign-related work. The procurement manager along with the campaign department plan the content of the campaign, involving suppliers, volume, price, and the marketing mediums (through newspapers, TV, radio, etc.). The input to the planning is calculations of gross sales volumes (SKU), which are forecast using calculations in SAP. The outcome is the difference between calculated regular sales volumes and expected sales volume increase from the campaign.

As observed by SOX, with a functioning digital twin in place, in the pre-meeting stage of the S&OP, instead of gathering for consensus building or joint forecasting (Thomé et al., 2012), S&OP leaders could indulge in what if analysis of all possible scenarios, such as *what happens if price is increased by 10%, what happens if the product promotion goes down, what happens if a different supplier is chosen*, and so on, and assess the budget and waste implications of the choices made. Such objective analysis could significantly support the decisions taken at the executive meeting.

Traditionally, S&OP focuses on cost efficiency and high service level. In fact, for campaigns the service level is as high as 98% in Case X. High service level implies *high stock levels*, and that increases the risk of wastage. Mena et al. (2011) categorized such waste as caused by *misdirected performance measures*. Nonetheless, waste/pollution reduction does not necessarily involve higher costs, and in fact could lower costs (Hart, 1995). Retail food waste may also be prioritized based on a combined score with respect to monetary and environmental impact (Dreyer et al., 2019). Promotions may also be affected by the activity of competitors if they have planned campaigns during the same time period or have recently completed one. An inability to account for competitors' actions might also have an impact on sales and waste. Furthermore, promotions of short-shelf-life products can result in household waste, since they induce consumers to buy more than they need (Mena et al., 2011). For products with a longer shelf-life, a failure to account for the possibility that consumers have already stocked up on the product as a result of the past campaign might have an impact on the stores' predicted sales and waste in the following periods. The implications of such trade-offs with typical cost-driven decisions might be analysed through a DT and at the executive meeting—total visibility and real-time interactivity is expected to lead to more accurate retail planning with less waste across the value chain.

> Especially in grocery retail and fresh products, considering cannibalization and halo impacts of campaigns on alternative products as part of forecasting and replenishment can improve the planning accuracy significantly and lead to reduced spoilage… [DT based planning helps to see the] impacts of commercial decisions such as new products, price points, and promotions to inventory, capacity and resource requirements. For example, offering promotion to product B instead of product A with projected exceeding of capacity, and immediately see if that helps to balance the supply and demand in line with business goals. - SSP

> We usually don't know what sold yesterday or when it will deteriorate once the products reach the stores. We used machine learning to anticipate what consumers buy and which expiration dates they choose. Some buy the one with the longest life left, while others choose the one with the least. Thus, we can estimate store inventory using that model. After that, we may calculate the likelihood of selling or wasting them. If we foresee waste in the coming days, we can cut product prices to sell them before they spoil or cause waste. - SSP

4.3.3. Addressing variabilities caused by new product introduction

Case X launches new products three times a year in fixed time slots/weeks—Mondays of week 8, week 18, and week 38. Thousands of products are stocked and several hundred products are renewed/changed/repackaged at each renewal period. New suppliers can be included during these three time periods per year. This requires a careful and fact-based assessment of the portfolio and the SKUs—to decide on which new SKU should be brought in or which SKUs are not doing well over the past few months, how the SKUs have been before, and what must be taken out and what must be added. The success of the product launch depends not only on the historical analysis of the existing products but also on the *forecasting accuracy* (Mena et al., 2014). With perishable products having a short shelf-life, inaccuracies in forecasting will most certainly generate waste. Additionally, the introduction of new products may lead to unpredicted demand patterns and can affect the demand for *alternative products*, which could cause waste (Mena et al., 2011). These are crucial considerations for planning new product introduction. Forecasting error may be reduced with up-to-date data mining but cannot be completely eliminated (Mena et al., 2011). In Case X, the sales volume is forecasted by using inputs from the supplier, which is seen to be subjective and over-optimistic. They also consider inputs about comparable products. The historical data are inadequate to predict the effects of new product introductions, and a lack of sufficient primary data from customers could hamper the forecasting accuracy. The order size is, therefore, set to cover between one- and two-weeks' demand. While there is a growing trend in expanding the range of products, only 5% of new products introduced survive over time. What if analysis using a fine-grained digital twin modelled to predict the behaviour of the targeted consumers could prepare managers to plan better for unforeseen events as well as find a balance between alternative and new products. Such DT models do not solely rely on the supplier's inputs but also capture the market trends from secondary sources, such as social media, media reports, and other available sources (Chae, 2015), as well as the consumers' likely behaviour. This behaviour modelling is particularly relevant for new product introduction as there is no historical data available.

> There is big potential in reducing uncertainty and unnecessary waste in consumer goods value chain around new product introductions using accurate demand forecast, point-of-sale (POS) data, cross-businesses collaboration and data sharing, and digital supply chain twin. Using POS data of products with similar attributes to the new products as references and demand profiling derived from relevant product/store hierarchies, gives most accurate prediction of the end-consumer demand for the new product, and should be used as the input for the digital twin to provide the implications of the future inventory requirements for each store or fulfilment center, distribution center and further for supplier based on assortment, introduction dates, optimized safety stocks, replenishment dates etc… POS data to model cannibalization and halo impacts of alternative products within categories. – SSP

5. Discussions

Waste has been at the forefront of the ongoing sustainability and circularity discussions. The zero-food waste strategy aims to prevent waste or reallocating food surplus through better planning. The primary causes of surplus are variabilities throughout the food value chain that are overlooked or unaccounted for due to a lack of capabilities for an integrated decision support system and visibility, and thus a more accurate understanding of what, when, and how much to order. While for grocery retailers, such as Case X, managing surplus food and food waste is strategically important, the focus of planning for a long time has majorly been on efficiency, high service levels, and cost reduction (Roscoe et al., 2020; Stüve et al., 2022; Sundgren, 2022). Nonetheless, by predicting and detecting variabilities, waste can be prevented or at least reallocated. This is independent of any additional measures that might otherwise affect efficiency or even service levels. Reducing waste can reduce costs (Hart, 1995).

S&OP as a process to align strategic goals with operations enhances coordination along the value chain for improved forecasting and demand supply integration. Technology and data are considered prominent mechanisms for coordination in S&OP (Tuomikangas and Kaipia, 2014) and their influence is only expected to grow with the advent of Industry 4.0 technologies (Schlegel et al., 2020; Wang et al., 2020; Jonsson et al., 2021). Thus far, due to technological limitations, it has been difficult to monitor, detect, or predict variabilities and, consequently, many of these were not considered in the planning process. With DT (Semeraro et al., 2021), it is now possible to model nuanced considerations for stability and zero waste.

From the above, we infer:

Insight 1: *Digital twin-enabled planning have the potential to facilitate a zero-waste value chain strategy by preventing and mitigating variability and not necessarily by compromising efficiency and service levels.*

The structuring process in Section 4 revealed that digital twin implementation is not a one-size-fits-all approach. The meaning and scope of digital twins varies depending on whether a coarse-grained, fine-grained, or a hybrid model is developed. The models may be data intensive or behaviour-centric. Digital twins supporting S&OP are different from digital twins of assets or machines that follow the laws of physics, can acquire accurate and timely data, and are fairly stable systems. It is a model of a dynamic social system that is typically too complex to be a purely coarse-grained model. A hybrid of coarse- and fine-grained models is more suited, with a special attention to which aspects are to be fine-grained and which are not. In addition, the role of the behavioural model when historical data are not available is quite significant, but it requires a thorough understanding of the context, which the digital twin developers from technology companies may lack. The development of such a digital twin, therefore, is a gradual process that requires the digital twin developers to work closely with the managers (domain experts) from the organizations.

From the above, we infer:

Insight 2: *The deployment of digital twins to achieve zero-waste food value chains necessitates a co-development mindset and a high level of managerial involvement. These in planning systems are not well suited as generalist packaged solutions.*

The purpose of S&OP translates to effective decision making that is aligned with the strategic goals and operational capabilities. With the deployment of digital twins, the decisions may now be categorized as (a) those that are subjective, informal, or more holistic and require human control but may be aided by a decision support system or digital twin—we refer to them as "augmented" decisions, (b) those that are less subjective or not holistic, but complex and conditional, and are aided by machine intelligence but without human control—we refer to them as "autonomous" decisions, and (c) those decisions that are structured, routine, or actuarial—we refer to them as "automated" decisions (Padovano et al., 2018; Wall et al., 2020; Langer and Landers, 2021). Technology has made possible this translation of the many subjectivities in decisions to be structured and objective (Langer and Landers, 2021). The traditional S&OP process reflects this subjectivity by requiring many meetings with representatives across functions to make joint or consensus-based decisions. Coordination through formal meetings at fixed intervals has been at the heart of the S&OP process. The purpose of such formal meetings is to reduce the silo culture of the organizations and the consequential information asymmetry and inefficiencies. With digital twins' real-time data acquisition, analytics, and predictive capabilities, many of these efforts may be repurposed. This has implications for changing the emphasis away from coordination for more integrated planning and towards system-supported enhanced decision making, which is more subjective and holistic and has a large influence on waste and profitability. Such decisions could gain from visualizations or what if analysis-based predictions and recommendations (Wall et al., 2020). Other, less important decisions may be simply automated, or they may be made to be autonomous if subjected to conditional complexities.

"Augmented" decisions, for example, could involve those associated with new product introduction or campaigns and could gain from extensive what if scenario analysis. As elaborated in Section 4, campaigns cause waste in a number of ways. Campaign planning, when supported with digital twin-based what if analysis, could improve decisions and reduce variability and waste. For example, it could model the effects on alternative products or competitor activities, as well as consumer purchasing behaviour and history, for a more nuanced assessment and informed decision making. Campaigns also lead to consumer household waste that is typically considered beyond the scope of planning. Consumers supposedly lack an awareness of the scale and environmental impact of food waste (Papargyropoulou et al., 2014). Digital twin-based planning could also help in evaluating such trade-offs in campaign planning as pushing products through "buy-one-get two-free" (Filimonau and Gherbin, 2017) when a zero-waste value chain is the strategic priority. Given that the major bulk of decisions are either autonomous or automated, managers could now focus on initiatives such as product stewardships (Hart, 1995), like engaging in consumer awareness through campaigns to train them on the benefits of organic products (such as fruits) that may look less attractive but are supposedly superior in quality.

"Automated" decisions could include, for example, automatically alerting food banks of the status and delivery schedule based on the predicted food surplus. This could help food banks to plan better as they are presently reliant on ad hoc and passive responses from the retailer (Filimonau and Gherbin, 2017; Sundgren, 2022). Digital twin-based automated decisions could facilitate food donation activities to be more proactive and reduce food wastage and human effort in monitoring and organizing deliveries. A formal donation policy with the food banks may guide such donation activities.

Digital twin-based "autonomous" decisions are relevant for assessing complexities or changing conditions without human interventions and intelligent selection from a set of alternative actions (Feldt et al., 2020). For example, when the objective is waste reduction, autonomous replenishment systems may outperform automatic replenishment systems (Kiil et al., 2018a; Barat et al., 2019). This is because traditional automatic replenishment systems generally are guided by fixed operating rules, whereas, autonomous systems are more adaptable, and involve self-learning/-organising to adjust to uncertainties and changes with warehouses, trucks, or products.

From the above, we infer:

Insight 3a: *Managers could use digital twins for planning to distinguish more objective decisions from those that are more subjective and impactful and that require special attention to attain zero (food) waste plans.*

Insight 3b: *What if analysis and visualization using the digital twin could help managers better comprehend the subjectivities and trade-offs of more impactful decisions such as product launches or campaigns; it would augment their ability to uncover data patterns and linkages. Purely objective decisions could be automated, and conditional decisions such as order replenishment could be autonomized.*

6. Contributions and conclusions

This study offers two distinct theoretical contributions. First, we extend the concept of *zero-defect manufacturing* to *zero-waste value chains*, and second, we introduce the idea of a digital twin-enabled S&OP and elaborate on how the technology can transform the traditional S&OP process to address supply chain variabilities for zero-waste value chains.

6.1. Zero-defect manufacturing to zero-waste value chains

We posit that the ZDM mindset, as well as the strategies that have previously been confined to the realm of manufacturing quality management literature (Psarommatis and Kiritsis, 2022), is a crucial step in the direction of achieving zero-waste value chains. Food waste has a significant effect on the environment all the way from production to disposal. When food is wasted, it is a waste of resources and energy that was expended in the production of that food and the emissions that resulted from it (Dreyer et al., 2019). Waste is a result of variabilities along the value chain that managers fail to predict or detect (Germain et al., 2008; Taylor and Fearne, 2009). We demonstrate how digital twin-enabled S&OP planning may be used as an intervention to predict and detect variabilities across the value chain to prevent and reallocate food surplus, allowing us to bring the zero-waste value chain concept to fruition. This paves the way for a stream of research at the intersection of zero-defect manufacturing, value chain variability, waste management, and Industry 4.0 technologies.

6.2. Digital twins as an enabler for tactical planning

While prior studies have indicated that information technology can be a game changer for supply chain planning (Ivert and Jonsson, 2014; Jonsson and Holmström, 2016; Xu et al., 2021), this study goes a step further to demonstrate how digital twins, in particular, enhance planning and coordination to realize zero-waste value chains. Digital twins can enable objective and actuarial decision-making for the hitherto complex and subjective S&OP planning decisions that require collaboration and consensus among many stakeholders. The remaining few crucial decisions benefit from augmenting managers' decision subjectivities with system-acquired data and analytics. Most notably, a digital twin-enabled S&OP process is influenced by a holistic understanding of the planning landscape and interlinkages, a real-time overview, and reduced exposure to individual or functional biases or conflicting interests, all of which were considered shortcomings of the traditional process. Future research can extend these observations with empirical categorization of the planning decisions that could be automated, autonomous, and augmented, along with the performance implications of such technology-enabled planning.

6.3. Managerial implications

This study argues for a proactive approach to address the food waste problem by preventing and reallocating food surplus rather than banking on reactive waste management and circular approaches such as landfilling or incinerating waste or recycled as by-products. Effective planning at a tactical level is particularly important for managing demand and supply and responding to variabilities in this context. By aligning strategic priorities with operational capabilities and facilitating cross-functional collaboration along the value chain, S&OP plays a significant role in the quest for zero waste. Utilizing digital twins enables visibility of supply and demand changes, real-time monitoring of the planning ecosystem, and the capacity to perform what if analysis to predict variabilities and consequences.

Additionally, this study also reveals four zero-waste value chain strategies that can be realized using digital twins-enabled planning. Digital twins could predict and prevent food waste along the value chain. The discussions ascertain the shortcomings in the traditional planning process to suggest alternative perspectives towards zero waste. These should lead managers in examining their planning variables and processes and in reviewing the need to transition to a digitally enabled planning system. Food waste has social, environmental, and economic consequences. A value chain-wide zero-waste strategy could boost competitiveness and sustainability.

Further, this study elaborates on how digital twins can be deployed based on context, contingencies, and the types of models that may serve different goals. Unlike many other technologies, the success of a digital twin is dependent on the model's accurate representation of the domain being modelled. When it comes to deploying digital twins, especially those of social systems, a one-size-fits-all strategy is not appropriate.

Author statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the Computers in Industry Journal.

Data Availability

The data that has been used is confidential.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Acquisition and accumulation of intellectual capital

See the Appendix A section here.

Representative 1st Order Data (respondents' quotes)	2nd Order Themes
"Executives want to do all of this cool fancy stuff, but they need to have the underlying data and so you find that the companies that are leading in S&OP have gone through a whole data process they have a method of gathering it, cleaning it, maintaining it, and presenting it so because again, you've heard the adage, garbage in, garbage out so even if you bring in data into the S&OP, if it is not correct, the decisions you're making are not correct, and so that's the biggest challenge. But also, an area of opportunity where you can start to leverage digital twin and now capabilities to gather data, manage it, clean it, and make it available."- SOX "When we use DT in some field, it depends on the purpose, you need to create different types of models, so as we see, if your objective is sales and	Assessing between the many models

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(*continued*)

Representative 1st Order Data (respondents' quotes)	2nd Order Themes
operations planning, it is kind of not a single system but a system of systems. And each system within the system of system is taking certain decisions and these decisions are probably optimum within those silos. But that doesn't guarantee the robustness of the overall operations. That's the problem with the process, that DT can address" DGX "So there is a slight difference between the digital twins and other technologies like blockchain or any other kind of thing because this is more of an aid for decision making or understanding the things. It is not like you just want to automate something, but it's more of a you want to understand few things… the purpose of digital twins is to help to understand or analyze systems – that is why your system is behaving like that. Then you can say that OK, my system is not achieving my goal and I want to introduce certain things and you don't know whether that will that change that you are thinking will actually help you to achieve your goal." DGX "In pure data centric technique you capture historical data and then you try to analyze and predict. So for that, all kind of statistical technique, AI/ML techniques, etc. works well. But the problem for such kind of model is they are kind of vulnerable to, which is known as survival bias. If you are operating in a very static environment and you have significant data, then data talks about everything, then you don't need any simulation. You can just interpret and data and say that what can happen in the future. By, contrast, in an environment where things are changing every day or every moment, just data is not sufficient to basically explain the system. Then you need to introduce a behavioral aspect, and then you need to simulate and see. Coarse-grained models try to capture the entire system and in a broad or more aggregated level or higher level of abstractions. The entire system of system can be captured as a monolithic model and then you can simulate or analyze to understand things." But, in business systems, you need to understand the heterogeneity and individualistic behaviour of each element of the system. You need to understand people. You need to understand each process. You need to understand if there is any product or items, that may have different characteristics. So that's why you need a more of a fine-grained model. Some people use the combinations data and behaviour-based models" - DGX "We call and X-ray approach. It's mainly for our test purposes and when we talk with customers and progress the sales cases and so on, but basically that is an approach where we in the short time, so talking about weeks rather than many months, so basically take all the customer data and what we do an X-ray on the supply chain. So basically, taking all their data, making a representation of their supply chain and try to simulate that if solution was used in optimizing the different parts of the supply chains or what would the outcome be? So that's maybe the simplest, what is a digital twin in our way?" - SSP "Customers are heavily involved, but from a technology point of view, our solution is like a platform… built based on the date from the customer. Of course, the frameworks of how demand or how different variables influence demand, they are almost universal…But we need to adjust it to the behaviour of that particular customers." - SSP "Collecting that history data from the transactional history data from the customer and then master data, defines basically the physical structure of the supply chain to be modelled as well. What are the stores in different locations in part of the supply chain, so what are the stores you have, what are the warehouses replying to those stores, what are the Central DCs (?), hostage suppliers and manufacturing sites then related to those stores and that relationships between all of these locations. Quite important part of the implementation is agreeing on how the data of the customer is mapped to the structure of our system." - SSP	
With digital twins, I've got advanced analytics, I've got artificial intelligence, machine learning, you know all of those cool things, but I need data to support all of that, and so where is that data? who's maintaining that data? who's managing that data? Generally in digital twin implementations, data is the biggest issue that you're going to have. Executives of course want to do all of this cool fancy stuff, but they need to have the underlying data. You would find that the companies that are leading in S&OP have gone through a whole data process; they have a method of gathering it, cleaning it, maintaining it, [without which] it is only garbage in, garbage out - if data you bring in S&OP is not correct, the decisions you're making are not correct, and so that's the biggest challenge." SOX "I developed a digital twin of the city to predict COVID's spread using such a model. Viruses are unseen elements. People's movements and behavior are unknown. How they interact with their community is also unknown. For the model to be accurate, it must incorporate demographic variations and related behaviors, such as taxi drivers meeting numerous individuals in one day. You must understand such things. You must also understand the virus's traits, how it spreads (air or contact), and what kind of contact is required. So, capture everything." – DGX "You need to think about - I would not go into detail level for certain things, so you use coarse grained model there, and for a few things, you need more fine grained way of thinking so you combine the two"- DGX "When you say that, OK, there are machines, there are people and there are functions/partners (a combination of people and certain machines). And if people are behaving slightly differently, your productivity could be very different. So in that sense you need to consider each of the people. Each of the person probably as a kind of element in the digital twin, so it's not a monolithic thing. So that's one extreme end of the use case where you have to focus on each element and sub element and all those things and then you construct a digitial twin.In another case, you probably don't want to understand that people's productivity or how people's productivity is contributing to the overall operations and all. So you are just focusing on the macro entities or macro behavior of the system. In that case, you can just create one monolithic model for the entire thing and it will help you to understand certain things at macro level."- DGX "To deploy DT, you need to focus on the domain. So what kind of concepts are there? Whether or how can we capture the those concepts in a precise way? What are the micro behavior, macro behavior or emerging behavior that are seen in this domain and so on.So these are very basic things that you need to consider and then once you create a virtual representation, the next thing is a validation. So for example you can create a digital representation of anything, but how do you ensure that this representation is faithful representation of the reality? So that is a very challenging job" DGX "There are so many points where we could add stochasticity and evaluating what that should be for thousand different points, is really hard. So, we've selected points where we have it and then for the rest we just deterministically calculate forward. We utilized the stochastic nature of the world in parts of the solution. So, for example, when we try to understand how much stock we should keep for individual products in individual stores, there we kind of estimate the likelihood of us running out of products in a stochastic manner. I think if you would do like really long-term scenario planning type of activities that you would like to test out different supply chain setups and then I think the more stochastic way of adding a noise and randomness to that kind of simulations would show you maybe some outliers situation, For example, to go over my capacity limits in truck or warehousing limits and so on" SSP "Building such models for a retail supply chain with all of those facilities, it would be a huge task. They, of course, don't need to be as ambitious though, but where do you draw the line that what is enough detail, and what is not. And that's why we have decided to go and add in places where we see it's needed and then otherwise, we go that deterministic." - SSP	Sensing how detailed to model

Appendix B. Envisioning DT capabilities for tactical planning

See the Appendix B section here.

Representative 1st Order Data (respondents' quotes)	*2nd Order Themes*
"Typically what you do, you introduce change in a real system and try to understand what will happen, but that requires building that system, implementing things, and such kind of things which is very cost and effort intensive…People generally try out things, you get the feedback from their reality and then it try to refine and such kind of things happen. So instead of doing that, can you create a virtual representation and introduce the change in that representation and see what would be the consequence. So that's one way of adaptations. It helps in adaptation. It helps if you have something in mind about the supply chain" – SOX *"Scenario based planning would be more useful. For example, we could use it in terms when lock downs and closed borders to Sweden. We did do some scenario analysis there. The war in Ukraine, we also did some scenario analysis, so it is not like we do not use it at all."* – Case X "Through scenario planning, you can test out if it is actually a realistically executable plan because you can simulate that if we are doing these decisions, what are the implications on the supply chain? Will there be some bottlenecks? Do we have enough warehousing capacity to execute this plan? You can see other problems and you can decide if we need to add a new warehouse, or do we actually need to change the plan so that we can actually execute it. You don't need to guess and hope that you can do it, at a high level, but test this type of detail with the digital twin."- SSP "As part of the S&OP process and other planning processes, it's for the planner to play around with different scenarios - what happens if your demand is higher than expected and what happens if you don't get the materials as planned, and then thinking of the different scenarios and playing around with those and having a Plan B… the key is to have one aligned plan. Of course, the organization is primary and then on execution level you need to be able to quickly react to the changes when the plan doesn't go as you thought it would go" -SSP "If the supplier of milk says that we only can give you 1000 cartoons of milk in a given week, but you actually would need 2000. So, then we actually need to take that information and reflect what is the impact of that then back to the stores. So, it kind of runs the simulation first in one direction and then the other direction. And that is then the kind of virtual replica of the actual supply chain; all the information is flowing there back and forth. The data is captured in near real-time, which is on a daily basis all the data in the twin is updated, or even multiple times a day." - SSP "Now due to this global war and all kind of things, probably many things are disrupted, right? So you need to think about how you want to operate very differently. So that means you have to design your own supply chain in a very different manner based on the geopolitical situations which are emerging." -SOX "One huge advantages of a digital twin is you've represented that solution. I can now start to run scenarios and evaluate scenarios. So what happens if I increase by 10%? What happens if my production goes down? What happens if I use an alternate and take production from another place? Or if I use an alternate supply you can start to evaluate this and this is where the CFO then comes in. You can start to put numbers behind it and start to see what's the cost of doing it? Whether that's a short term investment or a long term investment" – SOX "Then you can start to evaluate those scenarios in the pre-S&OP and in the executive S&OP these inform the bigger decisions" SOX	High fidelity simulation
"So far we've been talking within the four walls of the organization, you've got suppliers, you've got customers, it starts to go outside of that. So on the supply side, I can start to also show my tiers of suppliers"- SOX "As a kind of follow on to the pandemic and challenges that we've seen globally in the supply chains and so on, we've seen a lot more interest among our customers on kind of expanding the scope of the planning to really start to actually collaborate with other partners in the supply chain. Retailers want to build capabilities where they actually collaborate together with their suppliers as they have not been able to get the same service levels from the suppliers that they have been able to with traditional methods before the pandemic. This has gained a lot of interest in recent months and years and so on because of the scarcity issues. With digital twin capabilities of the high level of automation and visualization you can actually effectively do that collaboration as well." - SSP "We are working quite heavily on the fact that companies would be able to track the flow of the goods pretty much in real-time in, in the global supply chains. When you have global flows of goods across a complex network, you want to understand where the ships are and where the trucks are going, be able to seamlessly integrate with other solution providers who, for example, provide this kind of information in real-time from the trucks, ownerships, and so on. So, you really know where the specific order is at the moment and is there a reason to expect that there is a delay from the expected delivery time and so on." - SSP "The whole system is trying to do the best for managing the demand process. We are also looking at the costs in the value chain and it is not given that the process should be totally demand driven. It could be that in the future it should be a calculation also on the costs. Because we are now serving the stores with what they need and the warehouse and what they need for the demand, but we are not really thinking about how to minimize the transportation costs and how to do a manipulation with the needs to fill up the track. And that is a complicated system issue as well, trying to connect the demand process with the cost driven process to move the goods." – Case X "With DTs, you know where and if an order will be late. Again, if there is a cause to anticipate a shipment is late, the planner needs to be informed so that they can take preventive measures, such as adjusting the shorter-term plans beyond the agreed upon S&OP level plans."-SSP "A lot of optimization possibilities and opportunities. So as an example, if we have local producers of convenience food or meat products for whatever fresh products. So, when the retailer is purchasing a certain big batch, so how do we optimize the production of that specific batch at the production facility and a kind of optimize the freshness and availability on the store shelves as well? So that we don't from a manufacturing perspective, we don't produce a big batch which is then sitting in the warehouse of the supplier for a few days before it's actually shipped to retailers. So, there's I think a lot of lot of those shelf-life days that we could still optimize in many situations by synchronizing that operations in a better way." SSP	Integrating with the supplier network
"Two years ago when COVID hit, nobody had planned for that in December of 2019 or January 2020, but in March and April all of a sudden things changed, and then S&OP had to react to that. So yes, you were going to align to the budget and then start to see why are there discrepancies within the budget and then what can we do to get on track or do we have to redo the budget numbers based on what we're seeing in S&OP." – SOX "The financial plans, that is how much a company is planning to sell follow some category-level planning for the upcoming years which include assessing questions such as how much on which category, their implications on the stock or supply situations, and what it takes to achieve the sales targets. But these plans and assessments are at a high level without sufficient knowledge of what are the actual products to be sold, how they go into the different stores and warehouses, and the like – the detailed planning is more often not well linked with the high-level plans." – SSP We are using historical aggregated data and not aggregate what is in the system for every SKU. we are using pre-allocation, based on the data from aggregated forecast, and trying to manage the stores and the capacities at the warehouse and the transport during the process. In the future it could be nice to aggregate on micro-SKU and not from aggregated historical data- Case X *"I am pretty sure that in the future to succeed in promotion, you need cross-function, and not only this strongly functional organization as we have today."* – Case X "Traditionally, there's been a lot of challenges, including those with technologies that they're not able to kind of take the aggregate plans more to the detailed, daily level execution levels and they have not been able to kind of discuss seamlessly on the different time horizon topics" - SSP "The main message is that digital twins can help generate these much more detailed plans for the future on individual SKUs in the store in a day - that's kind of the level where we can then take these plans each year in the end." SSP	Integrating vertically with the top management

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Representative 1st Order Data (respondents' quotes)	*2nd Order Themes*
"Although S&OP is a formal process where ideally in week 1 you do this, in week 2 you do that, and then in week 3 and week 4, in reality, this is not the case. If I start in week one, it's not that everything is good and done, and I move on to week 2 without having to worry about what I did in week 1. So in reality, this is where digital twin capability could support, where decisions are continuous and activities are iterative or dynamic. It's sort of homologous and sort of all done together." SOX "Exceptions will start to flow up as alerts, stating there are demand and supply imbalances. They will start to work those, and if they can do it, they will manage them." SOX "It brings all of the information together and supporting the decision still has to be made by people The Director of demand or supply, he knows, OK, my expert on demand side is seeing this. He's adding value and augmenting the forecast. All of that and so we believe the number is 100 not 125 or it's 115, not 120 type of thing. But the digital twin allows all of that information there people can see it and it allows them to make decisions rather than somebody spending three days gathering all the information and spreadsheets trying to figure it out." - SOX "It's mostly for ease of understanding what's happening and visualizing some impacts, but the great length of how the system is actually used is then about to automate more or less 100% everything. So, we generate the how many cartoons of milk each individual store is going to order today, tomorrow, or day after tomorrow, because that is running the daily supply chain operations. That's what the system does. How it's then used, is that we have plenty of dashboards on a high level illustrating how things are going. So, we look at the high-level KPIs, and are we operating at the level that we should be? Is there something wrong somewhere that actual planners would need to have a look at and controlling the machine on high level rather than going into details of adjusting individual orders or individual forecasts. The DT driven solution highlights the exceptions where there for some reason has been a forecasting error or something like that, so the user or planner needs to actually take action teach the solution to work in a better way in in the future." - SSP	Monitoring interventions

Appendix C. Utilizing DT for a zero-waste value chain planning

See the Appendix C section here.

Representative 1st Order Data (respondents' quotes)	*2nd Order Themes*
"With shorter product lifecycles and with changing and diverse customer demands, what companies are now doing is seeing the impact of external factors. I can now tie in weather data, a festival going on, and such pieces of information, and with a digital twin and the machine learning tools, I can start to crunch all of that information and improve the forecast." – SOX *"And then the other advantage is you can imagine in larger organizations how many decisions are getting made and then which decisions are important, which decisions can be automated. As a planner, I can only make a handful of decisions, but tell me which are the most important decisions" SOX* "It's about 40% reduction in waste by just managing the supply chain better. Typically, we have also been able to increase sales at the same time, so it hasn't meant that we've just used inventories, but rather we've been able to have the right product in the right place and at the right time. The reasons being, for example, utilizing the weather information; some products are weather reactive, and when there's good weather we have more availability, and when there's bad weather we have less, and all these drive supplies and reduction in the waste." – SSP "Especially in the grill assortment, the weather is important, and has to be done manually. We also talked about using weather forecast to improve the sales forecast, and have done some tests and not always happy with the results. Because the weather situation is a day-to-day level and can change quite rapidly from day to day. So, if you have great accuracy at store level but you do not have the same accuracy on the replenishment level, you can not act on that information and have that amount of stock in store." – Case X "When covid hit, there's no autonomous solution that could have solved a crisis like that of a 50% change in demand from central stores and like 100% increase of demand in some items that with the time frame that they could have not been able to add new warehouses to deal with that capacity demand. But they were able to keep their stores open and serve the customers with our solution. They were able to prioritize, now we're talking about the configuration of the solution to adapt to these changes. So, they were able to prioritize different products based on their importance to the customers and then also shift the demand from their other locations to another. So, this is something that I think I will never guess. There will not be fully autonomous solutions to solve this." – SSP "It can be that you for some reason haven't sold as much of those fresh products that you thought, so now the system cannot solve that anymore, but needs help from the user to decide. What do we do, do we reduce the price or what do we do? Do we give it away for these food banks? So, what is the solution to not spoil or waste all of that food that is now in the warehouse? The reason why that happened is could be unknown, for example, that sales didn't go as planned or the products arrived in the warehouse with much less expirations days left then they should have had. There's a lot of exceptions happening all the time in the supply chain. "- SSP	Addressing regular period variabilities
Generally, food and beverage are very seasonal. In Norway, the consumption of the product is going to increase tremendously in the summertime. So, they will try and get their SKUs ready for the summer, so there will be a big push for new SKUs in the summertime. Or if there's a major sporting event or festival, there will be a push for SKUs at that point as well. If you've got stable SKUs, generally the forecast is good in statistical forecasting, but now with shorter product lifecycles and just changing and diverse customer demands, what companies are now doing is seeing the impact of external factors." - SOX "In the Nordics, until items arrive at the store, we know really well what the expiration date is, but once it arrives at the shop, we don't know exactly what was sold yesterday, and what the expiration dates on what was sold. We built machine learning models, that try to estimate what people buy and which expiration dates do they pick. So, some people pick the one that has the most life left and some people want to buy the one that has the least for whatever reason. So, then we can use that type of model to estimate how much there's roughly left in the store. Then by knowing that we can then also calculate if we are likely to sell them or if are we likely to have some waste. And if there will be waste in the coming days, we can trigger for example price reductions for those products, trying to get rid of them before they kind of spoil or we create waste" – SSP "The forecast will improve in time when we get if we get more accurate information. Let's say we have a promotion next week that has only occurred once, and only once to compare to, then the next after that will have two to compare to, so better forecast on the third and fourth and so on. So, we will take into account the actual sales from previous promotions. So, if it generated waste, the next will most likely produce less, since the sales were not as we expected." Case X "We are collecting receipts from all the stores and use that on promotion planning and everything… We are not measuring if we are doing Facebook for instance if that make sales and influence… but we are comparing the data if you buy this article, you are more likely to buy these articles as well. And if this promotion affects other article group and so on." Case X	Addressing variabilities caused by campaigns

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Representative 1st Order Data (respondents' quotes)	*2nd Order Themes*
"The biggest issue is that the historical data is not sufficiently enough, or the new articles will not have good enough history to rely on. The system will need some history it can lean on to make good decisions ahead of time." – Case X "The company to manage the portfolio will look at all of their SKUs. Which new SKUs should be brought in or which SKUs are not doing well and should be taken out; they go into very detailed analysis. They will look at their portfolio and see for the last one month, two months, three months. How these SKUs have been before? It's not that they are going to just cut things immediately, or just add things. This needs to be done with fact and not with emotion." - SOX "Sales generally use numbers, then there's no impartiality or any favoritism, and they will look at the numbers, check performance and then start to understand the portfolio and start to prune or add." SOX "Demand is forecasted by using input from supplier (sales volume estimates) (the supplier estimate can be subjective and over optimistic) and input from comparable products. The forecast is communicated with the suppliers, which confirm by sending a confirmation of the ability to deliver." - Case X "The first order size is set to cover 1–2 weeks demand. Approximately, only 5% of new product releases survive over time." - Case X	Addressing variabilities caused by new product launch

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