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Invited Review

E-fulfillment and multi-channel distribution – A review

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Abstract

This review addresses supply chain management issues specific to Internet fulfillment in a multi-channel environment. It provides a systematic overview of managerial planning tasks and corresponding quantitative models. Our objective is to twofold, namely to enhance the understanding of multi-channel e-fulfillment by documenting the current state of affairs, and to inspire fruitful future research by identifying gaps between relevant managerial issues and available academic literature.

One of the recurrent patterns in today's e-commerce operations is the combination of 'bricks-and-clicks' – the integration of e-fulfillment into a portfolio of multiple alternative distribution channels. From a supply chain management perspective, multi-channel distribution provides opportunities for serving different customer segments, creating synergies, and exploiting economies of scale. However, in order to successfully exploit these opportunities companies must master novel challenges. In particular, the design of a multi-channel distribution system requires a constant trade-off between process integration and separation across multiple channels. In addition, sales and operation decisions are ever more tightly intertwined as delivery and after-sales services are becoming key components of the product offering.

Keywords: Distribution; E-fulfillment; Online retailing; Literature review

1. Introduction

Despite the end of the initial hype, Internet sales have seen tremendous growth rates over the past years (Forrester Research, 2005). While the retail market share of Internet sales is still small its quarterly growth rate of 8.6% in 2004 largely outweighs the corresponding 1.3% growth of total retail sales (Dinlersoz and Hernandez-Murillo, 2005). After the initial over-enthusiasm, more sustainable models of e-commerce have started to emerge. One recurrent pattern is the combination of 'bricks-and-clicks', the integration of online sales into a portfolio of multiple alternative distribution channels. In 2003, multi-channel retailers accounted for 75% of the online sales in the United States (Forrester Research, 2005). This development is fed from two sides. On the one side, many traditional retailers have added an online channel to their portfolio. On the other side, 'pure-play' Internet retailers are opening physical stores or are collaborating with traditional retailers, as in the case of Internet

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pure-player iParty.com that opened 33 physical stores in the USA (Campanelli, 2001). Hence, understanding the interplay between multiple channels is essential for understanding Internet fulfillment. While online sales and multi-channeling provide rich opportunities, the design of the underlying distribution processes also confronts companies with novel complexities. To the best of our knowledge, no review article has yet addressed the specific supply chain management issues of Internet fulfillment in a multi-channel environment. This paper attempts to fill this gap by providing a systematic overview of the relevant issues and linking them to available operational research models. Our objective is to twofold, namely to enhance the understanding of multi-channel e-fulfillment by documenting the current state of affairs, and to inspire fruitful future research by identifying gaps between relevant managerial issues and available academic literature.

Before reviewing specific planning issues, we include a few additional comments on multi-channeling to set the stage. Opportunities and challenges of a multi-channel strategy concern both marketing and operations management. Furthermore, decisions in both fields are ever more tightly intertwined.

From a marketing perspective, different channels differ in their abilities to perform various service outputs. The Internet channel is particularly powerful in providing information to the customer, thereby reducing the buyer's search costs. Another advantage of the Internet channel is the ability to provide a very large range of products. Much of the value of the internet to consumers comes from providing access to products in the long tail (Brynjolfsson et al., 2003). On the other hand, an advantage of the traditional channel is the proximity to customers – that customers can buy a book and receive it instantly. Offering multiple complementary channels provides a greater and deeper mix of customer service, thereby enhancing the seller's overall value proposition (Wallace et al., 2004). Channel preferences vary between customers. But even individual customers are increasingly becoming multi-channel shoppers, preferring different channels at different moments and at different stages of the shopping process (Nunes and Cespedes, 2003). On the downside, major marketing-related concerns in multi-channeling include cannibalization and channel conflicts (Webb, 2002). An additional distribution channel may partly cannibalize the sales of existing channels, rather than growing total sales. Conflicts may arise between different divisions that manage a company's different channels, but even more so between different supply chain members, for example a manufacturer competing with its own resellers through a customer-direct Internet channel (Tsay et al., 2004). Consequently, managing the overall portfolio, rather than individual channels is key in multi-channeling.

From an operations management perspective, multi-channeling may yield synergies that help reduce e-fulfillment costs. E-fulfillment, delivering physical goods to the customer, is commonly cited as one of the most expensive and critical operations of Internet sellers (de Koster, 2002a; Lummus and Vokurka, 2002). Economies of scale from the integration of multiple channels need to be weighed against specific requirements of each individual channel. In particular, the economics of customer-direct Internet channels tend to differ from those of other channels due to small, single-order transaction sizes (Currah, 2002). Thus, companies need to make trade-offs when deciding which processes to integrate across channels and which processes to separate (Gulati and Garino, 2000).

The aforementioned marketing and operations management aspects are increasingly interrelated. Many markets have seen a shift from customers buying stand-alone physical products to customers seeking 'total solutions', i.e. a bundle of a physical product and related services. Services include, e.g., maintenance, consumable supplies, and end-of-life recovery. In an online channel, delivery is a key service element. Furthermore, just as mass customization has made the consumer a 'co-maker' of the physical product, companies are now tailoring their service processes to individual customers' needs. This means that customers are gaining significant impact on company processes, and it underlines the importance of coordinating marketing promises and operations capabilities.

In the remainder of this paper we highlight the different planning tasks that arise in this setting. We proceed as follows. Section 2 delineates the exact scope of the paper and provides a framework that structures our discussion. Sections 3 and 4 form the core of this paper. They discuss supply- and delivery-related e-fulfillment issues, respectively. Each section first discusses managerial planning issues observed in practice and then reviews corresponding operational research models. Section 5 summarizes our conclusions.

2. Scope and framework

In this section we delineate the scope of our analysis and position it within the existing literature. Furthermore, we outline a framework that serves to structure our discussion throughout the remainder of the paper.

Several excellent review papers are available that address the impact of the Internet on supply chain management, including Keskinocak and Tayur (2001), Johnson and Whang (2002), Swaminathan and Tayur (2003) and Gimenez and Lourenco (2004). In addition, the handbook edited by Simchi-Levi et al. (2004) provides a detailed overview of related research areas. What distinguishes our contribution is (i) the specific focus on fulfillment operations, (ii) the systematic comparison of managerial issues and quantitative tools, and (iii) the particular attention to multi-channeling.

The scope of this paper is primarily inspired by the perspective of a multi-channel retailer. Its focus is on physical distribution processes in B2C e-commerce, i.e. on the processes that serve to convey a tangible product to the final consumer. These processes are commonly recognized as a key challenge in online distribution channels, primarily due to the difficulty of efficiently handling small transaction sizes of individual customer orders. We distinguish this setting from B2B e-commerce where the Internet primarily changes the information processes. The issues in our setting also differ from those in a manufacturer's Internet channel where channel conflicts due to disintermediation are a prime concern. This is an important field of its own right that has been extensively addressed in the literature (see e.g. Tsay et al., 2004). Furthermore, we focus explicitly on the distribution of physical products and therefore do not consider online channels of pure service businesses, such as banking, even though multi-channeling is an important marketing strategy in many service sectors (Coelho, 2004). Environmental and ecological consequences of Internet shopping are also beyond the scope of our paper (see Sarkis et al., 2004).

In the subsequent sections we address various planning issues arising in multi-channel e-fulfillment. To structure the discussion we map the planning tasks on two dimensions, namely, the supply chain stage and the planning horizon (comp. Fleischmann et al., 2002).

Along the first dimension we distinguish the four supply chain stages depicted in Fig. 1:

- *Sales* denotes all processes that directly interface with customer demand, such as pricing, order promising, and forecasting;
- *Delivery* encompasses the activities that physically move the product to the customer. In the case of home delivery, this is known as 'the last mile';
- *Warehousing* is concerned with the storage and handling function. Depending on the supply

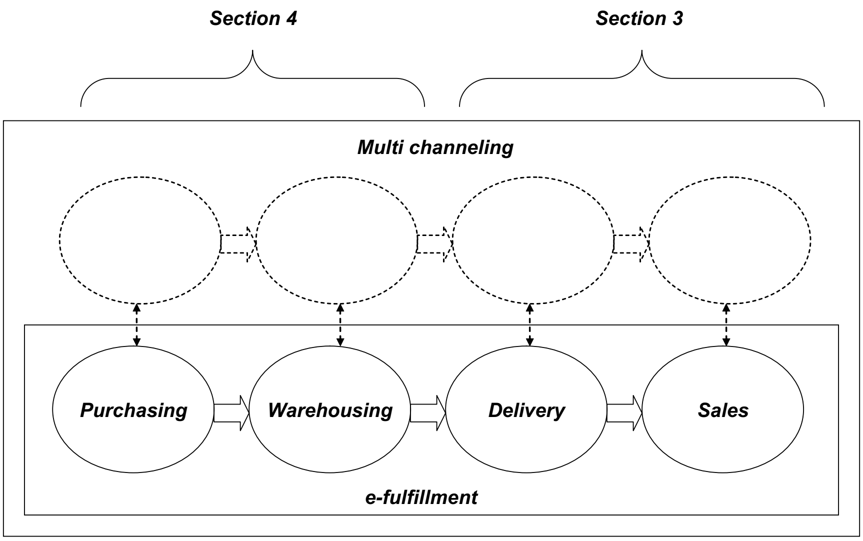

Fig. 1. Structuring the multi-channel e-fulfillment distribution process.

chain's decoupling point, the warehousing stage may be omitted or shifted to an upstream supply chain party;
- *Purchasing* is our term for all supply processes, notably ordering of final products.

Throughout this paper, we use the term 'e-fulfillment' to denote the collection of these processes. Note that, in line with the previously explained retail perspective, we do not include a manufacturing stage.

On the second dimension, supply chain planning tasks are commonly structured according to their planning horizon, i.e. from long-term strategic to short-term operational. We follow this approach within each of the above supply chain stages.

For each planning task we first discuss what, if anything, distinguishes e-fulfillment from traditional supply chains. Second, we consider the potential interaction with other channels in a multi-channel context (see Fig. 1 for an illustration). This concerns, in particular, trade-offs between integration and separation of processes across multiple channels.

We emphasize that the above structuring only serves as a means for organizing our discussion. We do not mean to imply that the different planning tasks are independent or that the different supply chain stages should be managed in isolation. On the contrary, we recognize online information exchange as an important enabler of supply chain integration. The marketing-operations interface has been receiving much attention in the recent supply chain management literature (Marketing Science 50, 2004, Journal of Operations Management 20, 2002). This interface is particularly relevant in e-fulfillment since the delivery service is an essential component of the product offering. In other words, the customer buys a bundle of a physical product and a delivery service (and possibly other after-sales services). Consequently, companies need to coordinate their sales promises and their delivery capabilities. Because of this close interaction, we discuss sales and delivery planning tasks jointly in Section 3. Similarly, Section 4 encompasses warehousing and purchasing issues.

3. Sales and delivery planning

Traditional sales-related supply chain planning tasks include long-term product program planning, medium-term pricing and forecasting, and short-term order promising (see e.g. Fleischmann and Meyr, 2003). Particular features of these tasks in an e-fulfillment environment notably arise from the fact that the delivery service makes part of the product offering. Embedding in a multi-channel structure gives rise to additional trade-offs. In what follows, we discuss the impact of these factors by planning task. Subsequently, we relate the observed issues to quantitative decision support models presented in the academic literature. Table 2 at the end of this paper lists the models by category.

3.1. Delivery service design

3.1.1. Issues

As with any company, Internet sellers need to design their product offering. This involves specifying both the product assortment and the offered delivery service, which is an important determinant of customer satisfaction (Boyer and Hult, 2005). Product assortment decisions are strongly interrelated with investments in inventory. By decoupling customer location and inventory location, the Internet drastically changes the underlying economics of assortment planning. Specifically, online channels may achieve strong pooling effects and thereby can afford a broader assortment than physical stores. For a further discussion of these issues we refer to Section 4.1. The quality of the fulfillment service is addressed in a growing body of literature on physical distribution services (Rabinovich and Bailey, 2004).

From a customer service perspective, concepts for bridging the 'last mile' to the customer can be divided into customer pick-up versus (home) delivery (Daduna and Lenz, 2005). The latter can be further subdivided into attended and unattended delivery (Kamarainen and Punakivi, 2002). While unattended delivery increases delivery flexibility, this concept is only applicable for products that can be safely deposited, e.g., in the customer's mailbox. The well-known example of US online grocer Streamline illustrates the difficulty of extending unattended delivery to more sensitive product categories. Streamline went bankrupt after being unable to earn back its investments of providing customers with refrigerated reception boxes.

For attended home delivery, a company and its customer need to agree on a delivery time window. The length of this window and its timing during the day are important aspects of the customer's perceived service. The same goes for the delivery lead time, i.e. order placement and delivery. At the same time, all of these factors have an immediate impact on the seller's delivery costs. Striking the right balance between cost and service is challenging, in particular in highly competitive environments, such as the grocery market (see Boyer et al., 2003).

Another e-fulfillment service element concerns the handling of customer returns. Internet sales face particularly high return rates since customers cannot try and feel the product beforehand. For example, online apparel retailers experience return rates totaling up to 45% of their orders (Tarn et al., 2003; de Koster, 2002a). Costs of return handling, which include bridging the expensive 'last mile' for a second time, can easily eradicate the economic viability of an online channel. Therefore, designing efficient return processes is of prime importance (Min et al., 2006). This again leads to a trade-off between customer service (i.e. the return policy) and operational costs (Yalabik et al., 2005). One way, in which companies are trying to shift this balance is by offering support services, such as installation support for electronic products, as a method to reduce product returns.

Traditional sales channels offer many potential synergies for the marketing of an Internet channel. In particular, a well-established brand name helps build trust with the customer, which is essential for online sales (Chen and Dhillon, 2003). The presence of a traditional distribution structure also yields additional options for the delivery service design in e-fulfillment. Physical store pick-up points are a fairly common alternative to customer home delivery. Online orders are picked and packed in a store where the customers can then pick them up (www.bestbuy.com, www.freerecordshop.nl), possibly via a dedicated pick-up lane (www.lowesfoods.com, www.foodfactory.nl). In this approach it is the customer who bridges the crucial 'last mile'. Other advantages of a pick-up structure include low capital investments and possible carry-over effects on in-store sales (Boyer et al., 2005; Johnson and Whang, 2002).

The presence of a physical distribution structure can be particularly beneficial for return handling. Most multi-channel retailers offer online consumers the option to return products via offline stores. This approach not only helps reduce return handling costs but it is also greatly valued by the customers (Forrester Research, 2005).

3.1.2. Models

Regarding the choice of the e-fulfillment product offering, the modeling focus in the literature has been on the delivery service. Several authors have addressed the issue of choosing an appropriate delivery service level, in terms of time windows and lead times. Some of the proposed models directly optimize the service offering by considering both costs and revenues. Other models take a what-if approach, highlighting the cost impact of a given service offering.

Several papers related to the ECOMLOG project of the University of Helsinki present simulation-based analyses of different delivery strategies for e-groceries (Punakivi and Saranen, 2001a; Punakivi et al., 2001; Punakivi and Tanskanen, 2002; Yrjola, 2001). Yrjola (2001) develops cost estimates for several alternative fulfillment strategies. The results award particular potential to hybrid structures that gradually expand e-fulfillment capabilities of traditional stores. Punakivi and Saranen (2001a), Punakivi et al. (2001) and Punakivi and Tanskanen (2002) compare transportation costs for attended and unattended delivery and assess the impact of the delivery window length. The results illustrate the efficiency gains of relaxed time constraints. Fully flexible, unattended delivery reduces costs by up to a third, relative to attended delivery within 2-hour windows. Similarly, Lin and Mahmassani (2002) use simulation to evaluate the impact of different delivery policies on the operations of an e-grocer. They illustrate the trade-off between delivery cost and customer service by highlighting the potentially significant cost impact of tight delivery time windows. Robuste et al. (2003) model the effect of time windows on delivery efficiency by continuous approximation. They demonstrate that the impact of time windows increases with increasing delivery vehicle capacity. Hsu and Li (2006) seek optimal delivery shipment cycles that strike a balance between delivery costs and customer service in terms of delivery lead times. They present a non-linear profit maximization model with lead-time dependent demand. Costs include purchasing, transportation, and inventory. Numerical examples illustrate the benefit of adjusting shipment frequencies to temporal and regional demand variations, rather than imposing a static policy.

We are not aware of any optimization models that explicitly consider delivery service choices in a multi-channel setting, e.g. choosing between home delivery and store pick-up. The reason may be that the number of alternatives for these strategic choices is small, and they can therefore be addressed separately, rather than requiring a comprehensive overall model.

What may be more remarkable is the scarcity of optimization models for return policies in e-fulfillment. This is in sharp contrast with the extensive literature on end-of-life returns on the one hand (see e.g. Dekker et al., 2003) and with the many models of buy-back contracts for supply chain coordination on the other hand (see e.g. Tsay et al., 1999). In the spirit of the latter, Yalabik et al. (2005) propose a game theoretic model that is tailored towards a retail environment. Specifically, they model a retailer's buy-back price decision, which influences demand of two customer segments.

3.2. Pricing and forecasting

3.2.1. Issues

Pricing decisions play a key role in any business. Service components, notably delivery, add an extra dimension to this issue in e-fulfillment. Companies need to set prices both for the physical products and for the delivery service. Common policies often combine both price elements, e.g. in the form of free delivery of sufficiently large orders.

Two factors render pricing a particularly powerful lever in online sales, namely significant pricing flexibility and extensive data availability. Typically, online sellers can change prices much more easily than traditional stores. Consequently, they can use pricing for short-term demand management (Baker et al., 2001). Besides dynamic posted prices, common online pricing policies include various types of auctions (Kambil and Van Heck, 2002). Interestingly, many firms are selling almost identical products online through auctions and fixed prices simultaneously (Etzion et al., 2006). What complicates e-fulfillment pricing decisions is the need to anticipate the ensuing cost consequences in the delivery operation. In addition, overly complex pricing policies may leave customers confused and distrustful (Garbarino and Lee, 2003).

The second major factor that increases pricing power in e-fulfillment is data availability. What is a major challenge for operations, namely dealing with individual customer orders, is a rich opportunity for marketers. Availability of transaction data of individually identified customers not only provides a rich basis for forecasting but, more importantly, allows targeted communication with the customer. This explains the particular relevance of customer relationship management (CRM) in online retailing.

Detailed data provides a basis for segment-specific pricing and promotion. In particular, firms can effectively cross-sell products and services that closely match a particular customer's preferences, as in the example of Amazon.com suggesting additional book titles, based on the customer's browsing behavior (Akcura and Srinivasan, 2005). Effective cross-selling requires a firm to select appropriate product bundles and to design a corresponding pricing strategy. In summary, we see a shift from reactive forecasting to a much more active demand management in e-fulfillment.

The presence of a traditional sales channel adds further dimensions to the pricing decision. In particular, retailers need to choose whether to offer the same prices – and price changes, such as promotions – across all channels or whether to price-differentiate. Some retailers choose identical prices for the physical products and use additional delivery fees as the main steering element of the online channel (see e.g. www.albert.nl).

In addition, traditional sales channels benefit from the rich data collected in the online channel. Forrester Research (2005) argues that advanced multi-channel tactics include CRM across multiple channels.

3.2.2. Models

The marketing literature reflects a long history of customer choice models (Erdem and Winer, 2002). Detailed data on Internet browsing and on e-commerce transactions opens significant opportunities for additional empirical research in this field. Van Den Poel and Buckinx (2005) and Jenamani et al. (2003) are examples of recent papers, which concentrate on explaining and predicting customer behavior on the Web.

The aforementioned models are primarily descriptive. In addition, a significant stream of prescriptive models is available for short-term price optimization. Making part of the well-publicized field of revenue management (Talluri and Van Ryzin, 2004), these models assess in particular the benefits of dynamic pricing policies over more stable prices (see for example Gallien, 2006). While not all of these models are focusing on e-fulfillment specifically, many of them appear to be applicable, due to the particular pricing flexibility in online sales. The same goes for the large set of auction and bidding models (Kalagnanam et al., 2004).

The above models essentially maximize revenues. Another line of research explicitly integrates cost and revenue effects of dynamic pricing. In particular, many authors have proposed combined inventory-pricing models. For a more detailed review of this rapidly expanding stream of research we refer to Chan et al. (2004) and to Elmaghraby and Keskinocak (2003).

As discussed in the previous subsection, the impact of dynamic pricing on e-fulfillment delivery costs appears to be particularly relevant. We are aware of two models explicitly addressing this issue. Asdemir and Jacob (2002) propose a dynamic pricing model for the delivery windows of a grocery home delivery operation. Similar to standard revenue management models, demand is stochastic and includes several customer classes. The model uses dynamic prices per customer class to balance capacity utilization. The authors analyze the structure of the optimal pricing policy as a Markov decision problem and numerically investigate the profit increase relative to a constant pricing policy. Campbell and Savelsbergh (2006) also consider price incentives to influence a customer's choice of a delivery window in a home-delivery operation. They propose a deterministic optimization model for choosing the discounts that explicitly captures the routing costs of a given order. A simulation analysis indicates that the suggested incentive schemes can significantly enhance profit.

Another stream of pricing-related research is concerned with optimal cross-selling. Kamakura et al. (2003) use a combination of survey data and customer databases to identify opportunities for cross-selling. They propose a statistical model to predict customers' likely buying behavior. This then serves as a basis for selecting the best prospects for cross-selling new products or services. Wong et al. (2005) propose a data-mining algorithm for finding a profit-maximizing set of items for cross-selling. They approximate the initial model by a quadratic program, which they solve heuristically. Netessine et al. (2006) consider the problem of dynamically cross-selling products or services in an e-commerce setting. Following a revenue-management approach, they develop a stochastic dynamic program for a finite horizon, multi-item inventory system. In each period, the company needs to decide which products to bundle and which price to charge for this bundle. The authors suggest several solution heuristics and test them numerically. The results suggest that dynamic cross-selling is most beneficial when inventory approximately equals expected demand. In a slightly different setting, Akcura and Srinivasan (2005) consider an online retailer's opportunities for cross-selling customer information to a third party. The paper proposes a game-theoretic model for the interaction between the retailer and the consumer. The results suggest that firms can achieve customer intimacy by committing to not cross-selling excessively.

Pricing models for a multi-channel setting appear to be scarce as of yet. For a review of general coordination issues between traditional and Internet channels see Cattani et al. (2004). We are aware of only one model that specifically addresses pricing decisions of a multi-channel retailer. Cattani et al. (2006) analyze optimal pricing policies in this setting for different degrees of autonomy of both channels. They assume that an individual customer's utility of buying a product decreases in the product price and in the channel-specific purchasing effort. Based on computational experiments, the authors conclude that optimizing web-channel prices without changing store prices often provides a reasonable heuristic for maximizing total profits.

3.3. Order promising and revenue management

3.3.1. Issues

Traditionally, short-term sales planning centers around order promising, roughly speaking the seller's response to an incoming customer request. Order promising plays an important role in manufacturing. The specific planning issues depend on the production environment. In a make-to-stock environment, planning systems calculate available-to-promise (ATP) quantities, indicating the number of products that can be committed to a given delivery date, based on projected replenishments (Fleischmann and Meyr, 2003). In a make-to-order environment, delivery dates depend mainly on downstream production capacity, and throughput time estimates play an important role. In traditional retailing, order promising is more straightforward since products are typically sold directly from stock. It is again the service component that adds to the complexity of order promising in e-fulfillment. In order to satisfy a customer order not only the requested product has to be available but also sufficient delivery capacity (analogous to assemble-to-order production). Based on these factors, the Internet retailer has to commit to a certain lead-time or estimate-to-ship date. Flexibility in the quoted lead-times can help increase e-fulfillment efficiency (Xu et al., 2006). In addition, the retailer may have some flexibility regarding where to retrieve the product – as opposed to physical stock in a traditional retail store (see Section 4 for a detailed discussion of inventory considerations in e-fulfillment).

In general, customer orders differ with respect to their contribution margins and their delivery costs. This gives rise to revenue-management issues in e-fulfillment, similar to those well known in the airline and hospitality industry (McGill and Ryzin, 1999). E-tailers have an incentive to use their inventories and delivery capacity for the most profitable orders. In the case of high utilization it may not be optimal to simply accept all orders first-come-first-serve until inventory or capacity are exhausted. Online order intake provides the retailer with additional flexibility in the allocation of inventories and capacity to customer orders. The benefits of exploiting this flexibility for a more selective order acceptance increase with increasing order heterogeneity and with decreasing inventory and capacity. This allocation decision also plays a role in the online rental business (e.g. www.Netflix.com), where customers commonly accept any of a set of products of their interest. What distinguishes revenue management in e-fulfillment from classical revenue management is the potential cost impact. In contrast with the prototypical 'airline' setting, marginal costs of an order are non-negligible in e-fulfillment and, what is more, delivery costs for different orders may be interdependent.

E-tailers have different revenue management levers at their disposal, including dynamic pricing and a dynamic adjustment of the offered delivery options (e.g. time slots). This links order promising to the short-term pricing decisions discussed above. In all of these cases, revenue management benefits from the real-time availability of rich customer data. Again, maintaining a certain level of transparency may be important for customer satisfaction.

In a multi-channel setting, order promising may cross the boundaries of individual channels. For example, in-store inventories may be available to online buyers. In this case, customer segmentation based on channel type, and a corresponding prioritization in order promising, may be beneficial since opportunity costs of missed sales tend to differ by channel.

3.3.2. Models

The large body of research on lead-time quotation and due-date management in manufacturing (see e.g. Keskinocak and Tayur, 2004) seems a natural starting point for order promising models in e-fulfillment. However, standard models do not appear to be immediately applicable to delivery services, due to significant differences in the underlying costs structures. Bundling of individual orders into delivery routes creates interdependencies between orders that differ from those in manufacturing. The waiting for a complete delivery tour accounts for a major part of the customer lead time. We are not aware of any models in the literature that specifically address lead-time quotation in e-tailing.

Revenue management has grown into a major field of research over the past decade. Model variants abound (see Talluri and Van Ryzin, 2004). Broadly speaking, the underlying managerial task is to sell scarce resources to the most profitable customers. Abraham et al. (2006) address the specific allocation decisions that arise in an online rental environment. In a retail setting, the allocation decisions are often intertwined with inventory replenishment decisions. We discuss the corresponding models in Section 4 in the context of inventory management.

As explained above, the e-fulfillment delivery process yields additional criteria for differentiating between customers. Depending on the requested delivery time and location, some customers may be more expensive to serve than others. Thus, if capacity is scarce, delivery cost differences should be taken into account when deciding which orders to accept. We are aware of only one paper that explicitly addresses this issue. Campbell and Savelsbergh (2005) propose a model for deciding whether to accept or reject an incoming home delivery request. Their analysis is based on insertion heuristics for a vehicle routing problem. They suggest several variants for incorporating expected future orders. A numerical study compares these variants and underlines their superiority over a simple first-come-first-serve order acceptance.

We see the development of revenue management approaches for home delivery operations among the most relevant current research issues in e-fulfillment and expect significant additional contributions in the future.

3.4. Transportation planning

3.4.1. Issues

On the delivery side, short-term planning concerns the actual transportation of the goods to the customer. The scope of this operation closely depends on the chosen delivery concept, as indicated earlier. In the case of in-store pick-up, 'transportation' may be limited to moving the goods to a check-out counter. Combining shipments with regular store replenishments may yield economies of scale.

Home-delivery implies a more extensive operation. Cost-efficient processing of small transaction sizes is a major challenge. Especially in the case of low-value items, such as groceries, transportation costs are a key determinant of the business viability. Hub-and-spoke networks provide a common way to create economies of scale while expanding geographical coverage (see e.g. www.ocado.com).

Dedicated home delivery, as opposed to delivery by mail, requires the planning of appropriate transportation routes. The degree of routing flexibility and thus transportation efficiency closely depends on the delivery service design, notably on the offered delivery time-windows.

In B2C Internet retailing new routing schedules have to be planned more frequently (usually daily or twice a day) than in a traditional B2B delivery environment. The reason is that many B2C orders are impulse buys whereas B2B purchases are often repetitive (Buck Consultants International, 2006). This leads Du et al. (2005) to argue that B2C environments exhibit a greater need for quick-response dynamic vehicle dispatching systems than B2B environments.

3.4.2. Models

Vehicle routing is a classical field of combinatorial optimization. Modeling and algorithmic contributions abound (see e.g. Toth and Vigo, 2001). Braysy and Gendreau (2005a,b) provide a recent survey of solution algorithms for vehicle routing problems with time windows (VRPTW).

Many of these models appear also to be applicable in e-fulfillment. The particular challenges of this environment, such as significant cost pressure, seem to affect parameter values primarily, rather than the underlying problem structure. VRP variants that seem particularly relevant in an e-fulfillment setting include the dynamic vehicle routing problem (DVRP), in which new orders arrive during operation (Fleischmann et al., 2004). Similarly the period vehicle routing problem with service choice (PVRP-SC), in which delivery routes must be constructed for multiple periods and delivery frequency is a decision variable, is relevant to home delivery operations (Francis et al., 2006; Francis and Smilowitz, 2006).

Weigel and Cao (1999) report on a vehicle routing problem with time windows in e-fulfillment at Sears, Roebuck and Company. Sears operates the largest furniture and appliances home-delivery service in the USA. The authors construct a series of algorithms tailored to handling the large problem size. Du et al. (2005) emphasize the dynamic nature of e-fulfillment and propose a combination of several existing algorithms for quick-response delivery in an online B2C environment.

Xu et al. (2006) link transportation planning to inventory deployment. Specifically, they consider the re-allocation of accepted customer orders to different warehouses while maintaining the original lead time commitment. Re-allocation may reduce transportation costs by taking into account more recent additional orders. The magnitude of these benefits depends on the degree of lead-time flexibility. This problem highlights the hierarchical planning structure of order promising and execution. The authors formulate the re-evaluation problem as a multi-commodity flow model. They propose near-optimal heuristics and apply them to an illustrative case involving a global Internet retailer.

4. Supply management

In the previous section we addressed issues and models related to the delivery and sales function of e-fulfillment. In this section we consider the processes further upstream in our supply chain framework (see Fig. 1). Supply and storage are the key functions at these stages. Corresponding planning issues range from long-term design issues to short-term execution. Particularities of e-fulfillment mainly arise from small transaction sizes. Important trade-offs of multi-channeling pertain to the aggregation of inventories. In what follows, we first discuss these issues systematically. Analogous with the previous section, we then review models from the Operational Research literature that correspond with the identified issues. Table 2 summarizes these models.

4.1. Distribution network design

4.1.1. Issues

Network design, including the choice of facility locations and corresponding transportation links, is a key strategic decision in any supply chain. In a retail environment, location choices mainly concern storage and transshipment facilities. The same is true in e-fulfillment. What is unique to e-fulfillment is the fact that inventories are decoupled from customer display. This increases the e-tailer's flexibility in locating inventories and allows for a larger assortment (Randall et al., 2006; see also Section 3.1). On the other hand, inventory locations are closely linked to the design of the delivery process discussed in the previous section. In conclusion, it is a trade-off between economies of scale and risk pooling on the one hand and delivery efficiency on the other hand that drives inventory locations and, in particular, the degree of inventory centralization. The impact of the delivery component is particularly important because of the relatively small transaction sizes, which often entail significant transportation costs.

The absence of physical inventory on display allows Internet retailers to avoid inventory ownership altogether by delivering customer orders directly from their suppliers' inventories. In this arrangement, known as drop-shipping, the retailer focuses on the sales function, and leaves the physical fulfillment processes to the supplier (Bailey and Rabinovich, 2005).

Drop-shipping is a common practice for non-perishable make-to-stock items, such as books and CD's. It provides a means for risk pooling by integrating the inventories of multiple retailers or retail outlets, which enables them to offer a larger assortment. On the other hand, the retailer concedes some of his margins, control, and customer proximity to his supplier (Randall et al., 2002). For a viable co-operation, retailer and supplier need to strike a balance between service level agreements and delivery costs.

A multi-channel setup yields obvious potential synergies on the supply side. Arguably, the biggest advantage concerns greater purchasing power and the leverage of established supplier relationships. Other synergies may arise in the physical distribution network. In particular, multiple channels may share inventories, thereby reaping pooling benefits. However, economies of scale can be hampered by different transaction sizes in different channels, e.g. pallet-sized orders of a retail store versus individual items in e-fulfillment. In this context, it is worth noting that storage facilities of an e-fulfillment channel share characteristics both with traditional warehouses and with traditional stores. The specific e-fulfillment channel indicates which characteristics prevail. This is reflected in three types of e-fulfillment structures commonly distinguished in the literature (de Koster, 2002a,b; Lummus and Vokurka, 2002):

- *Integrated fulfillment* – building e-fulfillment capability into existing distribution centers that also deliver to conventional stores;
- *Dedicated fulfillment* – via a purpose-built "green-field" operation;
- *Store fulfillment* – picking online orders from regular retail shelves for separate, dedicated delivery;

Murphy (2003) discusses some of the key e-grocery initiatives in North America, distinguishing between store-based versus warehouse-based fulfillment. He underlines that space constraints limit the e-fulfillment volume in the store-based model since professional order pickers and regular customers interfere with each other. Yrjola (2001) propose a hybrid approach in which the fulfillment structure differs by product.

It is not only the online channel that benefits from the synergies of a multi-channel approach. Conversely, a traditional retailer may expand his assortment by adding an online channel (Singh et al., 2006). This gives rise to new planning issues, concerning which products to offer through which channel(s). In general, fast movers are suitable for physical stores, whereas slow movers are more suitable for an online channel. Since the Internet channel comes at the expense of longer customer lead times, customer service preferences also play a role in these channel assortment decisions. In addition, the presence of an online channel may affect product display decisions in a physical store, e.g. if customers can order through online terminals in the store.

4.1.2. Models

Discrete location-allocation models form the prevalent modeling approach to distribution network design. Countless modeling variants are available in the literature, ranging from simple single-stage, single-product models to complex non-linear probabilistic models. For a recent and extensive review and classification of facility location models see Klose and Drexl (2005).

In principle, many of the standard models also appear to be applicable to the network design of an online channel. This may explain why one does not find many network design models that focus on e-fulfillment specifically. A notable exception concerns drop-shipping models, with a focus on inventory placement. Typically, these models combine strategic inventory allocation issues and operational inventory control. We discuss those models that focus primarily on the operational component in a separate subsection on inventory management (Section 4.3). Among the more strategic models, Netessine and Rudi (2006) examine drop-shipping arrangements from a supply chain coordination perspective. They propose a game-theoretic model of a two-echelon supply chain comprising a wholesaler and multiple retailers. A single-period analysis reflects the trade-offs related to inventory risk and its impact on the optimal channel choice. Netessine and Rudi (2004) consider a multi-period variant of this model. They argue that drop-shipping entails a marketing-operations misalignment that results both in under-stocking and in deficient customer acquisition. Consequently, for both the retailer and the wholesaler drop-shipping is only beneficial in the case of a relatively high wholesale price. The authors show how to coordinate this supply chain by means of contracts.

Several models in the literature consider the impact of product returns on logistics network design (see e.g. Fleischmann et al., 2003). Min et al. (2006) focus on e-fulfillment specifically. They propose a model for locating return centers that consolidate returned products before shipping them to a central repair facility. The model focuses on trade-offs between freight rate discounts and inventory reduction. The authors formulate a non-linear mixed-integer programming model and solve it using a genetic algorithm.

Despite the apparent trade-offs and the heterogeneous solutions observed in practice, we found few quantitative models addressing a multi-channel distribution network design. The available models focus mainly on inventory aggregation effects and rely on multi-echelon inventory theory. Specifically, they consider divergent two-echelon systems with a central warehouse at the top echelon and retail stores at the bottom echelon. Alptekinoglu and Tang (2005) develop a model of the distribution of a single product to multiple sales locations through multiple cross-docking depots. The authors determine ordering and allocation policies for each depot that minimize total expected distribution costs. They compare two fulfillment scenarios, namely fulfillment from the store or from the warehouse. The model highlights the risk pooling benefits of inventory aggregation. Chiang and Monahan (2005) study a two-echelon inventory model comprising two alternative distribution channels, namely traditional retail stores and an Internet-enabled direct channel that is served from a central warehouse. The system receives stochastic demand from two customer segments that differ in their channel preferences. The paper compares three different distribution strategies, namely store-only, Internet-only, and a combined bricks-and-clicks approach. Numerical examples show the dual-channel strategy to outperform both of the single channels.

Some other related models are rooted in the literature on assortment planning. See Kök et al. (2006) for a recent review. The majority of the available planning models considers a single assortment, namely either the same assortment in all channels or the assortment of a single channel. We see assortment planning over multiple channels as a valuable area of future research. We are aware of one paper that explicitly considers assortment and stocking decisions in a multi-channel retail setting. Singh et al. (2006) propose an analytical inventory model using a stochastic choice process to generate demand according to a multinomial logit (MNL) random utility model. The results confirm the intuitive conclusion that adding an Internet channel enables a retailer to provide a wider product assortment; using the Internet channel to offer the less poplar products.

4.2. Warehouse design

4.2.1. Issues

Another set of strategic issues is the internal design of storage facilities. Traditional issues in warehouse design include the selection of a proper storing method, the choice of appropriate handling equipment, and the warehouse layout (de Koster et al., 2007). Order picking costs account for the largest part of warehousing operating costs. This is even more true in B2C e-fulfillment operations, which typically involve small pick quantities from a large number of items. This underlines again the assemble-to-order nature of e-fulfillment. Split-case or piece-picking are common picking methods in these environments, methods that are relatively more labor-consuming than case or pallet picking.

In a B2C environment, picking quality is highly important since the assembled order is delivered directly to the end-customer. Picking quality can be supported by advanced picking technologies, such as radio frequency terminals, wireless speech technology, and pick/put-to-light systems. However, viability of the corresponding investments requires high order volumes.

In Section 3 we discussed the particular relevance of product returns in e-fulfillment. This is also reflected in the warehouse design. A large fraction of the returned products is essentially as good as new and can therefore be resold. However, this requires a systematic process for feeding returns back into inventory, possibly after inspection or cleaning (de Brito and de Koster, 2003).

As discussed above, a multi-channel setting offers opportunities for integrating inventories of different channels at a single location, which can be a warehouse or a store. In general, however, this will require design adjustments to make these locations fit for efficient Internet order picking.

4.2.2. Models

For a general review of models concerning the design and control of order-picking operations we refer to de Koster et al. (2007). Small transaction sizes render order picking more labor intensive for an Internet channel, thereby increasing the need for efficiency. A few authors have proposed specific models for warehouse operations in a B2C e-commerce setting.

Two papers consider split-case sorting systems that sort items from opened (or 'split') cases into the corresponding customer orders. Johnson and Meller (2002) study the performance of such an automated split-case sorting system. They develop analytic performance models for different system configurations. Russell and Meller (2003) address the decision of whether or not to automate the split-case sorting process. They develop a descriptive model of the major trade-off between picking and packing efficiency. Batching increases the picking efficiency but decreases the packing efficiency. The model is used to evaluate alternative system designs. Xu (2005) studies a two-region warehouse in an e-tailing setting. One region is used for order picking, the other holds reserve stock. The author models this system as a stochastic multi-item two-stage, serial inventory system with space constraints.

We are not aware of any quantitative models addressing the integration of product returns into warehousing processes in e-fulfillment. For a qualitative discussion we refer to de Brito and de Koster (2003).

4.3. Inventory and capacity management

4.3.1. Issues

Medium and short-term planning tasks on the supply side of e-fulfillment focus on inventory replenishment. Based on demand forecasts, appropriate stocking levels must be determined for each storage location. In particular, this includes setting safety stocks to buffer against demand uncertainty.

At first sight, inventory management in an Internet channel differs little from any other channel. What adds novel characteristics to this process is the interrelation with demand fulfillment. We have argued in Section 3 that online sales offer particularly rich opportunities for dynamic pricing and revenue management. Inventory management must also anticipate this type of short-term demand management for setting appropriate stocking levels.

This particularly holds in the case of joint inventories for multiple channels. As discussed earlier, different channels may imply different opportunity costs for lost sales and therefore require different service levels. These different requirements should be aggregated into an overall inventory level and an accompanying fulfillment policy.

The aforementioned product returns may further impact inventory management in an Internet channel. If the return volume is significant it may be advisable to take outstanding returns into account when placing a replenishment order, especially in the case of long supplier lead times.

In addition to physical product inventory, e-tailers must manage their fulfillment capacity. This again reflects the service component of the Internet channel's product offering. Capacity management, notably workforce planning, corresponds with the 'replenishment' of this service component. One of the challenges in retailing concerns seasonal demand fluctuation. In a traditional retail store these fluctuations affect decisions on order quantities, shelf space allocation, markdown pricing and sales force levels. In e-fulfillment, demand fluctuations, with respect to the moment of delivery, also affect the utilization of the delivery capacity and therefore tend to have an even stronger impact than in traditional retailing. In addition to annual demand patterns, demand differences during the day (morning–evening) and during the week (mid-week–week-end) are particularly important in e-fulfillment. Staffing levels need to be adjusted to these demand fluctuations. This includes both delivery and order picking capacity. Since delivery requirements tend to be more variable and more interrelated across orders than picking requirements, capacity management of the delivery process is considered to be a greater challenge.

4.3.2. Models

As discussed in the previous subsection, inventory management issues specific to e-fulfillment arise from the interaction with short-term demand management. Some of these issues are addressed by inventory rationing models. Inventory rationing is a yield management strategy for a heterogeneous market that reserves some inventory for high margin customers. The corresponding models generally consider two customer segments with different contribution margins and different service time requirements. Kleijn and Dekker (1998) surveyed many of the early papers in this field. More recent contributions to the inventory rationing literature that specifically address online channels include Cattani and Souza (2002) who compare the benefits of inventory rationing over a simple first-come-first-serve policy in different scenarios. In particular, their numerical study considers different customer reactions to delay, namely lost sales and backlogging. Ayanso et al. (2006) consider a similar model. They assume that orders that cannot be satisfied from stock are drop-shipped from the supplier. Their paper illustrates the impact of several problem parameters in a simulation study. In addition, it highlights the importance of determining the correct threshold level in inventory rationing. Ding et al. (2006) consider the use of dynamic price discounts to encourage backlogging of demand from those customer classes that are denied immediate service. The paper develops dynamic programming algorithms to determine both the optimal discount offer and the quantity allocated in each period.

As discussed earlier, a few authors have analyzed inventory control policies for e-fulfillment with drop-shipping. Bailey and Rabinovich (2005) propose a model that is inspired by the situation of an Internet book retailer who can serve demand either from his own inventory or by drop-shipping. Assuming fixed plus linear cycle costs, the authors develop analytic expressions for the optimal order quantities of both fulfillment options and analyze their sensitivity to several input parameters. The results show in particular, that it may make sense to use both fulfillment options simultaneously. Khouja (2001) comes to a similar conclusion based on a news vendor type of analysis. He assumes that only a fraction of the customers is willing to accept drop-shipping in the case of in-house inventory shortage. The model identifies the optimal mix between both fulfillment options.

An extensive stream of literature addresses the integration of product return flows into inventory systems (see e.g. van der Laan et al., 2003). Most of these models are concerned with the remanufacturing of end-of-life returns. Recent models that consider returns from direct channel sales include Vlachos and Dekker (2003). They develop news vendor formulations for several problem variants and derive analytic expressions for the corresponding optimal order quantities. Mostard et al. (2005) and Mostard and Teunter (2006) extend this model by allowing more general demand-return relationships. They compare the optimal order quantities for different demand distributions and develop a distribution-free heuristic that appears to perform well in most realistic cases.

5. Conclusions

In this paper, we addressed key issues in B2C e-fulfillment from a multi-channel perspective. Moreover, we reviewed corresponding quantitative models in the operations research literature. In this section we summarize our main observations and draw conclusions for future research directions.

Table 1 highlights the main planning issues in e-fulfillment and multi-channeling identified in Sections 3 and 4. Many standard supply chain management issues are also relevant for e-fulfillment. However, a few aspects appear to be specific. This includes the service component inherent to e-fulfillment. An online channel not only provides a physical product but also several related services, most notably delivery. The delivery service may range from making the product available for pick-up to time-specific home delivery. The management of this service component of e-fulfillment gives rise to novel planning issues. On the one hand, companies need to choose an appropriate level of delivery service and a corresponding price. On the other hand, they need to manage the necessary resources, notably transportation capabilities, to provide this service.

Another topic with characteristics specific to e-fulfillment is demand management. Typically, online sellers are more flexible than traditional retail channels with respect to pricing and order promising. While this flexibility generates a significant potential for increasing revenues through differentiation, it also implies the need for appropriate strategies to be successful. Notably the aforementioned service elements underline this need. Demand management has an immediate impact on service requirements and thus on costs, thereby requiring both factors to be coordinated in order to maximize profit.

Table 1
Issues in e-fulfillment and multi-channel distribution

		E-fulfillment	Multi-channel
Sales and delivery planning	Delivery service design	Last-mile service, delivery time windows, return options	Store pick-up, in-store returns
	Forecasting and pricing	Delivery fees, dynamic pricing, cross-selling, lead-time quoting	Price coordination
	Order promising and revenue management	Delivery yield management, cost and revenue based segmentation	Cross-channel yield management
	Transportation planning	Routing for home delivery, dynamic routing	Joint delivery
Supply management	Distribution network design	Inventory location, drop shipping	Inventory aggregation, shared facilities, assortment planning
	Warehouse design	Degree of automation, warehouse layout, return handling	Different transaction sizes
	Inventory and capacity management	Safety stocks, integration with demand management, inventory rationing, integration of returns, staffing levels	Aggregate stock levels, service differentiation

A third area worth noting is the multi-channel embedding of many of today's successful Internet channels. Multi-channel retailers often achieve important synergies in terms of increasing market power, both on the sales and on the purchasing side. With respect to the fulfillment processes, one typically observes a trade-off between economies of scale from the integration of multiple channels on the one hand and efficiency gains from a dedicated process design on the other hand. These trade-offs arise, for example, in the location and layout of facilities and in the aggregation of inventories. The latter case also raises issues in inventory deployment since different channels may require different service levels. Therefore, a simple first-come-first-serve policy may be inappropriate for inventories shared across multiple channels. CRM plays an important role in providing the basis for more differentiated deployment strategies.

Many standard operations research models provide a basis for addressing supply chain planning issues in e-fulfillment and multi-channel distribution. Yet, specific issues warrant modeling extensions and novel approaches. Table 2 lists the models that we reviewed in this paper, which address specific e-fulfillment issues.

A few observations are in order. First, the number of dedicated models to date is remarkably small. We see room for significant contributions in literally all areas of e-fulfillment. Specifically, we would like to highlight two main directions, which we believe offer significant opportunities for future research and modeling efforts: (i) a closer integration of demand and supply management in e-fulfillment and (ii) the interaction between e-fulfillment and other distribution channels.

Over the past decade, many researchers have contributed to developing tools for revenue management and dynamic pricing. More recently, these demand management elements have been integrated into inventory control models. Applications in e-fulfillment call for a similar integration of demand management and distribution management. E-tailers need to decide on many aspects of the offered delivery service, such as delivery time windows and customer lead times, and on corresponding prices. These decisions have an immediate impact on demand and thereby on revenues. At the same time however, they also influence fulfillment costs. This influence is a particularly complex one in the case of attended home delivery. Since delivery costs of different orders are interdependent, due to joint

Table 2
Quantitative models for e-fulfillment and multi-channel distribution

		Quantitative models
Sales and delivery planning	Delivery service design	Yrjola (2001), Punakivi and Saranen (2001a), Punakivi et al. (2001), Punakivi and Tanskanen (2002), Lin and Mahmassani (2002), citeyearbib81, Hsu and Li (2006) and Yalabik et al. (2005)
	Pricing and forecasting	Kalagnanam et al. (2004)[a], Chan et al. (2004)[a], Elmaghraby and Keskinocak (2003)[a], Asdemir and Jacob (2002), Campbell and Savelsbergh (2006), Kamakura et al. (2003), Wong et al. (2005), Netessine et al. (2006), Akcura and Srinivasan (2005), Cattani et al. (2004)[a] and Cattani et al. (2006)
	Order promising and revenue management	Talluri and Van Ryzin (2004)[a], Campbell and Savelsbergh (2005)
	Transportation planning	Toth and Vigo (2001)[a], Braysy and Gendreau, 2005a,b[a], Fleischmann et al. (2004), Francis et al. (2006), Francis and Smilowitz (2006), Weigel and Cao (1999), Du et al. (2005), Xu et al. (2006)
Supply management	Distribution network design	Klose and Drexl (2005)[a], Netessine and Rudi (2006), Netessine and Rudi (2004), Min et al. (2006), Alptekinoglu and Tang (2005), Chiang and Monahan (2005), Singh et al. (2006)
	Warehouse design	de Koster et al. (2007)[a], Johnson and Meller (2002), Russel and Meller (2002), Xu (2005), de Brito and de Koster (2003)[a]
	Inventory and capacity management	Kleijn and Dekker (1998)[a], Cattani and Souza (2002), Ayanso et al. (2006), Ding et al. (2006), Bailey and Rabinovich (2005), Khouja (2001), van der Laan et al. (2003)[a], Vlachos and Dekker (2003), Mostard et al. (2005) and Mostard and Teunter (2006)

[a] Review paper/textbook.

delivery tours, assessing the effective cost-service trade-off is far from obvious. Insight into these interdependencies is crucial for choosing appropriate service levels. These insights will provide the basis for a more dynamic demand management, akin to traditional revenue management.

To date, very few contributions have addressed this integration of supply and demand, cost and revenues in e-fulfillment. We see a great potential for highly relevant research contributions in this area. Asdemir and Jacob (2002), Campbell and Savelsbergh (2005) and Xu et al. (2006) provide valuable starting points in this direction.

The second broad area of research opportunities, in our opinion, is the interplay between online and physical distribution channels. To date, a very small number of models explicitly takes the multi-channel context of many of today's Internet retailers into account. This is in striking contrast with the huge number of papers dedicated to channel conflicts. Qualitative literature and managerial contributions highlight a number of important trade-offs in the design of multi-channel fulfillment processes. These relate to, for example, channel-tailored pricing, integration of return handling across channels, and channel-specific assortment and inventory planning. Most of the available models address these issues for a single channel. Moreover, models which do address multiple channels often assume homogeneous channels. We see value in a more portfolio-oriented approach to these issues, seeking to exploit the strengths and weaknesses of specific channels and the synergies between them. Obviously, such an approach raises issues of complexity. We believe that the trade-off between a detailed model of an individual channel and a more simplified model of a channel portfolio by itself is a topic deserving closer analysis.

In conclusion, we see significant opportunities for managerially relevant and theoretically challenging contributions in the field of e-fulfillment and multi-channel distribution. Hopefully, this review will serve to stimulate this line of research.

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