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A multi-objective model for order cartonization and fulfillment center assignment in the e-tail/retail industry

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ABSTRACT

In this study, two decoupled and integrated integer programming models for joint order cartonization and FC assignment in the retail industry are proposed. Moreover, a multi-objective genetic algorithm (GA) with a NSGA-II selection operator is introduced. The results of applying integrated and decoupled models, along with the proposed GA to the problem, show the efficiency of the proposed decoupled model and the ability of the proposed GA in exploring the tradeoff between cost and time of the fulfillment process. Moreover, it is observed that integrating cartonization into order fulfilment improves overall shipping cost and time.

1. Introduction

The e-tail/retail industry has experienced a substantial sales growth in the last couple of years (Mulpuru et al., 2014). However, despite the optimistic future pictured for the e-tail/retail industry, the market experiences volatility. In some instances, sales decline for a short period of time (Gibson et al., 2015). In this situation, competition among retailers is tightened and there is continuous pressure to improve operations and supply chain capabilities. One of the main processes in operations and supply chain is the fulfilment process. The fulfilment process is responsible for taking the right product, cartonizing it, and shipping it on time while keeping costs low (Espino-Rodríguez and Rodríguez-Díaz, 2014; Lin and Shaw, 1998; Thirumalai and Sinha, 2005). Only the outbound shipping element of the fulfilment process can be 3.2–4.6% of sales (Acimovic and Graves, 2014).

Fulfilment centers (FCs) are an integral part of the physical fulfilment process. Cartonizing and assigning orders to FCs are important and challenging decisions that should be made at the operational level of the fulfilment process. Cartonization deals with assigning one or more ordered items to one or several cartons, and in this regard, is closely related to the bin packing problem. The objective of cartonization is to minimize the number of cartons created. Orders to FC assignment determines from which FC each customer's order is fulfilled and directly affects outbound shipping cost and delivery time. Orders to FC assignment and cartonization decisions are usually taken separately. However, this may lead to sub-optimal results.

The common practice in the retail industry is to cartonize and assign received orders to FCs on a first-come-first-serve (FCFS) basis where each order is fulfilled by the cheapest/closest FC that has inventory. However, it may be more beneficial to use a dynamic approach: buffer orders and then cartonize and assign them to FCs. A dynamic schema of order to FC assignment has already been

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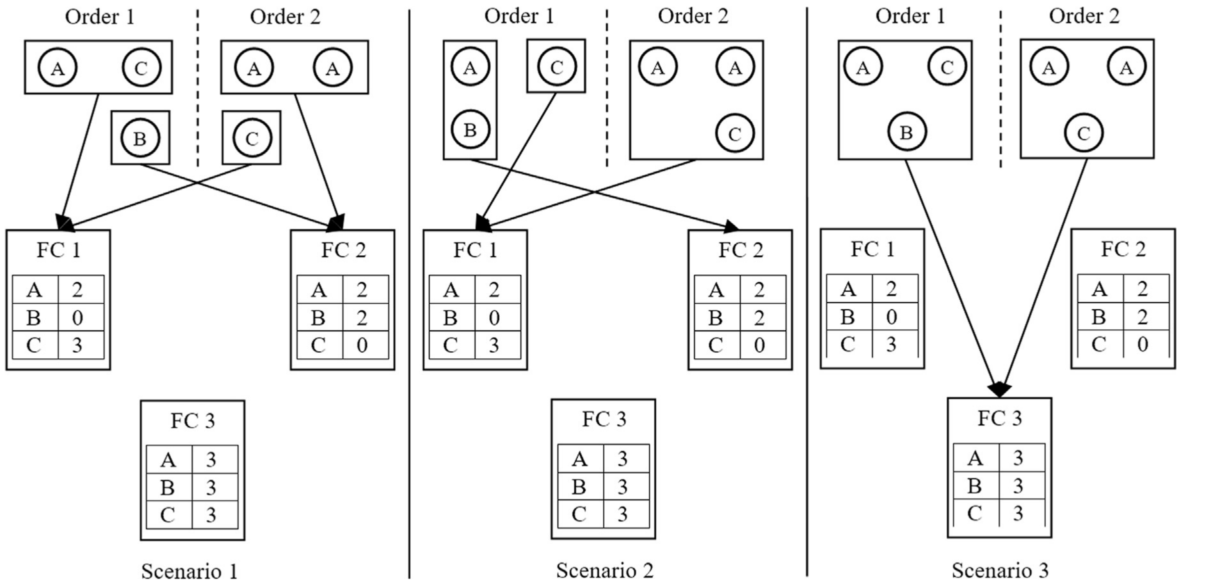

Fig. 1. Three cartonization and assignment solutions based on first-come-first-serve policy (scenario 1) least delivery time (scenario 2), and least shipping cost (scenario 3).

addressed by several researchers (Bhargava et al., 2016; Xu, 2005; Xu et al., 2009). However, studies about this subject usually consider the cost of shipping an item solely based on item type. In real cases, shipping cost is related to the number of cartons shipped. Thus, depending on which items are cartonized together, shipping cost varies.

Finding the right products to be cartonized together and shipped from the right FC greatly impacts shipping cost and time. To explain this, consider a simple example with three FCs, two orders from two customers, and three products (Fig. 1). Assume customer 1 places his order prior to customer 2. Fig. 1 shows the inventory of the products in FCs, as well as three possible scenarios for fulfilling orders. The cost and time of shipping one carton from FCs to customers are tabulated in Table 1.

In the FCFS scenario (scenario 1), since order 1 is received prior to order 2, it is fulfilled first. Thus, items A and C, ordered by customer 1, are cartonized together and shipped from FC 1, which is the closest FC to customer 1. Since FC 1 does not have enough inventory of item B, this item is shipped from FC 2 to customer 1. Following the same logic, a carton including two units of item A is shipped to customer 2 from FC 2 and a carton including item C is shipped to customer 2 from FC 1. In this scenario, customer 1 receives the first carton in one day and the second carton in one and a half days. Thus, delivery time for customer 1 is one and a half days. The average delivery time and cost for scenario 1 is one and a half days and $24 respectively.

In the second scenario, a retailer waits until both orders are received, and then decides how to assign them to the FCs. In this case, an effective decision is to fulfill order 2 from FC 1 in one carton, and order 1 from FCs 1 and 2 in two cartons. In this scenario, the overall average delivery time and cost are one and a half days and $19 respectively. In the third scenario, a retailer ships from FC 3 for $18, but the average delivery time increases to two days. As one can see, the FCFS policy (scenario 1) is not optimal, but depending on the decision maker's preferences, scenarios 2 and 3 are optimal. If the delivery time has higher priority for the decision maker, then he can choose scenario 2, and if cost minimization is his concern, the decision maker can choose scenario 3.

Besides delivery time and cost, cartonization also affects the optimal solution. For instance, assume that in Fig. 1, each carton holds a maximum of two items. In this case, for scenarios 2 and 3 to be feasible, it is necessary to break the cartons that include three items into two, which leads to higher shipping cost. However, if cartonization decisions are considered while assigning items to the FCs, scenario 1 is chosen due to low shipping cost and time. Therefore, it is essential to simultaneously solve the order to FC assignment and cartonization problems. Placing items in fewer cartons decreases shipping cost, but if these cartons are shipped from a faraway FC, it increases delivery time. Similarly, delivery time is reduced by splitting orders into several cartons and sending them from nearby FCs.

Table 1
Cost and time of shipping one carton from FCs 1, 2 and 3 to customers 1 and 2.

	Cost		Time (day(s))	
	Customer 1	Customer 2	Customer 1	Customer 2
FC 1	$5.00	$7.00	1	1.5
FC 2	$7.00	$5.00	1.5	1
FC 3	$9.00	$9.00	2	2