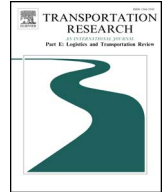


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# Transportation Research Part E

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## Dual-channel warehouse and inventory management with stochastic demand

Fawzat Alawneh, Guoqing Zhang\*

Supply Chain and Logistics Optimization Research Centre, Department of Mechanical, Automotive & Materials Engineering, University of Windsor, Windsor, Ontario, Canada



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### ABSTRACT

This study examines the inventory policy for the emerging dual-channel warehouse, which has a unique structure where the warehouse is divided into two areas: one for fulfilling online orders and the other for storing products and fulfilling offline orders. A multi-item inventory model was developed considering the warehouse capacity constraint, demand, and lead time uncertainty. Solution methods are provided for both uniform and normal distributions. Adopting the proposed inventory policy for a dual warehouse is cost effective and adds flexibility to the warehouse and supply chain. The study also offers managerial insights on some critical issues faced by companies operating in a dual-channel context.

### 1. Introduction

Online sales have experienced a significant growth in recent years (Wu, 2015). The total e-commerce sales in the United States reached \$341.8 billion in 2015, which is a 14.8% increase from 2014 (U.S. Department of Commerce). It is believed that this increase was because many firms upgraded their single-channel, offline sales business models to dual-channel clicks-and-mortar models, which integrate both online and offline sales, during that time. Moreover, it has been predicted that such growth in online sales will continue: web-influenced sales are expected to grow annually by 6% between 2015 and 2020 (Wu, 2015). Studies have shown that in 2008, 94% of the best financially performing firms were dual-channel sales firms (Kilcourse and Rowen, 2008). The emergence of dual-channel firms was mainly driven by the expansion in internet use and the advances in information and manufacturing technologies providing competitive advantage to the supply chain (Gunasekaran et al., 2017).

Firms introducing online sales are facing many challenges in terms of logistics and delivery processes, such as large volumes of very small orders, short delivery lead times, flexible delivery (for example, nighttime and even 24-h shipping), and the picking and packing process for single unit orders, in addition to the usual challenges of the conventional business. Warehouses or distribution centers must be ready to prepare orders coming from both offline stores and online shoppers. The conventional warehouse designed for physical stores and delivery does not work under a dual-channel business environment. For example, warehouse workers cannot use the same picking patterns for online orders as for physical shoppers (Master, 2015). Warehouses operating in the current digital era of e-commerce must have the all-purpose infrastructure, which is capable of sharing information, being interconnected, and handling different orders from different customer segments with different features such as diverse order sizes and delivery lead times (McCrea, 2017; Graves, 2012).

Two common strategies for warehouses or fulfillment process in the dual-channel business environment are the decentralized and centralized policies. A firm with a decentralized warehouse policy establishes a dedicated e-fulfillment warehouse and has separate

\* Corresponding author.

E-mail address: [gzhang@uwindsor.ca](mailto:gzhang@uwindsor.ca) (G. Zhang).

warehouses where each sales channel has separate inventory, operation, and commercial teams. In many situations, using a decentralized policy for all channels in dual-channel strategies results in inefficiency (Bendoly, 2004; Zhang et al., 2010; Hübner et al., 2015). Despite the current profits of these firms, they lack inter-channel coordination, which leads to long-term inefficiency and consumer confusion (Zhang et al., 2010).

The strategy of using a centralized warehouse, i.e., one integrated warehouse or several warehouses clustered in the same location, to serve both online and offline orders for a region has recently gained popularity and is the most common organizational structure for dual-channel markets (Agatz et al., 2008; Hübner et al., 2015, 2016). The strategy’s growth in popularity is owing to the advantages that have been perceived by the firms adopting it. Such firms include the International Business Machines Corporation, Hewlett-Packard, Whirlpool Corporation, Pioneer Corporation, Hamilton Beach, and Nike (Huang et al., 2012; Zhang and Tian, 2014; Li et al., 2015; Panda et al., 2015; Xiao and Shi, 2016). The advantages of this structure include reducing the facility cost by building an integrated warehouse, reducing warehouse space and inventory required for both channels, increasing the coordinating ability and flexibility of fulfilling both online and offline orders, and increasing the service levels.

One of the challenges in running the dual-channel warehouse is how to organize the warehouse and manage inventory to fulfill both online and offline (retailer) orders, where the orders from different channels have different features. Two important differences are the order size and order time. Typical online orders are placed at random times and are usually of small sizes, while typical offline orders are placed at scheduled times and are usually of large sizes (Agatz et al., 2008). Those differences affect the warehouse structure and operation. Many firms with dual-channel distribution systems have difficulty on developing an effective inventory policy to reach an optimal channel performance. One of the key issues they face is deciding on the optimal order quantity and reorder point when a new sales channel is introduced. Moreover, they need to consider both capacity constraints and uncertain demands (of both offline and online channels).

New streams of research have recently commenced studying dual-channel supply chains. One stream has focused on the competition and coordination that arise between sales channels (Hua and Li, 2008; Lu and Liu, 2015; Lin, 2016; Matsui, 2016; Wang et al., 2016; Chen and Chen, 2017). Another stream has studied the challenging logistics and processes of fulfilling online orders once they have been placed (De Koster, 2003; Tetteh and Xu, 2014). Research has also been centered on price and service interaction between channels (Yao and Liu, 2005; Ryan et al., 2013; Panda et al., 2015; Rodríguez and Aydin, 2015; Liu et al., 2016; Xiao and Shi, 2016; Yan et al., 2016; Giri et al., 2017; Matsui, 2017), and online order fulfillment processes (Agatz et al., 2008; Mahar et al., 2009). Inventory management in dual-channel supply chains has also been explored (Khouja, 2003; Yao et al., 2009; Zhang and Tian, 2014; Zhao et al., 2016). However, none of the emerging research streams has examined inventory management in a joint warehouse while considering the operations and capacity of the warehouse.

Therefore, this study examines the inventory policies for joint warehouse or distribution systems, called dual-channel warehouse in dual-channel business. As an important part of logistics, the warehouse plays a critical role in fulfilling the demands from both channels. The dual-channel warehouse has a unique structure: the warehouse is separated into two areas, one for fulfilling online orders and the other for storing products and fulfilling offline orders, as shown in Fig. 1(c) (The details will be explained in Section 3). A warehouse with such a structure is utilized by retailers, manufacturers, or third-party logistics (3PLs), who use a centralized warehouse for fulfilling both online and offline orders. We also have observed a couple of dual-channel warehouses of retailers or 3PLs in both China and Canada. A similar structure can be found in e-commerce firms that only have online customers (Xu, 2005), as shown in Fig. 1(b).

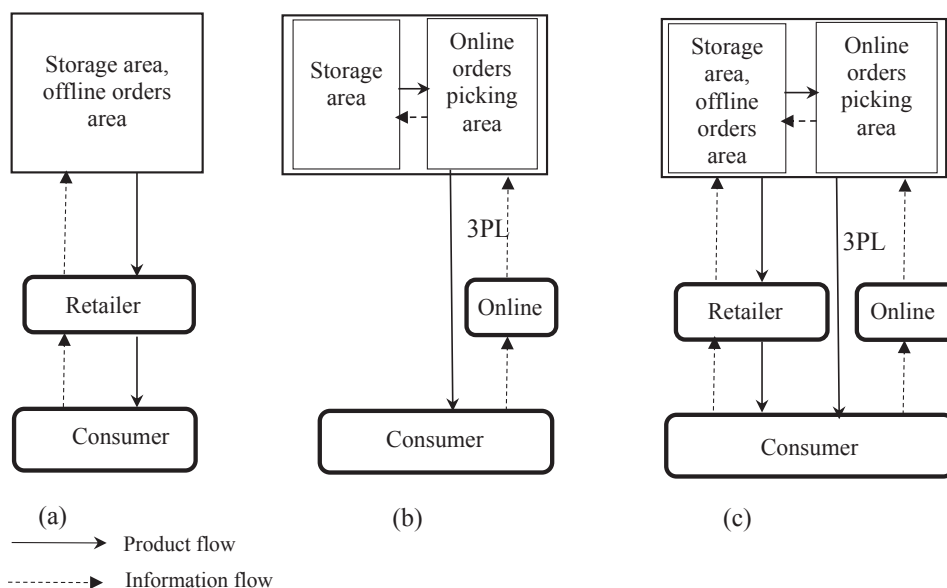


Fig. 1. (a)–(b) Single-channel warehouses and (c) dual-channel warehouse.

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