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Minimizing food waste in grocery store operations: Literature review and research agenda

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ABSTRACT

Research on grocery waste in food retailing has recently attracted particular interest. Investigations in this area are relevant to address the problems of wasted resources and ethical concerns, as well as economic aspects from the retailer's perspective. Reasons for food waste in retail are already well-studied empirically, and based on this, proposals for reduction are discussed. However, comprehensive approaches for preventing food waste in store operations using analytics and modeling methods are scarce. No work has yet systematized related research in this domain. As a result, there is neither any up-to-date literature review nor any agenda for future research. We contribute with the first structured literature review of analytics and modeling methods dealing with food waste prevention in retail store operations. This work identifies cross-cutting store-related planning areas to mitigate food waste, namely (1) assortment and shelf space planning, (2) replenishment policies, and (3) dynamic pricing policies. We introduce a common classification scheme of literature with regard to the depth of food waste integration and the characteristics of these planning problems. This builds our foundation to review analytics and modeling approaches. Current literature considers food waste mainly as a side effect in costing and often ignores product age dependent demand by customers. Furthermore, approaches are not integrated across planning areas. Future lines of research point to the most promising open questions in this field.

1. Introduction

Food waste is a crucial issue regarding sustainability and resource conservation. Despite the broad awareness of the problem, it is still insufficiently addressed in many ways and causes major ethical, ecological, and economic issues. For instance, one-third of the food that would still be fit for human consumption is thrown away worldwide, while more than 800 million people still face hunger (FAO, 2021). Moreover, food wasted along the supply chain is responsible for 6% of global CO_2 emissions (Poore and Nemecek, 2018). The United Nations, therefore, aim to halve food waste by 2030 (United Nations, 2015). The recent public awareness of the topic, pressure to improve environmental protection, and changing customer behavior amplifies the need for action in food supply chains. This urgency is especially valid for retailers, as they and households account for over 40% of the food waste generated (Flanagan et al., 2019; Stenmarck et al., 2016). Addressing food waste is further an economic necessity for grocery retailers: The costs associated with food waste amount to an average of nearly 2% of net sales (Klingler et al., 2016), almost equaling the average margins of grocery retailers (Glatzel et al., 2012).

Food waste also receives more and more attention in research. Figure 1 highlights the development of retail and food waste-related publications in peer-reviewed journals during the last decade, including any study type and management discipline. The retail food waste literature's initial focus has been quantifying waste (see, e.g., Lebersorger and Schneider, 2014; Stenmarck et al., 2016) and revealing causes for its occurrence (see, e.g., Mena et al., 2011). However, there has been a shift of topics towards food waste prevention in grocery stores. For example, Gruber et al. (2016) and Filimonau and Gherbin (2017) leverage interviews with store managers to show that increasing

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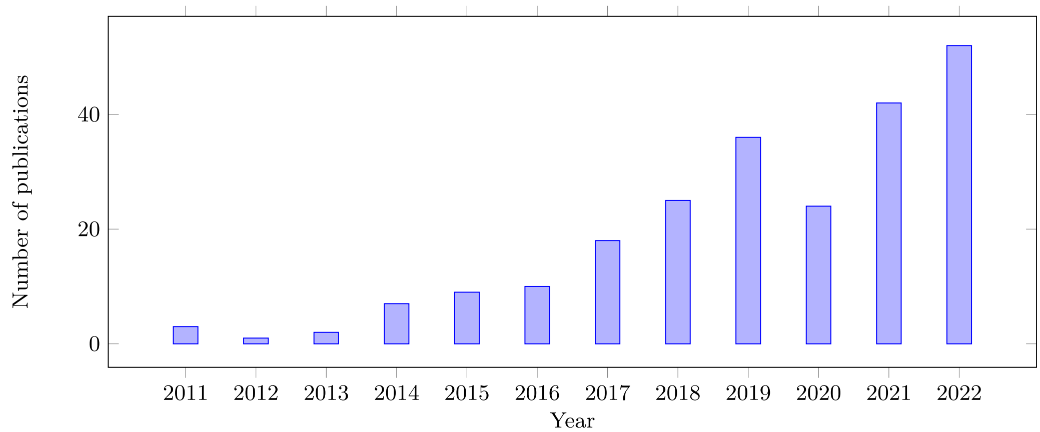

Fig. 1. Annual publications on food waste in retail in peer-reviewed management journals.

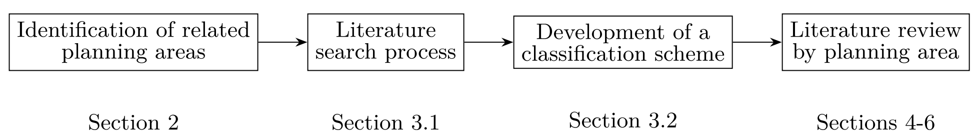

Fig. 2. Process of the literature review.

their autonomy reduces waste.

Despite recent progress in this research area, no work has yet systematized published research with a clear focus on store operations. However, grocery stores are where supply and demand meet and thus take a pivotal role concerning food waste prevention. The food waste hierarchy of the UN Environment Program (UNEP, 2014) highlights food waste prevention as the highest priority, followed by reduction (e.g., donations), reuse (e.g., animal feed) and incineration with energy recovery. From a retailer's perspective, prevention includes any measure to minimize food waste as long as the product can still be sold. Despite the relevance of prevention, Huang et al. (2021) show that reactive food waste fighting strategies such as donations to social organizations, re-processing, or disposal for animal feeding dominate retail practice. Effective proactive prevention measures often need to be improved. Recent studies emphasize weaknesses in-store operations, such as rapidly grown assortments (see, e.g., Teller et al., 2018; Riesenegger and Hübner, 2022), inappropriate inventory control methods (see, e.g., de Moraes et al., 2020; Mena et al., 2011; Wang et al., 2019), and ineffective pricing policies (see, e.g., Buisman et al., 2019). All works make it clear that more systematic measures and efficient planning are necessary for store operations. Huang et al. (2021) further conclude that the scope and scale of operations to address food waste in retail practice are not sufficiently understood. Moreover, Muriana (2017) stresses that more quantitative approaches are needed to support retailers in preventive approaches. Akkaş and Gaur (2022) specifically highlight the need to incorporate food waste prevention in-store operations planning. Retailers' current insufficient store planning processes must therefore be analyzed (see, e.g., Akkaş and Gaur, 2022; Broekmeulen and van Donselaar, 2019; Winkler et al., 2022) to identify improvement potentials and to enable a shift towards more preventive planning approaches.

There is a growing but still a very nascent area of analytics and modeling approaches aimed at minimizing food waste in retail stores by incorporating food waste as a cost- or decision-relevant element. Models differ in the scope of the decisions (e.g., inventory replenishment, pricing of overstocks), approach to model demand (e.g., customer withdrawal behavior, substitutions), and the integration of product-specifics (e.g., packaged goods with best-before date, continuously expiring products). Looking at related reviews, however, a systematic classification of modeling aspects, including food waste prevention in retail stores, is lacking. On the one side, there are review papers related to food waste in retail (see, e.g., Akkaş and Gaur, 2022; de Moraes et al., 2020; Huang et al., 2021), providing an overview of practices to reduce food waste without focusing on analytics and modeling. On the other side, available reviews on quantitative approaches solely focus on inventory models for perishable products (see Amorim et al., 2013; Bakker et al., 2012; Goyal and Giri, 2001; Janssen et al., 2016; Nahmias, 1982) or assortment and shelf space planning (see Bianchi-Aguiar et al., 2021; Hübner and Kuhn, 2012; Kök et al., 2015; Shin et al., 2015). Both areas lack an analysis of food waste and its impact.

We address this research gap by identifying and classifying literature for planning analytics and modeling dealing with in-store food waste and its prevention. More specifically, we aim to answer three main research questions to improve the understanding of the current state-of-the-art on planning problems and to devise the main streams for future research in grocery store operations:

RQ1: How is food waste incorporated into analytics and modeling of grocery retail store operations?
RQ2: What characterizes the setting of these planning problems that tackle food waste?
RQ3: Which main research gaps should be addressed to improve grocery retail store operations *vis-à-vis* food waste?

The three RQs are addressed in the remainder of the paper. The paper is organized as follows (see Fig. 2). As food waste management in stores is not yet an established and well-developed research field, we need to first define the scope. Section 2 sets the scope of our structured literature search accordingly. It derives the related planning issues for store operations in general and then identifies the areas that impact food waste. This analysis is based on the literature on store operations planning and food waste. It results in the planning areas (1) *assortment and shelf space planning*, (2) *replenishment policies*, and (3) *dynamic pricing policies*. We define and additionally motivate the relevance of these three areas to minimize waste at the store level proactively by highlighting the impact on food waste when these areas are optimized. Section 3 then details the literature review methodology. It first describes the approach of the literature search. Furthermore, we contribute with the introduction of a novel classification scheme. This helps to classify the papers across the three planning areas, namely regarding the depth of food waste

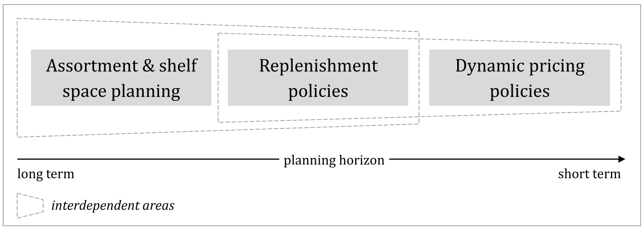

Fig. 3. Identified planning areas in grocery store operations with regard to food waste.

integration and the modeling characteristics of the problems. As food waste in stores is a nascent topic and the research stream is not yet well defined, this framework supports comparing the different contributions in a structured manner across all three planning areas. Section 4 (Assortment and shelf space), Section 5 (Replenishment policies) and Section 6 (Dynamic pricing policies) constitute the main body of this paper and analyze the related literature in each area according to the developed classification scheme. Each section discusses the current state of the art and research gaps revealed in detail. Section 7 concludes the review by discussing future research areas.

2. Food waste related planning areas at retail store operations

This section identifies food waste-relevant planning areas in grocery store operations. We first derive the planning areas from prevailing literature on store operations and food waste prevention. We then introduce each problem area individually and discuss its relation to food waste. Identifying relevant planning areas in grocery store operations provides the basis for our subsequent literature search and review.

2.1. Scope of planning areas in grocery store operations

Fisher (2009) and Fisher and Raman (2010) define assortment, inventory management, pricing, and store execution as the main areas to succeed in retail store operations. Mou et al. (2018) further see demand forecasting, checkout operations, and employee management as issues for store operations. Hübner et al. (2013) frame the tactical store-related planning as master category planning problems that include assortment configuration and planning of price promotions. They further define issues on the operational level, including store execution, replenishment, and employee management. This execution part is similar to Kotzab and Teller (2005), who identify in-store processes from goods receipt to shelf replenishment. The different planning steps exist due to different planning horizons and partially also because of different decision owners (see, e.g., Hübner and Kuhn, 2012; Kök et al., 2015). This analysis shows multiple definitions and scoping approaches to what belongs to store operations. Including the store operation issues that contribute to proactive food waste prevention is essential in our context. Other areas not relevant for food waste reduction (e.g., checkout operations (as in Mou et al., 2018)), without a focus on brick-and-mortar stores (e.g., online retail), or that serve as input to the store operations planning (e.g., forecasting (as in Mou et al., 2018)) are out of the scope of our research questions and hence our review. As our focus is on modeling and optimization approaches, topics unrelated to corresponding planning issues (e.g., employee management (as in Hübner et al., 2013)) are also excluded. We further match the store operation issues identified with empirical insights on food waste drivers in retail to identify the relevant planning areas for food waste prevention at stores. In detail, we leverage publications on store manager interviews (see, e.g., Filimonau and Gherbin, 2017; Gruber et al., 2016; Horos and Ruppenthal, 2021), process simulation and case studies (see e.g., Liljestrand, 2017; Teller et al., 2018), and literature reviews (see, e.g., de Moraes et al., 2020; Huang et al., 2021). This process enables us to identify ultimately three planning areas relevant for food waste prevention in grocery stores from an operations management perspective: (1) *assortment and shelf space planning*, (2) *replenishment policies* and (3) *dynamic pricing policies*. We will further motivate these three areas with insights on food waste impact below.

Figure 3 shows the areas concerning their planning horizon and dependencies. Grocery retailers define assortment and shelf space assignments on mid- to long-term planning horizons for 6–12 months as changes are related to supplier negotiations and the rebuilding of the store shelves (see, e.g., Hübner et al., 2013; Kök et al., 2015). Each product's shelf space defines the shelf quantity and builds the basis for replenishment policies where the retailers define the restocking frequency. This mid-term planning task is usually defined for 3–6 months (see, e.g., Hübner and Schaal, 2017c). The dynamic adaption of prices happens daily and constitutes a short-term operational problem (see, e.g., Buisman et al., 2019). The order is also reflected concerning food waste prevention. While assortment and shelf space planning, as well as replenishment policy, target to prevent food waste at retail stores, the pricing policy is at the borderline as it prevents food waste proactively, but may also be applied to minimize waste after a surplus in the store emerged. In the following, we discuss these three planning areas in their hierarchical sequence. We will define each planning problem in detail and then highlight its impact on food waste using empirical studies.

2.2. Assortment and shelf space planning

Definition The selection and sale of inventory are the *raison d'etre* of grocery retailing (Fisher and Raman, 2010). Retailers have to decide which items to include in their assortment and how much shelf space is assigned to each item (Bianchi-Aguiar et al., 2021; Hübner and Kuhn, 2012; Kök et al., 2015). If assortments are too large for the limited storage space, not all brands and variants can be displayed, and a selection of products must occur. When optimizing assortments and assigning shelf space, retailers must consider the item profits and dimensions, the shelf space available for product presentation, and the expected customer demand. The latter comprises not only the initial demand of a product but also substitution and complementary effects with other products (see, e.g., Campo et al., 2000; Gruen et al., 2002; van Woensel et al., 2007). Product demand may additionally depend on the available quantity and position on the shelf (see, e.g., Drèze et al., 1994; Eisend, 2014).

Impact on food waste The continuous product proliferation is challenging to manage. Offering broader assortments with varying characteristics (e.g., slow vs. fast-moving goods) increases the risk of overstocks and shortages at the same time, as shelf space turns into a scarce resource (see, e.g., Riesenegger and Hübner, 2022). Teller et al. (2018) indicate that more extensive assortments result in higher food waste since larger product ranges are more difficult to manage due to, e.g., lower forecast accuracy in long-tail items (see also Mena et al., 2011). In line with this, Broekmeulen and van Donselaar (2019) found that if 10% of the products with the lowest turnover were delisted, food waste could be reduced by around 8%. Riesenegger and Hübner (2022) identify that some assortments have become excessive, and reducing the variety significantly decreases food waste levels without a significant impact on sales. Hence, assortment and shelf space planning are essential levers in stores to minimize food waste.

2.3. Replenishment policies

Definition The ultimate objective of replenishment policies is to fulfill customer demand. It is intended to achieve the required on-shelf service levels based on a given assortment and shelf plan. Shelves are replenished following different inventory policies. The policies usually differ concerning the determination of the refilling quantity and the time of refilling (i.e., either triggered by an inventory threshold or in regular time intervals). The corresponding decisions impact the total inventory at stores comprising shelf and backroom inventory (Hübner and Schaal, 2017b). Suppose the shelf space for an item is insufficient to accommodate all the units delivered. In that case, goods are stored in the backroom and restocked later after items are depleted from the shelf by customers (Pires et al., 2015).

Impact on food waste Although replenishment is essential in any supply chain, it gains particular relevance in grocery stores due to the perishability of food products (Amorim et al., 2013; van Donselaar et al., 2006). For fresh and ultra-fresh products with short shelf lives, a fully stocked shelf inevitably leads to a situation where products regularly spoil before they can be sold. Broekmeulen and van Donselaar (2019) show that with 2% less on-shelf availability, food waste can be decreased by 28%. Riesenegger and Hübner (2022) and Gruber et al. (2016) propose product group and period-specific service levels, such as accepting partial out-of-stock situations in the evening. Besides targeting high service levels, other exemplary factors for overstocking are ordering constraints, such as minimum order quantities or the delivery in predetermined batch sizes (Akkaş et al., 2019). Finally, the consumers' withdrawal behavior (e.g., picking for longer expiration dates) may circumvent optimized inventory and replenishment policies (Winkler et al., 2023). Consequently, older products may remain on the shelf and potentially converge to waste. All this complexity must be considered for concerted planning approaches to prevent food waste in replenishment policies.

2.4. Dynamic pricing policies

Definition Product prices are the primary drivers of demand. The leading approach to craft pricing strategies is unveiling customers' willingness to pay. In order to promote sales, increase inventory turnover, and minimize overstock or wastage, retailers apply dynamic pricing (Şen, 2013; Wang and Li, 2012). To exploit customer behavior and stimulate demand with discounted prices, the frequency and timing of discounting and the discount level/rate need to be defined. The dynamic pricing policy can follow a continuous or a discrete approach. In a continuous policy, a price is defined for each selling period, i.e., the price charged can be updated every period (see, e.g., Yang et al., 2021). In contrast, discrete policies apply a price discount at a predetermined point in time, e.g., two days before expiration (see, e.g., Buisman et al., 2019), and stays the same for a given time (e.g., period or phase).

Impact on food waste Since the sale of products that have exceeded their best-before or use-by date is not allowed by law, discounting near-to-expire products may be considered as the ultimate decision within store operations. It is, therefore, a standard tool to stimulate demand in order to obtain a salvage value from overstocks and to prevent food waste simultaneously (see, e.g., Filimonau and Gherbin, 2017; Gruber et al., 2016). On the other hand, offering discounted products may lead to revenue losses, as customers could have chosen the product anyway. Discounting appeals to price-sensitive customers, and it might originate a strategic behavior in which customers wait for a discount to appear. Horos and Ruppenthal (2021) indicate that discounting works well for foods such as dairy or seasonal products but not for fruits and vegetables since customers require high freshness levels. The demand depends on the product group, the level of discount, and the motive of buying (see, e.g., Aschemann-Witzel et al., 2018; 2019; de Hooge et al., 2017; Helmert et al., 2017). Therefore, the trade-offs between shortage and waste costs (see, e.g., Buisman et al., 2019; Chen et al., 2011; 2018) and unexpected consumer behavior (see, e.g., Liu et al., 2018) need to be accounted for when defining the discount policy.

3. Methodology, classification and structure of review

After having identified the scope of our literature review by deriving the food waste relevant planning areas, this section details the review methodology applied in Section 3.1, before introducing a classification scheme in Section 3.2 as the basis for our review. We conclude this section by providing the structure of the reviews across all planning areas (Section 3.3).

3.1. Research process of the structured literature review

The review follows the guidelines for a systematic search and review to ensure an objective and in-depth gathering of relevant literature (Booth et al., 2016; Snyder, 2019). We utilize a threefold approach:

(1) initial keyword-based search in Scopus,
(2) backward and forward reference searching ("snowballing"), and
(3) a manual search in leading journals of the field.

(1) First, we started with an initial keyword-based search using the Scopus database. For the sake of focus, we only consider peer-reviewed articles written in English. Keywords were defined according to the area of the research (see Table A.1 in Appendix A) and combined for searching in abstract, title, and keywords of papers covered by the database. The first area comprises keywords related to product losses, such as expiration or outdating. The keywords for the second area are required to ensure the product focus, addressing only foods and perishables, while the third area reflects the retail stage by listing the different store formats. The fourth area finally specifies the planning processes identified in Section 2. In total, our search resulted in 2654 articles.[1] We focused exclusively on publications in international research journals related to retail and operations management. The selection of journals is based on the Journal Citation Reports provided by Clarivate Analytics in the subject area "Operations Research and Management Science" and additional journals in the field of retail management (see Appendix A for the complete list of journals). After removing articles from unrelated journals, 220 articles remained for further review, for which we subsequently performed a detailed review of the abstracts. We specified explicit inclusion and exclusion criteria that ensure the defined scope (Seuring et al., 2005). Only papers related to our scope (see Section 2) were selected. This means, for example, literature regarding distribution problems (e.g., delivery to the store), technological advances (e.g., packaging optimization, supply chain tracking), and regulatory aspects were excluded. 151 articles were removed during the first screening. In the second screening, we examined the full content of the remaining 69 papers using the same inclusion criteria. This reduces the body of literature to 32 articles. At least two authors conducted the first and second screenings independently to ensure the validity and reliability of the review. In the event of a disagreement regarding the in- or exclusion of individual publications, the respective papers have been discussed within the author team until consent was reached.

(2) Second, the reference sections of the selected articles were screened (backward search), and also articles that cite these selected articles (forward search) were examined to identify further matching work.

(3) Finally, we complemented the literature review with results from manual searches in leading journals in the field. This final step ensures that no significant and seminal paper that belongs to the scope of the paper is left out (e.g., because different keywords are used). Ultimately, we identified 44 papers matching the scope and research questions. The papers were then assigned to one of the three planning problems. If a paper could be assigned to multiple areas (e.g., replenishment and pricing), we allocated the paper to the area with its main focus. For example, when a paper focuses on studying different replenishment

[1] Please note that for the figure in the introduction, we use a different approach and include all papers concerning food waste in retail in peer-reviewed journals regardless of the discipline (e.g., including food journals) and methodology (e.g., including empirical studies) to illustrate the evolution of the relevance of the topic in general.

Table 1
Overview on food waste related assortment and shelf space literature.

Publication	Waste integr.[a]	**Demand modeling**[b]				**Product modeling**[c]				Decisions/**policies**[d]
		general		waste-specific		general		waste-specific		
		D/S	Effects	FD	WB	SP	MP	FL[e]	RL	
van Ryzin and Mahajan (1999)	WM	S	SB				✓	(✓)		A,OQ
Smith and Agrawal (2000)	WM	S	SB				✓	(✓)		A,OQ
Mahajan and van Ryzin (2001)	WM	S	SB				✓	(✓)		A,OQ
Rajaram and Tang (2001)	WM	S	SB				✓	(✓)		A,OQ
Gaur and Honhon (2006)	WM	S	SB				✓	(✓)		A,OQ
Kök and Fisher (2007)	WM	S	SB				✓	(✓)		A,OQ
Shah and Avittathur (2007)	WM	S	SB				✓	(✓)		A,OQ
Honhon and Seshadri (2013)	WM	S	SB				✓	(✓)		A,OQ
Hübner et al. (2016)	WM	S	SB				✓	(✓)		A,OQ
Hübner and Schaal (2017c)	WM	S	SE				✓	(✓)		A,SA,OQ
Hübner and Schaal (2017b)	WM	S	SE,SB				✓	(✓)		A,SA,OQ
Akkaş (2019)	WM	D,S	SE		✓	✓		✓		SA
Hübner et al. (2020)	WM	S	SE,SB				✓	(✓)		A,SA,OQ
Bai and Kendall (2008)	WM	D	SE	✓			✓		✓	SA,OQ
Chen et al. (2016)	WM	D	SE	✓		✓			✓	SA,OQ
Li et al. (2021)	FM	D	SE	✓			✓		✓	SA,OQ

✓: component considered; (✓): partially considered

[a] FM: freshness maximization, WM: waste minimization, WT: waste tracking.
[b] D: deterministic, S: stochastic, SE: space-elastic, SB: substitution behavior, FD: freshness dependent, WB: withdrawal behavior.
[c] SP: single product, MP: multiple products, FL: fixed shelf life, RL: random life time.
[d] A: assortment, SA: shelf space assignment, OQ: order quantity.
[e] (✓): shelf life is only considered within a single-period model, i.e. products are expired after the considered period.

policies and includes a price decision as a side-effect, it was assigned to the replenishment section (see, e.g., Li et al., 2012); when the work focuses on pricing policies but considers the possibility of replenishment during the time horizon (determining the order size), it was assigned to the dynamic pricing section (see, e.g., Buisman et al., 2019).

3.2. Approach for literature classification

We introduce a classification framework for reviewing our selection of papers connected to food waste in-store operations. The main goal of this framework is to provide the foundation for a structured discussion of the literature. This allows us to address and answer the first two research questions. Our classification framework works in two dimensions: (a) depth of food waste integration and (b) characteristics of the planning problems. The first dimension (a) helps to answer RQ1. It investigates how food waste is incorporated into the models. To that end, we classify the papers according to three different cumulative levels of integration (i.e., the first level includes the second and the third etc.). The criteria are ordered from the most to less desirable objectives concerning food waste.

- *Freshness maximization (FM)* – Optimization models incorporate product freshness into the decision. Hence, a proactive stance is taken to prevent waste by steering the planning decisions to maximize the freshness of the stock. For example, in replenishment policies, a work that positively weights an increase in ordering frequency to improve stock freshness would qualify for this level.
- *Waste minimization (WM)* – Optimization models are designed to minimize the amount of food waste in the setting described. This is, for example, the case if a cost factor for leftover items is introduced and overall costs are minimized.
- *Waste tracking (WT)* – Optimization models are designed to improve the economic performance within the given setting, but food waste is recorded and, based on this, levers for the prevention of food waste can be derived.

The second dimension (b) helps to answer RQ2. We devised three categories to help grasp the characteristics of the planning problems: *(i) demand modeling, (ii) product modeling,* and *(iii) decisions/policies* analyzed. While the first two categories are applicable across all planning problems, *(iii)* decisions/policies are problem-specific and need to be defined for each planning problem individually. We are also particularly concerned with characteristics related to food waste. Hence, for *(i)* demand modeling and *(ii)* product modeling, we discuss not only general model features but also modeling aspects specific to food waste to further refine the classification.

For *(i) demand modeling* we cover the following features:

- *General demand modeling* concerns the demand uncertainty and additional demand effects. The demand can be defined as deterministic (D) or stochastic (S). Furthermore, we consider additional demand effects that depend on exogenous input or interrelated decisions. This comprises substitution behavior (SB), price- (PE) and space-elasticity (SE).

- *Waste-related demand modeling* aims at modeling the dependency of customer choices on the level of freshness. The visual appearance and the expiration date influence customers in their buying decision, increasing the likelihood that older products remain on the shelves (see, e.g., de Hooge et al., 2017; Winkler et al., 2023). We differentiate between freshness-dependent demand (FD), where demand directly depends on the product condition, and withdrawal behavior (WB), where the order in which a customer takes a product from the shelf is considered, either last-expired-first-out (LEFO) or first-expired-first-out (FEFO).

For *(ii) product modeling*, we analyze:

- *General product modeling* is the number of items considered. The problem may take into account decision(s) regarding a single product (SP) or multiple products (MP) and the corresponding interdependence between products.
- *Waste-related product modeling* considers the perishable character of the product by incorporating the product's shelf life. The shelf life describes the time frame in which food can be sold in the store before it needs to be removed from the shelf due to expiration or spoilage, resulting in food waste. Grocery products can have either a given expiration date (e.g., any type of packaged goods) or a varying expiration date based on the product condition (e.g., any type of vegetables and fruits). According to pertinent perishable inventory literature and its reviews (Bakker et al., 2012; Goyal and Giri, 2001; Janssen et al., 2016; Nahmias, 1982), the shelf life can be integrated into two different ways: as a fixed lifetime (FL), for example, when packaged products have a given expiration date and predetermined deterministic lifetime (see Bakker et al., 2012; Goyal and Giri, 2001), or as random lifetime (RL) (see Goyal and Giri, 2001), when the lifetime of the products is unknown. The latter includes any type of age-dependent deterioration (e.g., modeled with probabilistic distributed lifetime) (see, e.g., Bakker et al., 2012), time or inventory-dependent deterioration (e.g., modeled with continuous functions) (see, e.g., Bakker et al., 2012; Goyal and Giri, 2001) or dynamic approaches that determine the product condition based on a discrete update of the condition based on input from sensors or other observations (see, e.g., Janssen et al., 2016).

Finally, for the papers that were analyzed for the different planning problems, we keep track of the *(iii) decisions/policies* analyzed. Of course, the nature of these decisions/policies is problem-specific. For assortment and shelf space planning, this relates, for example, to the actual decision context (e.g., selecting products), whereas for replenishment, the related refill policy (e.g., base-stock policy) is a crucial criterion. For pricing policies, an example is the depth and level of discounts that retailers may grant. The problem-specific decisions and underlying policies are further specified in the respective review sections.

3.3. Structure for literature review in each area

Applying the classification proposed, we review the existing literature across the three planning problems identified: assortment and shelf space planning (Section 4), replenishment policies (Section 5), and dynamic pricing policies (Section 6). Whenever a paper fits in more than one area, it was allocated to the section that best captures the main decision of the problem. We apply a common structure for the review in all three sections to allow an aligned discussion of literature:

- Summary of publications in a table that structures the publications according to the classification introduced. This is followed by a detailed discussion of prevailing literature and their problem characteristics in the corresponding areas.
- Identification of existing research gaps and subsequent discussion of future research directions.

We summarize commonalities and differences across the three planning areas as well as overarching research avenues in the concluding sections of this paper.

4. Assortment and shelf space planning

4.1. Related literature

The related literature in this area can be structured along three streams detailed below. Table 1 summarizes the corresponding publications of the three streams (i) assortment planning, (ii) integrated assortment and shelf planning and (iii) shelf planning with freshness-dependent demand. These papers have been collected by search methods (2) and (3) (see Section 3.1), i.e., by snowballing and a manual search in leading journals and related literature reviews. This was necessary as method (1), the initial keyword-based search, resulted in one paper explicitly focusing on food waste for the keywords specified. However, as empirical studies show, assortment and shelf configuration have a major impact on food waste (see Section 2.2). Furthermore, a rich literature on assortment and shelf space planning includes inventory decisions that penalize overstocks without clearly defining this as food waste (see, e.g., Hübner and Kuhn, 2012; Kök et al., 2015; Shin et al., 2015).

(i) Related literature on assortment planning The core of assortment models is to select products and to define inventory targets under stochastic demand. Even though research on assortment planning is generally well-advanced, there is up to date no paper that explicitly refers to food waste or uses any term related to food waste within the model approaches. However, the most advocated modeling approach is based on the multi-item and single-period Newsvendor model that considers overstock costs in its objective. The overstock costs represent penalty costs for food waste (i.e., perishable product inventory in general) and thus can be treated as an approach to waste management.

There is already a comprehensive literature on assortment planning. For example, the general reviews of Shin et al. (2015) and Kök et al. (2015) identify more than 100 publications on assortment planning, and several of them incorporate the notion of overstock. Including all these papers in our review is beyond the scope of this paper. As a compromise, we streamline our review by analyzing seminal works. The seminal works are identified in the mentioned literature reviews, have very high citation numbers and are often described as fundamental works for further extensions. As these papers are prototypical, it is sufficient to concentrate only on these assortment models to deliver answers to our RQs. The first part in Table 1 highlights the fundamental contributions in assortment planning.

Common across all assortment papers is the waste integration as overstock costs, the stochastic demand, and the inclusion of a kind of substitution. The multi-product models support the integrated assortment and order decisions (see also the categorization in the respective columns of Table 1).

The differentiating element of assortment optimization is the demand modeling approach. The related literature can be further split up into two approaches (see also Hübner and Kuhn, 2012; Kök et al., 2015), namely, utility-based and exogenous demand (ED) models. Related to the first part, in a seminal paper, van Ryzin and Mahajan (1999) introduce the multinominal logit model (MNL) to integrate customer demand based on customer utilities. The MNL is a discrete consumer choice model that assumes that consumers are rational utility maximizers. The demand model of van Ryzin and Mahajan (1999) considers out-of-assortment (OOA) substitution. In the second fundamental paper in this stream, Mahajan and van Ryzin (2001) extend the model to consider dynamically arriving customers and out-of-stock (OOS) substitution. A related publication is presented by Gaur and Honhon (2006), who study consumer preferences based on a static OOA substitution and modeled it with a locational choice model. Honhon and Seshadri (2013) are the first to further include dynamic substitution for OOS situations in their approach. A second set of assortment papers uses ED models that directly specify the demand for each product. If the preferred item is unavailable for any reason, a consumer might accept another item as a substitute following a predefined substitution rate. ED models are more flexible than MNL models and can consider varying prices or pack sizes as examples (Hübner and Kuhn, 2012; Kök et al., 2015). Smith and Agrawal (2000) and Kök and Fisher (2007) are considered in the literature reviews as the most influential work on assortment planning with ED models. Smith and Agrawal (2000) capture substitutions. To maximize total expected profit, the stocking levels of each product are set to achieve determined service levels. Kök and Fisher (2007) introduce an assortment and inventory model for perishable products and include a cost factor for disposals in the profit function. They solve the model for OOA substitution and show in numerical experiments that an increasing share of perishable products results in decreasing profits due to an increase in spoilage and, therefore, disposal costs. Hübner et al. (2016) extend the model presented by Kök and Fisher (2007) integrating OOS substitution. Their analyses show that considering substitution effects in a decision-based model significantly impacts the assortments, inventories and total profit. Next to these seminal works, there are two fundamental papers with relevant insights into the management of overstocks. Rajaram and Tang (2001) analyze the impact of product substitution. They evaluate the impact of substitution on order quantities and expected profits with a service-rate heuristic and show that substitution reduces shortages and overstocking. A further related important contribution in our context is presented by Shah and Avittathur (2007). It targets to find the optimal combination of standard and customized products. The authors consider demand cannibalization and OOS substitution. With high demand volatility and high substitution rates, it becomes beneficial to introduce standard products instead of slow-moving customized items. This also prevents overstock.

(ii) Related literature on shelf space planning The first publications on shelf space management comprise deterministic models that include space-elastic demand (see, e.g., Hansen and Heinsbroek, 1979; Urban, 1998) and cross-space elastic demand (see, e.g., Corstjens and Doyle, 1981; Irion et al., 2012; Zufryden, 1986). While the first describes the effect that the demand for an item increases with an increase in corresponding item space on the shelf, the latter effect concerns the same effect between different items, i.e., a demand increase of one item caused by increasing the space for another. The stream of literature in this area further developed into more integrated approaches such as store planning (see, e.g., Flamand et al., 2016, 2018; Ostermeier et al., 2021), shelf sizing (see, e.g., Düsterhöft et al., 2020; Hübner et al., 2021) or other marketing effects and inventory aspects (see, e.g., Hansen et al., 2010; Irion et al., 2012; Lotfi and Torabi, 2011). We further refer to Hübner and Kuhn (2012), Kök et al. (2015) and Bianchi-Aguiar et al. (2021) for general reviews of shelf space models. Common across all these papers is the assumption of a deterministic demand. As a result, overstock and food waste are not included by definition since the demand volatility of retail sales is not reflected. As waste is not possible per definition in deterministic models, we only review contributions with stochastic demand. The middle part in Table 1 summarizes these papers that a relevant for waste minimization.

Hübner and Schaal (2017c) introduce the first shelf space model based on stochastic demand. Like the assortment models, the profit function is on the Newsvendor model and includes a salvage value for overstocks. In an extension, Hübner and Schaal (2017a) further integrate assortment decisions and OOA and OOS substitution. By assuming lower salvage values for perishables, the authors show that less shelf space is assigned to perishables than non-perishables due to lower refunds in case of overstocking. However, with increasing substitution rates, shelf share grows also for perishable products, as the risk of overstocks decreases because of the higher demand for replacements. Hübner et al. (2020) further extend this decision model to a two-dimensional shelf-space setting (e.g., applicable for ultra-fresh products), where the horizontal and vertical positions are considered.

A different approach for shelf management is suggested by Akkaş (2019). The paper directly addresses food waste prevention by considering the product's shelf life when allocating shelf space. A Markov chain model examines the effect on profit and food waste for different scenarios, including the consideration of customer withdrawal and space-elastic demand. The author shows that the more shelf space is allocated to perishables, the higher the probability that products expire due to the higher shelf quantity, and accordingly, the lower the profit. Increasing space-dependent demand mitigates this effect, however.

(iii) Related literature with freshness-dependent demand The integration of freshness-dependent customer demand constitutes the third area that is relevant for food waste management within shelf space planning. Related problems model products using a random short lifetime, and the freshness of perishables decreases over time with a negative impact on demand. Further, the models take into account inventory-dependent demand, i.e., the demand decreases with lower inventory levels (see, e.g., Urban, 1998). A pertinent example is Bai and Kendall (2008). They introduce a deterministic, freshness- and inventory-dependent demand model. The demand is represented with an exponentially decreasing function determined by a decay rate and the current inventory. The single-period shelf space allocation model applies the number of facings and inventory quantity on the shelf as decision variables and introduces the surplus amount at the end of the cycle as an auxiliary variable. The latter is necessary to clear the shelf at the end of the period and consider the salvage value for the leftovers. In a related approach, Chen et al. (2016) express the demand as a linear function dependent on the shelf life. They also use an auxiliary variable to account for overstock available for sale with a price discount. The authors find that each period's optimal ending inventory level (i.e., the waste) grows with increasing base demand, space-elastic demand, maximum lifetime, ordering costs, selling price, and salvage prices but decreases as purchasing costs, holding costs, or shelf costs increase. Li et al. (2021) further extend the analysis on freshness-dependent demand by integrating backroom inventory. More specifically, they consider the impact of available backroom storage on the shelf space assignment and order quantity. Regarding food waste, they assume that products perish more slowly in the backroom due to better preservation. If only some inventory is stored on the store shelf and constantly replenished, the freshness on the shelf is improved, and a wider range of products can be presented.

Summary The assortment and shelf space optimization papers reviewed enhance literature with demand modeling advancements (e.g., OOS, cannibalization, or space-elastic demand). When specifying the demand models, different types of substitutions (see first set of papers (i)), combinations of space-elastic demand and substitutions (see set (ii)) and further variants of inventory- and freshness-dependent demand (see set (iii)) are incorporated. Some papers present a general approach (e.g., Mahajan and van Ryzin, 2001; Smith and Agrawal, 2000; van Ryzin and Mahajan, 1999), but their setting and findings can also be applied to grocery retailing, whereas others are specifically developed and applied in grocery retailing (e.g., Hübner et al., 2020; Kök and Fisher, 2007). The stochastic demand models are applied to perishable product categories, and, in most applications, some salvage value for the remaining stock is accounted for. Consequently, these approaches minimize food waste by penalizing end-of-period surplus inventories in monetary terms, although the term "food waste" has not been explicitly mentioned in most papers.

The shelf life is fixed and limited to one period. With the single-period Newsvendor's application, it becomes evident that replenishment frequency and quantity are not determined. However, products need to be reordered, shelves are partially depleted, or products have a longer shelf life than one period. The freshness-dependent demand modeling has been scarce so far but incorporates a more realistic customer behavior in particular about food waste. This is a small body of literature based on simplifying assumptions, such as deterministic demand or neglecting substitution.

Table 2
Overview on food-waste related replenishment policies literature.

Publication	Waste integr.[a]	**Demand modeling**[b]				**Product modeling**[c]				Decisions / **policies**[d]
		general		waste-specific		general		waste-specific		
	D/S	Effects	FD	WB	SP	MP	FL	RL		
Broekmeulen and van Donselaar (2009)	WM	S			✓	✓		✓		RP
Haijema (2013)	WM	S				✓		✓		RP
Haijema (2014)	WM	S			✓	✓		✓		RP
Haijema and Minner (2016)	WM	S			✓	✓		✓		RP
Lee and Tongarlak (2017)	WM	S				✓		✓		RP
Haijema and Minner (2019)	WM	S			✓	✓		✓		RP
Mallidis et al. (2020)	WM	S				✓		✓		OQ,DQ
Zhang et al. (2020)	WM	S			✓	✓		✓		OQ,DQ,RP
Clarkson et al. (2022)	WM	S				✓			✓	OQ, RP
Hansen et al. (2023)	WT	S			✓	✓		✓		OQ, RP
van Donselaar and Broekmeulen (2012)	WT	S			✓	✓		✓		OQ
Tromp et al. (2016)	WT	S			✓	✓		✓	✓	ITI, OQ
Janssen et al. (2018)	WT	S			✓	✓		✓		OQ
Ketzenberg et al. (2018)	WM	S			✓	✓			✓	OQ,DD
Li et al. (2012)	WM	S	PE	✓		✓		✓		OQ,P
Li and Teng (2018)	WM	D	PE	✓		✓		✓		EI,P
Zhang et al. (2021)	WM	S	PE,SE	✓	✓	✓		✓		OQ,P

✓: component considered

[a] FM: freshness maximization, WM: waste minimization, WT: waste tracking.
[b] D: deterministic, S: stochastic, PE: price-elastic, SE: space-elastic, FD: freshness dependent, WB: withdrawal behavior.
[c] SP: single product, MP: multiple products, FL: fixed shelf life, RL: random life time.
[d] RP: replenishment policy, OQ: order quantity, P: price, DQ: donation/discard quantity, ITI: inventory/technical interventions, DD: disposal date, EI: ending inventory.

4.2. Future research

The results of our literature review reveal three main areas for future research.

(1) Specific analysis of food waste minimization Although the link between assortment size and food waste has been examined empirically, no optimization approaches in this area directly target food waste. Despite costs for overstocks being part of the objective function, a specific analysis of food waste minimization is not available in the current modeling literature. Further numerical analyses are needed (e.g., using existing models and approaches) to evaluate the impact of different parameters on food waste. Research should investigate the interplay of different demand parameters like space-elastic demand, substitution and cannibalization, cost parameters such as shortage costs and salvage values, as well as product characteristics (e.g., slow vs. fast-mover). For example, a higher number of facings increases the revenues with the space-elastic demand. In contrast, it may result in higher food waste levels as the inventory on the shelves increases. Furthermore, the analysis should pick up the call for assortment reductions to minimize food waste. However, this requires a broader approach than only profit maximization and looking at the overall impact on customer interaction and marketing variables. As such, delisting slow-moving products is expected to prevent food waste but may negatively affect the service level and customer expectations. This calls for a multi-objective approach.

(2) Extension to multi-period demand and inventory models Only single-period demand and inventory models have been used so far. The development of customer behavior over time is not reflected (e.g., when variety is reduced), and the remaining inventory is assumed to be expired at the end of the single sales period. This may hold for some ultra-fresh products like prepared food (e.g., ready-to-eat salads) and bakery products, but only for some fresh categories like fruits & vegetables, sausages and meat or dairies. The fact that these products have a longer shelf life and a later expiration date has not been considered so far. Consequently, considering different product ages requires an extension to multi-period models that allow the partial transfer of inventory and potential demand to subsequent periods. In this way, the impact of different ages of products on the decision can be evaluated, and the actual expiration of perishable goods on the shelves within the considered time horizon can be observed. This may impact the assortment configuration as, for example, products with a longer shelf life are then more likely to be listed than products with short expiration dates.

(3) Modeling customer preferences for fresh products The freshness preferences of customers need to be integrated into stochastic models along with inventory-dependent demand. Again, a multi-period approach is required to gather the product age. The type of freshness preferences might also depend on the product type: while the attractiveness of fresh produce such as fruits and vegetables correlates with their visual appearance and requires considering a random shelf life, packaged goods have a fixed best-before date and follow a fixed shelf life. Both types impact potential demand and available stock and need to be incorporated into the demand and inventory models. While freshness-dependency directly influences the demand, customer withdrawal only affects the order in which products are removed from the shelf. A

particular share of customers usually prefers to take fresher items if available. This attitude needs to be efficiently modeled with sequentially arriving customers and their different withdrawal behavior. Further research should compare different LEFO withdrawal ratios for fresher products and the impact on assortments, replenishment, profitability and food waste.

Summary Reviewing assortment and shelf space models related to food waste has identified several research opportunities for further work. The single-period models must first be extended to multi-period assortment and shelf space planning to model the actual product deterioration more realistically. This will then allow considering different product shelf lives, product outdating, and sell-through rates over several periods. This is needed to analyze the impact of product replenishment on assortment and shelf space planning and to consider customer preferences for fresher products. A second research avenue should enhance the demand models and their impact on food waste. Effects such as substitution, which is already known from the standard assortment and shelf space models, can be studied concerning their impact on food waste. Similarly, the effect of food waste causing freshness-dependent demand on assortment and shelf space decisions needs to be analyzed.

5. Replenishment policies

5.1. Related literature

Table 2 summarizes the papers that tackle food waste through replenishment policies. These works can be clustered into three streams: (i) innovative food-waste-related replenishment policies, (ii) assessment of existing policies concerning food waste, and (iii) extension of replenishment with pricing policies.

(i) Related literature on innovative food-waste-related replenishment policies Retailers usually apply two main policies for replenishment: the Base Stock Policy (BSP) or order-up-to S policy places an order to raise inventory to a predefined quantity S; the Constant Order Policy (COP) places an order of fixed quantity Q. The need for a new order may be triggered by a reorder point s or by a time interval R, leading to policies with more than one parameter (e.g., (s,S), (s,Q), (R,S) and (R,s,S) as the most common policies) (see, e.g., Silver et al., 1998). The well-known Newsvendor, a single-period BSP, is the most used policy for products with a very short shelf life and food-related replenishment problems. We further refer to the reviews of inventory management with perishables (see, e.g., Bakker et al., 2012; Goyal and Giri, 2001; Janssen et al., 2016; Nahmias, 1982). Even though the literature on inventory models for perishables is generally well advanced, there is not yet any review that explicitly refers to food waste. A significant shortcoming of the policies is that they do not differentiate the inventory age of individual products. Hence, several innovative replenishment policies have been proposed in the literature to overcome this and to address food waste specifically. Our review is therefore focused on the analysis of replenishment policies in relation to food waste.

Broekmeulen and van Donselaar (2009) apply a (R, s, nQ) policy, where the orders represent multiple case packs n with size Q. They introduce the Estimated Withdrawal and Aging (EWA), which estimates the total quantity of products that will be outdated during the review period due to FEFO-LEFO withdrawal of customers. Employing simulation experiments, they found that modeling the withdrawal and ageing with the EWA increases the fill rate and decreases the average inventory and outdating compared to a base policy without this estimate.

Haijema (2014) also extends a BSP by introducing a policy that considers the stock age. They further introduce a disposal decision regarding the discard quantity based on future demand. As replenishment costs are to be minimized, this decision is intended to reduce holding costs for old stock and decrease lost profits from the sale of discounted products. The policy proposed may result in lower total costs but higher waste. The waste increases because of the proactiveness of the disposal. Haijema (2013) proposes a new basis for stock-level dependent ordering that extends (s, S) policies by limiting the order quantity Q to a minimum and maximum amount. In an environment with highly fluctuating demand, this is intended to prevent both stock-outs and overstock leading to expiration. By using policy parameters adjusted for each weekday, he shows that the quantity limits help to balance the age distribution of the inventory and minimize product expiration. Haijema and Minner (2016) provide an extended analysis of Haijema (2013) and examine various mixed BSP and COP policies based on the proposed policies with restricted order quantities to find the most suitable policies for different cases.

They compare the performance of twelve possible manifestations of replenishment policies, for example, with given batch sizes, different order-up-to levels depending on the inventory position, or by combining a minimum order quantity with a reorder point s. Regarding costs and product outdating, policies that can smooth orders by avoiding significant ordering variance and those that allow skipping orders show the best performance. The latter forces LEFO customers to meet their demand with older products. Such strategies minimize waste, particularly in contexts with many FEFO customers and high disposal costs. The follow-up study of Haijema and Minner (2019) proposes new policies that are additionally age-dependent. They either extend previous policies with an Estimate of Waste (EW) due to outdated products or assign weights according to the age of products in inventory. They compare the new policy with the optimal policy obtained via stochastic dynamic programming (SDP) (Nahmias, 1975) and the EWA mentioned above policy of Broekmeulen and van Donselaar (2009). The authors show that their policies with EW outperform the existing age-dependent policies and perform close to the result obtained with the SDP. However, the authors limited the research to zero order costs and acknowledged that the conclusions might change if fixed costs are incurred.

More recently, innovative replenishment policies have been extended to incorporate alternative channels. Lee and Tongarlak (2017) advance the replenishment policies by considering the so-called by-product synergy. It describes using excess fresh produce (from the primary process) to make prepared foods such as salads (secondary process) within the store. Three policies are investigated, which are extensions of a Newsvendor. The “Fresh Only policy” only optimizes the replenishment of fresh products. The “Optimal policy” considers the joint replenishment of fresh and prepared products. The “Hybrid policy” first optimizes for the fresh products and uses the expected excess for the by-products. Through a simulation experiment, the authors show that the Hybrid policy avoids over-ordering fresh products compared to the Optimal policy. Thus, it may be a good compromise between profits and waste. Second, based on a Newsvendor, Mallidis et al. (2020) develop an inventory model that minimizes waste by optimizing the timely donation of products near expiration. The policy considers a cycle length equal to the product’s shelf life and sets the order quantity at the beginning of the cycle. During the review period, the retailer observes the current stock: if the stock is below a threshold donation quantity, no quantity will be donated; otherwise, the retailer donates the difference between the current stock and the threshold quantity. They demonstrate the potential in a case study evaluating the trade-offs between quantity donated and profit losses. They conclude that the optimal threshold quantities to be donated decrease with higher cost/price ratios, and, as such, the donation policy is preferred for products with low-profit margins. Zhang et al. (2020) propose two new, relatively simple replenishment policies. The first policy suggests ordering up to the mean demand in each period and discarding a given inventory at the beginning of the planning horizon. The second policy is based on a Newsvendor. It is more flexible and considers the clearance at the beginning of each period. Both policies are derived for a FEFO consumer withdrawal but later compared with a LEFO behavior. The critical insight of such policies is that as the market that is served by an inventory point grows, managing perishable inventory is simplified because inventory expiration becomes negligible. In other words, centralizing inventories to serve different channels avoids the need to incorporate waste in the replenishment policies. Clarkson et al. (2022) are the first to assume that products perish independently from each other by considering an age-dependent perish probability. Using this approach, products from the same age class do not perish at the same time. The periodic review inventory control model with non-stationary demand considers outdating cost and is formulated as a Markov decision process with different heuristic solution approaches presented. Analyses show that order patterns significantly change compared to policies that assume simultaneous expiration. In addition to stochastic demand, Hansen et al. (2023) consider random lead times and develop a periodic review replenishment policy which dynamically determines the order quantity subject to a service level constraint. By means of simulation, they show that their developed policy outperforms COP, BSP, and EWA in terms of waste. They further evaluate the impact when lead time uncertainty is ignored, resulting in failure to reach the targeted service levels.

(ii) Related literature on assessment of existing policies concerning food waste This literature stream comprises publications focusing on alternative inventory-related strategies that retailers potentially apply to prevent waste. This includes deriving expressions to measure waste-related parameters and the impact of logistics/technical interventions, studying real-life constraints for retailers (e.g., the effect of closing days), or optimizing other decisions (e.g., discarding options and discounted prices). Van Donselaar (2012) propose two mathematical expressions for relative outdating (i.e., the relation between expected outdating and expected demand) to track food waste. One is based on theoretical assumptions, and another is derived from simulation and linear regression. They consider an EWA policy with only FEFO withdrawal. The main managerial implication of this study is the trade-off between outdating, safety stocks and fill rate. For example, the authors find that a fill rate of 98% results in 20% outdating, while reducing it by 5% implies a reduction to 10% outdating. Then, Tromp et al. (2016) assess the impact of different interventions on food waste and OOS. The authors use retail data and apply a periodic BSP policy with LEFO withdrawal behavior. They focus on a single product but with both fixed and random shelf life. Waste is estimated in two ways: one expressing the outdating quantity related only to time; and one that results from a quality decay model related to time and temperature. Moreover, only products of minimum quality and age can be kept on the shelf. All inventory interventions, such as reducing the safety stock or the review period, minimize waste at the expense of higher stock-outs. However, technical interventions, such as reducing the minimum quality threshold, lead to preventing both food waste and stock-outs. The impact of closing days on waste in retail stores is examined by Janssen et al. (2018). A periodic BSP policy is applied, considering mixed FEFO and LEFO withdrawal behavior, different demand patterns (i.e., systematic, seasonal and weekday trends), and a fill rate constraint. Furthermore, a new expression to determine the safety stock for a risk period (with closing days) is advanced. Based on their simulation experiments, they conclude that incorporating closing day constraints in the replenishment problem leads to slightly lower food waste. They further find that a store operating seven days a week instead of six reduces the relative outdating by 18.6%. Next to the general replenishment decisions, Ketzenberg et al. (2018) focus on optimizing the decision regarding the selling horizon of random shelf life products, i.e., the maximum number of periods a product is offered before it should be disposed of. This decision allows a trade-off between customer risk and waste costs. Heuristic policies are applied to obtain the ordering and expiration date decisions that minimize the average expected costs. This work concludes that removing products too early is much more costly than late removal. However, the conservative behavior of retailers tends to lead to the former strategy.

(iii) Related literature on extending replenishment with pricing policies While focusing on replenishment, some works acknowledge the interaction with short-term dynamic pricing decisions. First, Li et al. (2012) examine how the profit may be maximized when different inventory ages are not displayed together. The authors tackle a joint problem of replenishment and pricing with disposal costs. They use an order-up-to-level policy. At the beginning of the period, the retailer takes ordering and pricing decisions and decides if the ending inventory is disposed of or carried to the next period. The authors show that when the disposal cost is low, the retailer benefits by discarding earlier and selling new inventory. Also, the benefit of dynamic pricing is very high since it can be achieved with a small number of price changes. Li and Teng (2018) develop a model that optimizes pricing and inventory decisions considering that demand depends on price and product freshness. They demonstrate an equilibrium between the selling price and ending inventory and conclude that the equilibrium selling price remains constant with increasing shelf life. Hence, they suggest investments in preservation technologies to extend product freshness. More recently, Zhang et al. (2021) also approach the joint problem of replenishment and pricing but incorporated space-elastic demand. The replenishment policy follows a periodic BSP policy with a reorder point. The objective is to optimize reorder point and the discount price. Based on a discrete-event simulation, the results evidence that for short-shelf-life products, the reorder point should be low to avoid waste, whereas it may be large for extended shelf-life products.

Summary The papers reviewed in this section show that simulation experiments are the primary method applied to analyze food waste and evaluate the trade-offs between revenues/profits and waste amount/costs. In papers dealing with (i) innovative replenishment policies, the stochastic demand is a parameter that is not differentiating the product age and uses only specific ratios for FEFO and LEFO customer withdrawal, i.e. the customers select only the oldest or the freshest products, respectively, but not those in-between these extremes. Most papers only tackle single-product models, and thus, no considerations about shelf capacity and product interactions (e.g., substitution) are made in the analyses. Also, most of the papers consider that products have a fixed shelf life, and thus the freshness decreases linearly along the time horizon. Nonetheless, two papers (Ketzenberg et al., 2018; Tromp et al., 2016) consider products with random shelf life and thus make use of quality-decay models to simulate the deterioration of the product over time (see (ii)). It is also worth mentioning that some studies focus on extending the replenishment policies to incorporate disposal decisions, such as Ketzenberg et al. (2018) and Mallidis et al. (2020), as well as modeling the decisions of replenishment and discount of products near expiration jointly (see (iii)).

5.2. Future research

The literature review allows the identification of three main areas for future research.

(1) Replenishment policies aiming to maximize inventory freshness The proposed replenishment policies strive for profit maximization or cost minimization, respectively, where waste appears only as a cost component of the objective function or is solely tracked. Although several suggestions for preventing food waste, little attention has been paid to maximizing the freshness of the stock. For example, the stock freshness can be increased by restocking shelves more often. Therefore, the store delivery frequency and replenishment strategy need to be aligned. The same applies to shelf replenishment from the backroom, assuming that products age more slowly in the backroom. However, this needs to be adjusted to the actual customer demand for each product. If the freshness level on the shelf can be increased, this will also impact freshness-dependent demand and customer withdrawal.

(2) Incorporation of further general and waste-related demand aspects From the papers reviewed, only Zhang et al. (2021) incorporate space-elasticity as a demand effect, whereas substitution behavior is not considered in any work. Both are necessary to determine the actual customer demand and analyze their impact on replenishment policies, which might lead to a change in policy parameters. Subsequently, the demand effects need to be examined concerning their influence on food

Table 3
Overview on food waste related dynamic pricing literature.

Publication	Waste integr.[a]	**Demand modeling**[b]				**Product modeling**[c]				Decisions/**policies**[d]
		general		waste-specific		general		waste-specific		
	D/S	Effects	FD	WB	SP	MP	FL	RL		
Sezen (2004)	WM	D	PE	✓		✓		✓		DR,TD
Wang and Li (2012)	WM	D	PE	✓		✓			✓	DR,TD
Buisman et al. (2019)	WT	S	PE		✓	✓		✓	✓	DR,SS
Kayikci et al. (2022)	WT	S	PE	✓		✓			✓	P,DR,SA
Chung and Li (2014)	WT	S	PE	✓		✓		✓		DF
Wang et al. (2016)	FM	D	PE			✓			✓	PP
Tekin and Erol (2017)	WM	D	PE, SB	✓			✓	✓		PP
Adenso-Diaz et al. (2017)	WT	D	PE	✓		✓		✓		PEF
Chung (2019)	WT	S	PE	✓		✓		✓		DS,SA
Yang et al. (2021)	WT	S	PE	✓		✓			✓	PP,PID
Keskin et al. (2022)	WM	S	PE			✓			✓	PP,SA

✓: component considered

[a] FM: freshness maximization, WM: waste minimization, WT: waste tracking.
[b] D: deterministic, S: stochastic, PE: price-elastic, SB: substitution behavior, FD: freshness dependent, WB: withdrawal behavior.
[c] SP: single product, MP: multiple products, FL: fixed shelf life, RL: random life time.
[d] DR: discount rate, TD: time of discount, SS: safety stock, SA: stock amount, P: sale price, PP: price per period, DF: discount frequency, PEF: price-elasticity factor, DS: display strategy, PID: probability of information disclosure.

waste generation caused by replenishment policies. For example, customer substitution between similar products can decrease their order-up-to level S and decrease waste levels for one or both products since overstocks are prevented. Furthermore, none of the reviewed papers attempts to capture the effect of product freshness on demand in the replenishment policy. Although the majority of contributions consider customer withdrawal, considering a demand utility as a function of the product age, however, will allow a representation of customer preferences in-between the extremes of FEFO and LEFO withdrawal. The interest of this research stream is reiterated if the goal of the replenishment policy switches from traditional profit maximization to freshness maximization. The customer picking between different product ages when demand is freshness-dependent should be picked up in future models.

(3) Differentiating product age in replenishment policies The work of Janssen et al. (2018) is the only one that provides a replenishment policy considering the different ages of a product. Nonetheless, product ages are only considered in stock balance constraints, as the study assumes that products arriving at the retailer always have the same shelf life. In reality, however, the same products of one order might arrive at different ages. Considering different product ages upon arrival can influence the replenishment policy setting in general and their performance in terms of food waste since the variation of product outdating increases.

Summary Reviewing replenishment models shows that the papers generally track or minimize waste. However, the goal of product freshness maximization needs to be improved in this literature. In addition, innovative policies minimizing waste also lack the consideration of a demand dependent on the product's freshness rather than only FEFO or LEFO withdrawal. Considering such freshness effects may lead to more accurate replenishment policies that represent a multi-product setting and the inclusion of substitution and withdrawal behavior and space-elastic demand.

6. Dynamic pricing policies

6.1. Related literature

This section reviews the dynamic pricing papers integrating food waste into their study. A summary of the classification of each paper is depicted in Table 3. We can divide the studies into two main streams: (i) discrete pricing and (ii) continuous pricing.

(i) Related literature on discrete pricing policies Sezen (2004) is the first to account for a waste cost factor in discounting policies. To maximize the profit, the starting time of each phase and the discount rate applied is set. Using a simulation, it is shown that more discount phases are generally more profitable (i.e., two better than one, one better than none). Also, in general, the later the discount starts the higher the profits. However, the impact on waste is not analyzed. Driven by the importance of acknowledging the products' actual quality, Wang and Li (2012) study a similar problem, but considering random shelf life products. The shelf life definition is based on a deterioration rate which is determined by time and storage temperature. The deterministic demand depends on consumers' sensitivity to price and quality. The authors compare the single and multiple price discount policies through simulation experiments and evidence like Sezen (2004) that more price discounts allow higher benefits. The authors also show that less waste and higher profits are achieved when the discounting process begins earlier with a lower discount than when it is delayed but with a higher discount. Moreover, an excess discount may increase OOS, leading to lost sales.

Kayikci et al. (2022) also use a similar logic as in Sezen (2004), dividing the selling horizon into four phases. The product phase is defined according to the real-time freshness status. The demand is stochastic, and the consumers have a price and freshness reservation threshold (i.e., they only buy the product if the price is lower than the reservation price and the freshness is higher than the freshness reservation). Although replenishment is impossible during the selling horizon, the model defines the order quantity at the beginning and the selling price at each phase. The effects of sales price, order quantity, discount rate and freshness status on the retailer's profit and amount of waste generated are analyzed through simulations. The results show that there is a discount rate threshold that maximizes profit and minimizes waste to zero. Following the same line of analyzing the effect of discounts on several indicators, Buisman et al. (2019) study the influence of considering random versus fixed shelf life. Their work is one of the few works that include replenishment decisions (i.e., define the safety factor used in a daily order-up-to-level policy) during the planning horizon and manage the offering of the same product with different freshness levels. The demand is stochastic and split between LEFO and FEFO consumers, with the share influenced by the discounts given. They do not consider waste costs but simulate multiple scenarios to analyze the influence of the variables of interest (e.g., discount level and inventory safety factor) on the amount of waste generated. The authors observe that when the discount occurs two days before expiration (fixed or random), the profits and replenishment quantities decrease and shortage increases, compared to a discount on the last day of shelf life. The waste generated is primarily affected by the discount rate rather than the discount time, with the LEFO/FEFO consumer ratio becoming smaller and smaller.

(ii) Related literature on continuous pricing policies The influence of discount frequency is investigated by Chung and Li (2014). The authors consider a target stock replenishment and a probability demand function that trades off between the lowest price and the freshest product unit. Four pricing policies are analyzed: no-discount, discount once, discounts every two days and discounts every day. The simulation results for different product shelf lives show that the no-discount policy leads to higher profits than the others, whereas the last two policies outperform, on average, the discount once policy. Notwithstanding, the last two policies efficiently prevent waste to zero, while the other two generate high waste values (particularly the no-discount). Adenso-Diaz et al. (2017) investigate a similar problem, considering the offer of product units with distinct freshness levels and a deterministic demand function dependent on price, age and influence of age on price (linked with the discount level). When the last two parameters are equal, the function boils down to the linear discount practice of Chung and Li (2014). They propose a bi-objective model to decide the discount level that maximizes revenues while minimizing waste. The results show that increasing the age influence on the price parameter minimizes waste, allowing it to entirely prevent waste when the customer withdrawal of older units decreases linearly with age. For small values of this parameter, total revenues increase. However, there is a turning point when waste is fully prevented, for which an increase in this parameter only decreases the revenues. A central managerial insight of this work is that reducing waste by 50% reduces the revenue by no more than 20%.

As the only work tackling a multi-product setting, Tekin and Erol (2017) propose a deterministic approach for a dynamic pricing problem. The work analyzes two scenarios with a fixed price (higher or closer to the purchasing cost) and three other scenarios where the price charged per period relates to the freshness degree of: (i) the concerned product (high pricing), (ii) all stocks of the same product (medium pricing) and (iii) all stocks of all products in the same discount group (i.e., incorporating a substitution effect) (low pricing). The results show that in the high pricing scenario, the price decreases slowly in each period, whereas in the medium pricing scenario, the price decreases suddenly after crossing some freshness rates. While the authors account for a waste cost in the profit function, the impact of the policies on the waste generated needs to be studied.

Other works compare the traditional case, where only products with the same age (the oldest) are available on the shelf, with the case where products with distinct ages are offered simultaneously to customers. First, Chung (2019) highlights that the product package size can influence the consumers' behavior towards buying a product with lower freshness. Therefore, they include a probability of accepting a product with a given freshness, considering two cases: (i) the probability increases with the freshness related to large pack products, and (ii) the probability decreases with the freshness for small pack products. Two scenarios are investigated. In scenario 1, no discount is applied; only the oldest products are displayed on the shelves. In scenario 2, all available products are displayed, and a daily discount is applied. The simulation results show the following: when demand is higher than expected, the two scenarios behave similarly regardless of the shelf life of the products. When demand is accurately forecasted, scenario 2 improves sales and minimizes waste if the package size is large; otherwise, the two scenarios behave similarly. Second, the study of Keskin et al. (2022) focuses on the importance of perfect information regarding demand relationships and decay rate. The authors propose two pricing policies, for non-parametric and parametric demand noise distribution, and measure performance based on profit regret (i.e., profit loss caused by not knowing the perfect information). The retailers' profit takes into account disposal costs. Although the proposed model considers that a proportion of the inventory will perish without considering the products' age, the authors present an extension to account for age-dependent product decay and consumer LEFO withdrawal behavior. With this extension, a regret reduction of around 11% is achieved, highlighting once again the value of keeping track of products' freshness. The importance of freshness information is also studied by Yang et al. (2021) by comparing scenarios with and without the retailers accounting for quality information in their pricing policies in a setting with just one product age and no replenishment during the planning periods. The authors present the idea of product quality disclosure, considering that consumers have different perceptions, i.e., different consumers perceive an equal/lower/higher quality than the product has. Similar to Kayikci et al. (2022), the work assumes that the consumer has a price and minimum quality threshold. By disclosing the quality information, consumers' perceptions are adjusted, and more sales can be realized. Thus, the aim is to maximize total discounted profit by setting the product price and the probability of information disclosure in each period. Yang et al. (2021) confront the scenario with information disclosure with a scenario where the information is only retrieved and used by the retailer. Again, the results show that information disclosure helps to reach higher profits and minimize waste when the percentage of consumers with low perceived quality is above 50%.

Wang et al. (2016) is the only work on dynamic pricing policies that tackle food waste by maximizing the freshness level of the product offered. The work aims to maximize an aggregated consumer-based utility function that considers product freshness in addition to maximizing sales. The work is built on perceiving price fairness by equalizing the average aggregated utility of consumers along the selling horizon. The authors compare their proposal with static pricing and discount policies without consumer fairness perception. They demonstrate that the proposed policy achieves better overall consumer utility and does not sell less inventory than the other policies. However, in most cases, the proposed policy results in lower revenues. Nevertheless, the loss of revenue might be compensated by the long-term relationship that the retailer will build.

Summary The review indicates that most of them incorporate a freshness-dependent effect, which is highlighted as a crucial property in addition to the price effects that are modeled anyway. Only Buisman et al. (2019) consider FEFO/LEFO withdrawal, for which the proportion is influenced by the discounts made. Nevertheless, the most recent literature is focusing more on random shelf life, particularly dynamic shelf life (i.e., using sensors to determine the actual product condition), due to the new technologies available, pointing out that it allows more flexible and coherent discounting policies of the products, and subsequently waste, aligned with the actual product quality (Buisman et al., 2019; Kayikci et al., 2022). Only four papers consider disposal costs explicitly in the objective function, whereas most studies analyze discounting policies regarding waste tracking. Results are discussed regarding the trade-off between profits achieved and waste generated. It is noted that there is a discount threshold after which the impact on waste stabilizes, and the profits decrease (Adenso-Diaz et al., 2017; Kayikci et al., 2022). Still, studies that aim to maximize product freshness considering the simultaneous offering of products with different shelf lives or considering a multi-product setting are scarce in this related literature.

6.2. Future research

The literature review allows the identification of three main areas for future research.

(1) Real-time data on product quality The importance of accurate and real-time information on product quality is discussed in many works, and the increasing trend of IoT and other new technologies is opening the way to this area of research. Therefore, more dynamic pricing problems able to account for and leverage this information are critical. Moreover, the works of Yang et al. (2021) and Keskin et al. (2022) demonstrate the potential of information disclosure to customers about the product quality on food waste reduction. Such information allows customers to select products that otherwise would be left on the shelf, generating waste. However, the impact of the moment of disclosure on consumer behavior needs to be further investigated.

(2) Differentiating product age in discounting policies Only a few works have studied cases where the same product may be offered to customers with distinct ages or freshness levels. In such cases, the product's price depends on age/quality. Thus, the customers may select one or another item based on their preferences, leading to substitution behavior within the product offer. This calls for future research on new dynamic pricing studies that account for this substitution behavior in customers' demand models and its incorporation into profit maximization and waste minimization approaches.

(3) Consideration of demand interactions between products Only the work of Tekin and Erol (2017) considers a multi-product setting and incorporates the effect of other products' freshness. When the analysis is limited to one product, the interactions with other products, like substitution or cross-selling, can not be considered. For example, the price decrease of one (older) product cannibalizes the sales of other products. Therefore, the discount on one product may harm the waste of the other products. This calls for further research in food waste reduction and dynamic pricing when considering multiple products. Also, the regular promotions of retailers (e.g., weekly offers) and their impact on waste can be studied in this context. Thus, further research that integrates the interdependence between product discounts into dynamic pricing policies needs to be developed.

Summary The reviewed papers highlight the importance of keeping track of the products' freshness over time, providing accurate information to customers and designing adequate discount policies based on consumers' behavior towards freshness and price. In this context, the design of pricing policies considering products with different freshness levels and/or a multi-product setting, where specific products can be offered simultaneously while accounting for the possible substitution and cross-selling, are also promising directions for future research.

7. Summary, overarching avenues for future research and limitations

Interest and research to mitigate food waste has grown significantly during the last decade. Given the substantial economic, social and environmental impact of food waste, it is more important than ever to prevent it at all levels. Retail played and will continue to play an essential role in reducing the overstock at stores and beyond. While the causes and quantities of retail food waste have been widely researched, countermeasures have only recently begun to be explored. Better planning of grocery store operations will help to prevent food waste. As there is a growing amount of publications for analytics and modeling approaches but not yet any structured overview, we compiled the state-of-the-art literature.

We analyzed literature in three distinctive areas to answer RQ1: how food waste is incorporated into analytics and grocery retail store operations modeling. The areas (1) *assortment and shelf space planning*, (2) *replenishment policies*, and (3) *dynamic pricing policies* have been identified as the most relevant modeling and optimization areas to reduce waste at the store level proactively. We further review the literature in each area to identify waste management integration in current store operations problems. We found that *freshness maximization* is an untapped area and has yet to be integrated into planning models. Optimization approaches that focus on *waste minimization* draw on an economic penalization of overstocks (see, e.g., Hübner and Schaal, 2017a; Kök and Fisher, 2007; Li et al., 2012). Others develop replenishment strategies that take the age of the available stock into account (see, e.g., Broekmeulen and van Donselaar, 2009; Haijema and Minner, 2019). A third option is to directly integrate reuse options into the replenishment policy, for example, a secondary in-store use (Lee and Tongarlak, 2017). Pricing strategies are ultimately food waste minimization per se since profits are significantly reduced when products are not sold at all. *Waste tracking*, finally, is included as a measure to evaluate specific policies, interventions or decisions (see, e.g., Haijema and Minner, 2016; Tromp et al., 2016; van Donselaar and Broekmeulen, 2012; Zhang et al., 2021). We highlight the development of different streams and models in each area.

To answer RQ2, what characterizes the setting of these planning problems that tackle food waste, we leverage a structured review and classification scheme containing waste-specific modeling aspects, namely freshness-dependent demand, customer withdrawal behavior and shelf life. The standard classification is applied across all three areas to identify the type of waste integration, general and waste-specific demand modeling, general and waste-specific product modeling, policies applied, and the decisions taken in each contribution. This structured review identifies commonalities and differences across models and develops insights into food waste minimization approaches.

Answering RQ1 and RQ2 allowed the unveiling of the main research gaps that should be addressed to improve grocery retail store operations *vis-à-vis* food waste (RQ3). These gaps were indicated in each planning area and can now be given an overarching perspective.

Incorporating full economic, ecological and social impact of food waste

The current models in all areas focus either on profitability (like the assortment and pricing models) or do not quantify the impact of food waste (like some replenishment policies). For example, in assortment and shelf space planning, food waste is only penalized in monetary terms. However, focusing solely on lower profits falls short when considering the total costs and the ecological and social impacts of food waste. Disposal of products or the reuse and recovery practices necessary to treat overstocks usually generate additional efforts and costs (e.g., for redistribution, sorting in case of donation, or waste collection). The same holds if social aspects of wasted food (e.g., concerning unequal access to adequate nutrition) or environmental impacts (e.g., consumption of water, agricultural land and energy of unconsumed food) are not considered. For future research, the latter two factors can be approximated as cost factors. Thinking even further, models can also include more sustainability aspects, such as the inclusion of emissions for inventory holding (see, e.g., Pervin et al., 2023) The models would need to be reformulated as multi-criteria problems that account for all sustainability dimensions.

Enhancing each planning area with regard to waste integration

We classify three waste-related characteristics in our review regarding the characteristics of the planning problem: *(i) withdrawal behavior* and the *(ii) freshness-dependent demand* by customers representing the demand perspective, and the product perspective concerning fixed or random *(iii) shelf life*. These topics are common across the three areas and offer different opportunities for future research.

(i) The *withdrawal behavior* is primarily covered in the replenishment literature, modeling different shares of FEFO/LEFO withdrawal. Prevailing publications deal with the consequences of different withdrawal behaviors but need to investigate how assortment, replenishment, or pricing policies may limit opportunistic withdrawal. There needs to be an approach to tackling the problem of customers picking the freshest products and potentially exacerbating waste generation. Policies tailored to consider the inventory age when scheduling replenishment should be analyzed for its impact on food waste. For example, it would be interesting to investigate the optimal time to replenish fresh products on the shelf to control the available shelf lives. Shelf space allocation also has the potential to counteract undesirable withdrawal behavior actively. Considering the turnover frequency, the shelf inventory can be set so that too many different product conditions or ages on the shelf are avoided. This can prevent customers from searching for the longest expiration date in the first place. The need for more publications considering customer withdrawal is also present in the pricing area. Only Buisman et al. (2019) take withdrawal behavior into account. It should be investigated how dynamic pricing can be used as a powerful tool to control customer withdrawal towards a desired FEFO behavior.

(ii) Freshness-dependent demand is prominently addressed within the pricing area as it is a primary driver for adapting prices. Contributions in this area frequently combine freshness – with price-dependent demand, where demand increases with decreasing prices or after announcing a sales period. This, however, creates a critical trade-off: prices decrease as quality decreases, leading to a demand increase due to price elasticity. On the other side, freshness-dependent demand decreases as the quality drops (cf. Chung and Li, 2014). While some contributions also consider the additional impact of space-elasticity (see, e.g., Li et al., 2021; Zhang et al., 2021), the impact of freshness-dependent demand on assortment and shelf space planning and especially their potential to reduce food waste still needs to be comprehensively studied, particularly regarding stochastic demand. This is also true for replenishment policies, where the consideration of demand effects needs to be sufficiently addressed. Therefore, linking freshness-dependent demand and other demand effects constitutes a future research area.

(iii) Finally, integrating products' *shelf life* is essential in all areas. We found that shelf life is predominantly considered using a fixed lifetime, especially for assortment and replenishment models. This focus can be attributed to the dominance of single-period approaches. However, the effects and interrelations of different shelf lives over multiple periods cannot be examined in this way. With dynamic modeling of shelf life, also represented as product quality, freshness-dependent demand can be determined. However, this is not necessarily associated with food waste-related aspects in the papers reviewed. A more detailed analysis of the interrelation and interplay of shelf life or product quality, corresponding demand and food waste is a worthwhile path for future research directions.

Integrating comprehensive food waste management across all planning areas All three areas are discussed play an important part in in-store operations, but the individual planning problems are also interrelated, and planning steps need to be aligned. The definition of the shelf quantity as part of the assortment and shelf space as an example is only possible based on the underlying replenishment frequency. Although the importance of the interaction between all measures to reduce food waste is emphasized in empirical studies (see, e.g., Gruber et al., 2016; Winkler et al., 2022), the current models are mostly dedicated to one area. A sequential approach, however, neglects the interdependencies between areas, as decisions in one area also impact the degrees of freedom in another. Our review shows that replenishment policies are not yet integrated into assortment planning. When selecting the assortments, retailers determine the maximum shelf inventory of each product at the same time. Especially for fresh products, this also requires the consideration of replenishment processes that are aligned with the characteristics of perishables and the available backroom storage. However, this is not yet analyzed in the current literature. Further studies need to be more specific with regard to demand dependencies. Due to customer substitution, not all products have to be available at any time (van Woensel et al., 2007; Riesenegger and Hübner, 2022). In this respect, also the composition of the assortment plays a role: if products with high substitution rates are listed, fill rates will be different compared to items with low rates or even non-substitutable items. Future research for integrated approaches for joint assortment and replenishment planning is thus required to explore the potential of waste reduction fully.

Limitations The contribution of this review is subject to certain limitations. For instance, store operations are just one part of the entire supply chain. The execution of store operations depends, among others, on the decisions made in the upstream areas of the retail and food supply chain. Several influencing factors that need to be coordinated along the supply chain are not discussed, for example, case pack sizes (see, e.g., Wensing et al., 2018) or the minimum shelf life on receipt (see, e.g., Mohamadi et al., 2021). For these kinds of decisions, the involvement of several stakeholders is required. A further issue that is not addressed is forecasting. Modeling approaches need forecast as input to unfold the full potential, an aspect we neglected in this study. Furthermore, we have not included behavioral aspects related to planning (e.g., model usage) and the execution level of the store. Finally, since this review is limited to brick-and-mortar stores, the research gaps and areas for further research cannot be transferred to other channels, such as e-grocery retail or omnichannel grocery retailers.

The methodology adopted for our review may also generate some limitations. As we use only one database (Scopus) and the papers selected are both written in English and belong to peer-reviewed retail and operations research journals, it may narrow the analysis we intend. Some studies, which may turn out to be relevant in the field of in-store operations, could be missing in our review. We compensate this with a backward and forward search in the references and a targeted search in leading journals. Nonetheless, our analysis was thorough and allowed us to establish future research directions, and present valuable insights from the current literature.

Declaration of Competing Interest

We declare that accepted principles of ethical and professional conduct have been followed, any relevant information regarding sources of funding has been included, potential conflicts of interest (financial or non-financial) are made transparent, the research did not involve human participants or effect the welfare of animals.

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Appendix A. Keyword search and relevant journals

The following OR and management journals (in alphabetic order) were used for our search:

4OR - A Quarterly Journal of Operations Research; Advances in Operations Research; Annals of Operations Research; Applied Stochastic Models in Business and Industry; Asia-Pacific Journal of Operational Research; Central European Journal of Operations Research; Computational Optimization and Applications; Computers & Operations Research; Concurrent Engineering: Research and Applications; Decision Support Systems; Discrete Event Dynamic Systems – Theory and Applications; Discrete Optimization; Engineering Economist; Engineering Optimization; European Journal of Industrial Engineering; European Journal of Operational Research; Expert Systems with Applications; Flexible Services and Manufacturing Journal; Fuzzy Optimization and Decision Making; IEEE Systems Journal; IISE Transactions; IMA Journal of Management Mathematics; INFORMS Journal on Applied Analytics; INFORMS Journal on Computing; International Journal of Computer Integrated Manufacturing; International Journal of Industrial

Table A.1
Utilized keywords in Scopus.

Area A **Waste**	Area B **Product**	Area C **Retail**	Area D **Store operations**
wast*	food*	retail*	"store logistics"
loss*	grocer*	supermarket*	"store operations"
outdat*	perishab*	store	"in store"
spoil*		shop	assortment
deteriorat*		market	"shelf space"
expir*		baker*	display
decay*		commerc*	inventory
			ordering
			replenishment
			pric*
			markdown
			discount*
			promotion*

The search string was created by combining the keywords in the columns: "AND"-connector for connecting the single columns and "OR"-connector for connecting keywords within one column.

Engineering Computations; International Journal of Information Technology & Decision Making; International Journal of Production Economics; International Journal of Production Research; International Journal of Retail & Distribution Management; International Journal of Systems Science; International Journal of Systems Science: Operations & Logistics; International Journal of Technology Management; International Review of Retail Distribution and Consumer Research; International Transactions in Operational Research; Journal of Global Optimization; Journal of Industrial and Management Optimization; Journal of Manufacturing Systems; Journal of Operations Management; Journal of Optimization Theory and Applications; Journal of Quality Technology; Journal of Retailing; Journal of Retailing and Consumer Services; Journal of Scheduling; Journal of Simulation; Journal of Systems Engineering and Electronics; Journal of Systems Science and Systems Engineering; Journal of the Operational Research Society; Management Science; Mathematical Methods of Operations Research; Mathematical Programming; Mathematical Programming Computation; Mathematics of Operations Research; Memetic Computing; Military Operations Research; M&SOM – Manufacturing & Service Operations Management; Naval Research Logistics; Networks; Networks & Spatial Economics; Omega; Operational Research; Operations Research; Operations Research Letters; Operations Research Perspectives; Optimal Control Applications & Methods; Optimization; Optimization and Engineering; Optimization Letters; Optimization Methods & Software; OR Spectrum; Pacific Journal of Optimization, Probability in the Engineering and Informational Sciences; Proceedings of the Institution of Mechanical Engineers, Part O; Production and Operations Management; Production Planning & Control; Quality and Reliability Engineering International; Quality Technology & Quantitative Management; Queuing Systems; RAIRO – Operations Research; Socio-Economic Planning Sciences; SORT – Statistics and Operations Research Transactions; Studies in Informatics and Control; Systems & Control Letters: Systems Engineering; Technovation; Transportation Research Part B – Methodological; Transportation Research Part E – Logistics and Transportation Review; Transportation Science.

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