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1 Introduction

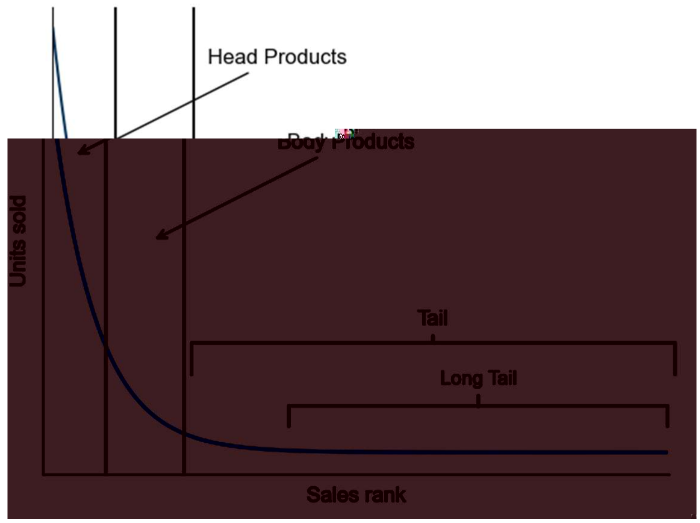
The E-commerce retail spending market has reached a volume of more than 1 trillion USD in the USA for the first time in history (Essling and Clough, 2023), demonstrating the importance of E-commerce for the consumer's purchasing behavior. While consumers spent most on groceries, apparel, and accessories (Essling and Clough, 2023), a retailer with an e-commerce channel can offer a vast array of products and product categories, because fulfillment centers (FCs) can be placed in comparatively cheap real estate areas and the Internet enables placing orders from everywhere and fulfilling orders from everywhere. As a result, customers discovered niche products, which led to the emergence of the so-called long tail. Long-tail products are defined as goods whose individual sales are low yet collectively contribute significantly to sales (Øverby and Audestad, 2021). The opposite of tail products are head and body products referring to products whose individual sales make up substantial high and medium shares of sales. They respectively correspond in well-known Pareto curves to classes A for head, B for body, and then C and higher for tail. Long-tail products lie at the low end of tail products, in Pareto curves they generally correspond to classes D, E, F and beyond.

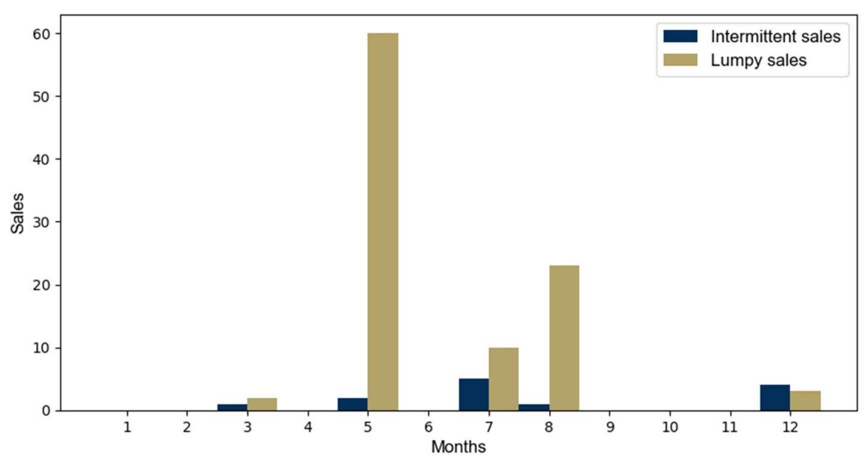
For the remainder of this paper, we use the term e-commerce retailer to refer to retailers with only an online platform as well as the e-commerce business of an omnichannel retailer. The e-

The work does not relate to the authors' affiliation with Amazon.com, Inc.

commerce retailer has three often conflicting, yet crucial goals: service level, long-term profitability, and sustainability, notably in terms of environmental impact. The first goal motivates carrying a large product portfolio to offer a one-stop shopping experience to the customer. Customer satisfaction in e-commerce can also be achieved by tailoring the delivery to the customer's needs in terms of delivery/pickup time, location, and reliability. Hereafter, we use the more general term

(Brynjolfsson et al., 2006; Goel et al., 2010). Despite the number of sales for long-tail products being low in absolute and relative terms, e.g. Johnston et al. (2003) report that 75 % of the product portfolio of a retailer have six or less orders per year and Chodak (2020) even describes products that have not been sold once in the year of the analysis, an E-Commerce retailer is motivated to carry a large product portfolio because the "one-stop shopping" experience for the end consumer can increase sales for highly demanded items as well as less popular products (Goel et al., 2010). Moreover, e-commerce allows aggregating niche tastes over entire regions as long as the delivery lead time is acceptable. The resulting aggregated demand of niche products might provide a business argument to carry a niche product (Brynjolfsson et al., 2006).





Boylan and Syntetos, 2021)

2.2 Order Fulfillment

Order fulfillment comprises confirming availability of ordered products, then picking, packing, and delivering the order. When ordering a product online, basic information about availability of the product is typically shown to the customer (e.g., is it in stock? What is the promised delivery time?). The information that the product is in the retailer's fulfillment center and does not need to be ordered from an upstream supplier may increase sales by 70% for an average product (Baldauf et al., 2021). Cui et al. (2020) researched how the availability of high-quality delivery services influences purchasing behavior in online retail where delivery quality encompasses speed, reliability, and pick-up and drop-off flexibility. They showed that the sales of long-tail products depend less on high delivery quality as compared to popular products. A potential explanation is that long-tail products are less likely to be offered by several competitors. This said, delivery speed and reliability are increasingly important factors for the buying decision as shown in a survey by X Delivery (2022). 56% of online shoppers abandoned an online cart because of too long delivery times or fees for delivery. In fact, 36% of shoppers expect free one-day or two-day delivery but only 1% of retailers can accommodate these expectations. Salari et al. (2022) demonstrated that accurate delivery time promise, i.e. neither overpromising nor under promising of the delivery time, can increase sales by up to 6.1%.

2.3 The Physical Internet

Introduced as a new paradigm for moving, deploying, realizing, supplying, designing, and using physical objects, PI aims to enable order-of-magnitude worldwide capability and performance improvements of logistics and supply chains in terms of efficiency, sustainability, and resilience (Montreuil, 2011). PI features include universal interconnectivity; smart modular containers for packaging, handling, and transporting physical objects; protocols, interfaces, and business models for open multi-party, multi-modal flow consolidation and asset sharing; and multi-tier mesh networks of openly accessible logistic hubs for crossdocking and consolidation, and deployment centers (e.g. storage, fulfillment) (Montreuil et al., 2013, 2014; Shaikh et al., 2021).

In the PI, distribution and transportation systems are hyperconnected. Their networks and constituents are connected on multiple layers, such as physical, digital, operational, transactional, and legal, notably through multi-tier meshed networks (Montreuil et al., 2018). Distribution systems leverage a distributed web of openly accessible deployment centers such as long-stay warehouses, distribution centers (DCs), and fulfillment centers (FCs), owned and operated by multiple parties, offering storage and fulfillment services. Transportation systems leverage multiple modes, services, and vehicle types to move goods from their origin to their targeted destination through multi-segment journeys enabling dynamic reconsolidation across multi-tier networks of logistic hubs. Sohrabi et al. (2016) and Kim et al. (2021) have provided optimization and simulation based experimental results documenting cost improvement on the order of 30% solely employing hyperconnected distribution or hyperconnected transportation, and on the order of 40-50% when employing both. Moreover, their studies revealed that providing higher service levels is less expensive with PI than conventional dedicated and hub-and-spoke based systems (Sohrabi et al., 2016).

(Pan et al., 2015) showed the system-wide inventory level and total logistic costs, consisting of inventory holding cost and transportation cost, are reduced for fast-moving consumer goods in PI compared to a classical hierarchical supply chain because of better selection of storage locations as well as flexible and responsive replenishment plans. For example, storage facilities cannot only source from a production site but also from other storage facilities which corresponds to a multiple-sourcing strategy. Additionally, Yang et al. (2017) demonstrated that PI inventory control performs better in the case of demand uncertainty or supply chain disruptions. According to Montreuil (2016), omnichannel business-to-consumers (B2C) logistics in PI can be designed in various degrees of interaction between the business and the PI entities with the two extremes of the business making order fulfillment and inventory deployment and replenishment decisions with internal teams and software all the way to where a fulfillment orchestrator is responsible for inventory and fulfillment decisions for multiple retailers, hence well poised to leverage economies of scale. Naccache (2016) concluded that small and mid-sized e-retailers would benefit the most from PI operations because a small e-commerce retailer aiming to provide one-day delivery windows over a vast territory may rely on hyperconnected distribution and transportation to dynamically deploy its products over a large distributed yet interconnected set of deployment centers, achieving concurrent high performance in terms of profitability, consumer satisfaction, and greenhouse gas emission reduction, without large investment costs and delays

3 Challenges of Long-Tail Products in E-commerce

E-Commerce retailers are confronted with decisional challenges on four fronts for all types of products: network-wide product assortment, network inventory level, inventory deployment across the network, and customer order fulfillment. Long-tail product management poses additional challenges due to the sheer size of the long tail, the low number of sales of each long-tail product, and the intermittent and lumpy characteristics of long-tail demand. In this section, we present the challenges for all four decisional fronts and explain how they relate to achieving service level, profitability, and environmental sustainability goals.

3.1 Networkwide Product Assortment

E-commerce companies tend to carry millions of products, notably giants such as Amazon and Alibaba. Both e-retailers base their product assortment decisions on their mission. For example, Amazon's mission "to build a place where people can come to find and discover anything they might want to buy online" advocates for its assortment to ultimately include all products made in the world (Hull, 2012). According to Chodak (2020), the long-tail in e-commerce results from the combination of the low marginal cost induced by listing a product on the online marketplace with the ease of finding products using an efficient search engine. This increases potential demand which can lead to higher sales. The more niche products are offered, the more heterogenous customers can be served, which again potentially can lead to higher sales. E-commerce retailers also employ recommendation system to "fatten the long tail", explicitly aiming to increase sales of long tail products as well as fast-moving products (Kumar and Bala, 2017). While customer satisfaction is a key frontside reason why products are offered, another backside reason is that once a product is stored in a fulfillment center, it might not be economical to retrieve remaining unsold units, so it is easier for the e-retailer to keep offering the product on the website until the remaining inventory is completely depleted.

3.2 Network Inventory Level

Decisions on how many units per product to have in the network are subject to forecasting capabilities, the batch sizes imposed by the supplier, potential discounts the supplier offers, and the desired service levels to customers. Despite recent progress, forecasting methods for intermittent demand are more difficult and less accurate than for fast-moving products and adoption of new forecasting methods in commercial software is slow (Boylan and Syntetos, 2021), resulting in imprecise forecasts. Even if true demand was known a-priori, the retailer might only be able to buy a batch with more units than necessary to robustly cover the forecasted demand due to the production process, other economies of scale or discounts (Zhu et al., 2015). For example, a product with a total demand of 10 units per year might have a minimum order quantity of 15 units. This leads to 5 units expected to bind capital beyond a year, incurring holding costs that decrease profitability. For a perishable product, these units must be discarded which is a waste of both financial and environmental resources. In addition, the service level the retailer wants to provide in terms of delivery time might require it to have a higher stock than total demand. If the retailer promises next-day delivery, then at least one unit must be stored within 24-hour reach of each customer. In large geographic markets such as the USA, this could mean that the product must be stored in more than ten FCs depending on available delivery modes to the e-retailer, again requiring more than a year's demand.

In particular, the first product stocking decision can lead to overstocking. The supply recommendation systems are not yet familiar with the product and lack historical data. The supplier, convinced that the product would become popular, pushes to start with high inventory. Lack of data leads to imprecise and/or biased demand forecasts. Hence, sales do not materialize as predicted (Chodak, 2020). In fact, early on, any product is more likely to become a long-tail.

3.3 Inventory Deployment

Inventory deployment decisions answer how many units of each product are to be placed in each FC given the current and projected networkwide inventory level, and where to replenish a specific FC from. In long-tail contexts, such decisions are exacerbated by the huge number of products with low and intermittent demand. Internal decision factors are the targeted service levels, network inventory level, the number, location and capacity of fulfillment centers the e-retailer is using and whether to employ static or dynamic inventory allocation. The market distribution in the serviced region, often highly correlated with population, is the main external factor on the inventory deployment decisions.

Despite lower supply costs because of storage in areas with low real estate prices (Hoskins, 2020), large-scale E-commerce retailers tend to carry millions of products such that even in large FCs, each product unit must justify the space it takes up. Consequently, fast-moving products that free up space quickly are preferred. Another reason why FC capacity is limited are the delivery expectations of customers discussed in section 2.2. To achieve short delivery times, FCs have to be placed close to the customers. As the majority of customers live in metropolitan regions where space is limited and real-estate costs are higher, FCs and the resulting holding costs tend to also be higher. This increases the competition for long-tail products in given FC because it is uncertain whether that unit will ever be demanded in the region the FC is supposed to cover. The solution space is also limited because of the low number of units per long tail product. If the supplier sends the ordered batch to the upstream inbound cross dock, splitting the batch and sending individual units s □ □ (prFCmiersss oero" bound a somewhat unique product, so they have contemplated their purchase decision for longer and consequently the additional waiting time for delivery is of less importance. To the best of the author's knowledge though, there has not been scientific studies whether the desired delivery velocity depends on whether it is a head, body, or long-tail product. Moreover, as the desired delivery time generally decreases, the desired delivery time for any item is expected to decrease as well. Going forward we assume that delivery time is one of the decisive factors in the buying decision for long-tail products and contributes to converting a website visitor into a customer.

	Profitability	Environmental Sustainability	Service level
Product Assortment	Profitable long-tail products	Little to no long-tail products	Variety of long-tail products
Network wide inventory level	Network wide inventory level to match demand	Network wide inventory level lower or equal to demand	Network wide inventory level necessary for service level promise
Inventory Allocation	Units stored in low-cost FCs, yet near enough customers	Zero marginal emissions through distribution	Units in potentially high-cost FCs close to customers
Order Fulfillment	Cheapest delivery mode	Delivery mode with lowest emissions	Delivery mode and time in line with customer preference

We summarize the generally desired solution for each of the above long-tail pertinent decisions with regards to our goals of profitability, environmental sustainability, and service level in Table 1 which shows that the three goals are conflicting each other. On the positive side, fast order-to-delivery fulfillment times may lead to higher customer satisfaction, conversion rate, and revenues. On the negative side, it may lead to higher overall customer price, induced costs, and higher carbon footprint. This is exacerbated when delivery transportation is done using modes relying on fossil fuels and generating high emissions. Since long-tail products have a small number of units in the network, their nearest-to-customer unit is, on average, further away from the customer than for head and body products. The question remains therefore what economic and environmental costs justify which service level.

4 Conceptual Framework

This paper contributes to the conceptual research towards PI and to solutions-oriented research by offering a concrete example on how e-commerce can start leveraging PI characteristics for long-tail products. In addition, the long tail theory also becomes more applicable to brick-and-mortar stores (Hoskins, 2020). Moreover, the word E-commerce is typically associated with large companies, like Amazon and Alibaba, but small and local stores, such as 'mom and pop stores', increasingly require and have an online channel. For example, the number of merchants on Shopify more than doubled between 2018 and 2020 (Backlinko, 2022). The framework presented here is of interest for small and mid-sized retailers because they can leverage economies of scale which are currently not available to them. Indeed, the concepts apply to a large portion of long-tail products as well as to a multitude of retailers selling the same long-tail product, enabling increasing cost savings (Kim et al., 2021; Pan et al., 2015).

We show how four components of the PI enable profitable, sustainable, and consumer-oriented long-tail inventory management and order fulfillment. These components are: hyperconnected transportation, hyperconnected distribution and its open space sharing, open inventory sharing, and open information sharing. The hyperconnected transportation system works best as intended if the other components are in place, and vice-versa. Therefore, we present a three-level framework that increasingly shifts from dedicated to openly shared spaces, inventory, and data, where each level is supported by hyperconnected transportation. For each level, we discuss impacts on sales, storage, transportation, and environmental cost, as well as service levels.

4.1 Level 0: Dedicated Spaces, Dedicated Inventory, Dedicated Data

For completeness, Level 0 describes the current situation that applies to most retailers. Each of them has their own storage facilities, where the inventory is owned and managed by the retailer (or its warehouse 3PL). That means orders are fulfilled only from the warehouse locations operated by the retailer. The retailer potentially loses sales if they run out of inventory, or the desired delivery time cannot be achieved. Even if they provide the desired delivery time, this might come at a high environmental cost, e.g., shipping with planes. Lastly, inventory decisions are made on the demand seen by the retailer only. As pointed out in 3.2, they might be forced to buy more than they will sell, resulting either in units sitting on the shelf and taking up space for faster turning products and/or units that are being disposed of.

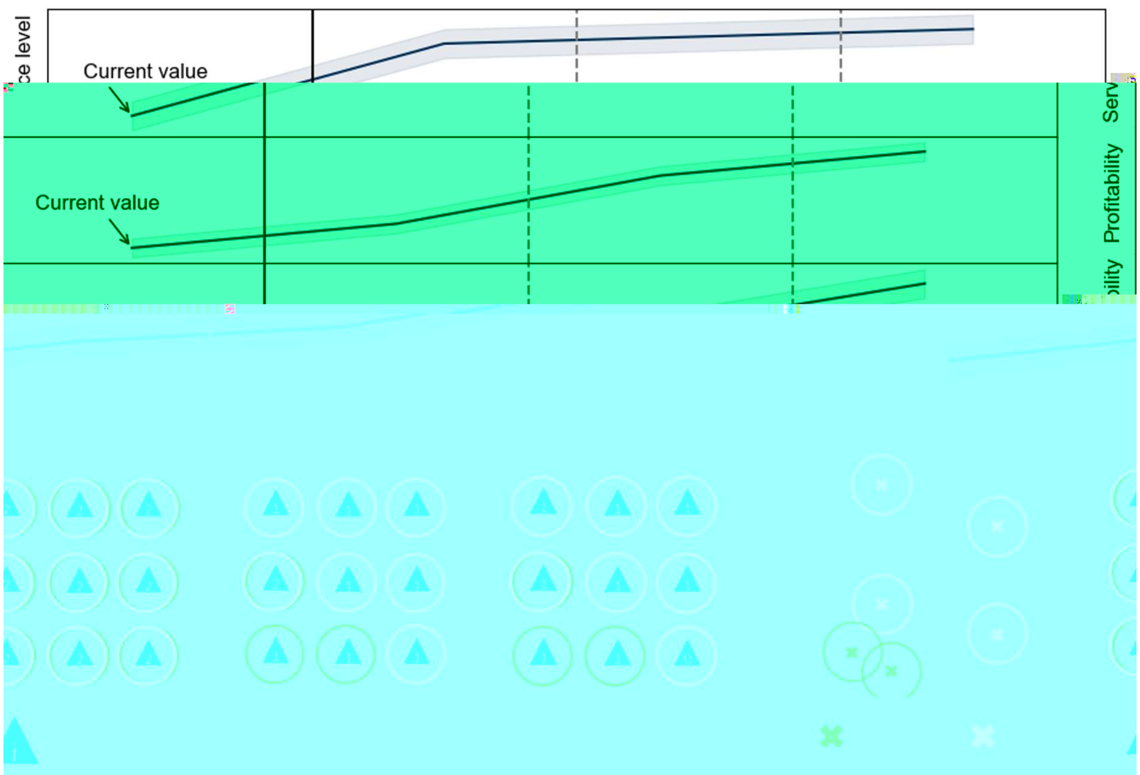
4.2 Level 1: Shared Spaces, Dedicated Inventory, Dedicated Data

Level 1 leverages the hyperconnected distribution system and the hyperconnected transportation system. The hyperconnected distribution system provides shared space through a network of interconnected open-access deployment centers. The networked centers are managed and operated by logistics service providers, and each retailer can dynamically use the shared space to locate their products better for desired durations. Level 1 does not require any interactions between e-commerce retailers that offer the same long-tail product.

The concept of sharing warehouse space can already be seen in industry. For example, STORD allows companies to flexibly book warehouse space across the US. While large E-commerce retailers tend to have a fulfillment network across a larger region, this is not the case for small and mid-sized retailers mainly because operating a warehouse far away from the base location is not profitable or operationally not feasible. However, being able to only rent space in a warehouse based on the space a few units of long tail product take up becomes economically more feasible for them. Kim et al. (2021) shows that inventory holding costs and hub usage costs can be twice and three times as high as in the dedicated system, respectively, but still incurring a 10 % overall cost reduction. The consolidation of shipments within PI can result in up to 27 % reduction in delivery time (Venkatadri et al., 2016; Yang et al., 2016; Orenstein & Raviv, 2022) and generate more satisfied customers (Kim et al., 2021). Consolidation reduces environmental cost in form of emissions and transportation costs by up to 50% (Kim et al., 2021). Hence, when assuming the same demand as in the dedicated system, using hyperconnected distribution and transportation for long-tail products will reduce lost sales and induced costs, and therefore increase profits while also providing better service levels.

4.3 Level 2: Shared Spaces, Shared Inventory, Dedicated Data

While Level 1 did not require any interaction between e-retailers, Level 2 expects retailers to share their inventory for order fulfillment. As retailers who sell the same long-tail product can be in different regions, they lower transportation costs and emissions by agreeing that an order is fulfilled by the retailer whose product units are closer to the customer. A potential long-term benefit is the reduction of the inventory level for each retailer while still serving the entire region with the same service levels. The quantification of this benefit depends largely on the minimum order quantity set by the supplier, targeted service level and the total demand, hence, requiring an extensive simulation study intended for future work. This said, for illustration purposes, consider a two-retailer scenario where the best outcome would be that each retailer only covers one half of the region with inventory, leading to a reduction in inventory costs by approximately 50 %. Legally acceptable protocols and transfer costs ensure achieving the intended benefits. PI literature (Pan et al., 2015; Yang et al., 2016) , as well as general literature (Liu, 2016; Yu & Wei, 2018; Sampath et al., 2022) on inventory sharing concentrates on inventory replenishment from one warehouse to another. Hence, the approach of shipping directly to the customer from a collaborating e-retailer is an extension of current inventory pooling methods tested in the PI context. Location data for product units needs to be made available confidentially by the retailers to a neutral fulfillment decision entity. As fulfillment decisions are completely automated nowadays, the retailers would not be required to disclose their data to the other participating e-retailers. Lastly, it should be noted that shared inventory could also be done without sharing spaces. We believe however that the most benefit is gained by implementing the components in a stepwise manner. For example, retailers may well trust this shared inventory scheme if the stock of each participating retailer is stored and made available in open-access fulfillment centers rather than in each retailer's dedicated fulfillment centers. Therefore, we concentrate on building one level on top of the other.



4.4 Level 3: Shared Spaces, Shared Inventory, Shared Data

PI relies on digital interconnectivity, interoperability and information sharing to operate its networks efficiently. We apply this idea to our framework of sharing sales/demand data to reduce inventory cost and emissions by requiring less total inventory. If long-tail product demand and sales data for a given period is shared among all participating retailers, they become aware of the true total demand. This is an inventory pooling through information sharing strategy. Generally, inventory pooling leads to a lower average inventory level which reduces inventory costs. A second effect of sharing demand and sales data is that individual inventory replenishment decisions are made accounting for the entire demand and sales. This leads to further pushing inventory sharing of level 2 (Section 4.3) to avoid ending up with unsold units in the system and the cost for replenishment orders.

Consider a case where the total year-to-date sales of a product was 6 units as of November over all retailers. A retailer who expected to sell 6 units annually and still has one unit in-stock might be more interested in sharing inventory when learning that their forecasting of their market share was an overestimate. Moreover, retailers might consider splitting batch orders from the supplier to the extent allowed by the law. As a result, inventory holding costs are reduced due to inventory pooling while the service levels of Level 1 and 2 are maintained. Environmental emissions are lowered due to the reduction a os e sideMinvenorhilr e oMa y teolM

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