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Evaluation of Inventory Allocation in Dual-Channel Retailing using Simulation: Fulfillment Cost and Cycle Time Considerations

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Abstract: Omni-channel retailing has grown exponentially since the onset of the COVID-19 pandemic and the associated increase in demand for fully online and buy-online-pickup-in-store (BOPIS) shopping options. As part of the evolution of demand fulfillment, retailers must reassess their fulfillment strategies with a focus on maintaining or improving customer service (in the form of product availability, shortened order fulfillment cycle times, and order accuracy) while maintaining or reducing inventory and order fulfillment costs (which incorporate order pick, packaging, and delivery costs). Achieving these objectives may include store fulfillment in addition to direct fulfillment from distribution facilities. The purpose of this research is to evaluate inventory allocation decisions in a retail dual-channel order fulfillment process, incorporating store fulfillment, for the purpose of minimizing order fulfillment costs and order fulfillment cycle time. A case approach, combined with discrete-event simulation modeling, is used to determine optimal inventory levels at both facilities. Strategic decision points are also assessed to maximize customer service within the bounds of cost constraints. Opportunities for further order fulfillment improvements are also discussed.

Key words: Order fulfillment, omni-channel fulfillment, store fulfillment, simulation, order fulfillment costs, order fulfillment cycle time, supply chain management, brick-and-mortar retail

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Introduction

Omni-channel retailing, or the fulfillment of retail orders through an integrated network of stores and distribution centers, has grown exponentially since 2020, with demand increasing for fully online and buy-online-pickup-in-store (BOPIS) shopping options. According to Ishfaq and Raja (2018), online sales increased 14.6%, or $341 billion, from 2014 to 2015, while in-store sales increased only 1.4% during that same period. U.S. Census Bureau data estimated total e-commerce sales for 2021 of $870.8 billion, continuing the approximate 14% year-over-year increase in online business, with e-commerce accounting for 14.7 % of total sales as of 4th quarter 2022 (U.S. Census Bureau 2023). Omni-channel fulfillment affords the retailer the opportunity to select the best fulfillment strategy for both buyer and seller, in contrast to traditional brick-and-mortar (B&M) retail, where customer fulfillment expectations are high and no opportunity exists to tap other sources of product (Torabi et al. 2015). In the omni-channel environment, retailers have decision opportunities related to which facilities to include in the network structure, fulfillment source, inventory allocation and assortment for each fulfillment node, allocation of inventory to multiple customers when inventory is low, and information sharing and product substitutionary policies (Hübner et al 2022).

To provide shorter order fulfillment time, higher customer service, and to make better use of traditional brick-and-mortar retail facilities, retailers have turned to store fulfillment as a means of leveraging store inventory to fulfill online orders, taking fulfillment pressure off currently existing distribution centers and distributing that demand to retail stores. As customer shopping preferences continue to evolve due to the availability of omni-channel purchasing options, retail stores are morphing as well, changing from the traditional focus of an indoor shopping experience for customers to a hybrid facility that allows in-store, pickup, and online order fulfillment. Target Corp. led this retailing trend (Reddy 2018), fulfilling 50% of its online orders through its brick-and-mortar stores in 2017 (Cain 2018). Part of this transformation involved re-arranging their B&M store square footage to allot more space for digital fulfillment. By positioning themselves for omni-channel success ahead of the COVID-19 pandemic, they experienced a 154% one-year increase in online sales at the end of Q3 2020, with 75% of their digital sales filled from existing store inventory (Ali 2020).

As part of the evolution of retail, companies must reassess their fulfillment strategies with a focus on maintaining or improving customer service (in the form of product availability, shortened order fulfillment cycle times, and order accuracy) while maintaining or reducing inventory and order fulfillment costs (which incorporate order pick, packaging, and delivery costs). Achieving these objectives may include store fulfillment in addition to direct fulfillment from distribution facilities. The purpose of this research is to model a retailer omni-channel order fulfillment process that incorporates store fulfillment using discrete-event simulation. A case approach is used to evaluate strategic decision points within the system, and opportunities for further order fulfillment improvements will be discussed.

Literature Review

There are multiple order fulfillment options available to omni-channel retailers, including distribution centers that service traditional brick-and-mortar retail stores, order fulfillment facilities dedicated to online order fulfillment, hybrid fulfillment centers, and direct-from-vendor fill options (Verhoef et al. 2015). Omni-channel options may include multiple retail channels (online or in-store) combined with integrated order fulfillment channels at the back end of the supply chain, allowing for fulfillment across a range of facilities and flexible fulfillment assets. This in turn provides the customer with a seamless order fulfillment experience (Taylor et al. 2019). The process of omni-channel fulfillment involves both order picking (from either a distribution center or in-store) and the last-mile home delivery options (excluding store pickup orders). Factors that affect these two decision points include "country specifics (e.g., population density), retailer specifics (e.g., capability for cross-channel process integration) and customer behavior (e.g., possibility of unattended home delivery)" (Hubner et al. 2016, 1). Meeting the expectations of online customers may mean compromises on the retailer's part involving product variety, availability, and order fulfillment time if the range of possible fulfillment options is not utilized (Lim and Srai 2018).

From the consumer's perspective, the in-store shopping experience is still valued and remains a viable choice in demand fulfillment options. Early in the history of e-commerce, Ranganatham and Ganapathy (2002) identified security and privacy issues as factors that made consumers hesitant to buy online. In the choice between omni-channel retailers, Gowar and Hoberg (2019) found that price was the leading consumer decision criteria, followed closely by lead time and convenience. The perception of convenience may shift when multiple fulfillment options are available, leading to fulfillment channel shifts (Gallina and Moreno 2014). In-store shopping also offers benefits other than the purchase of goods, such as entertainment, opportunities for social interaction and physical movement, and trip chaining (the inclusion of multiple stops/tasks in a single outing) (Mokhtarian 2004). It is therefore important that consumer behavior and preferences be understood to create an effective omni-channel fulfillment strategy (Ehmke and Campbell 2014). Because in-store shopping opportunities remain a valued shopping option for consumers, efforts by retailers to capitalize on their investments in retail outlets for multiple fulfillment options are worthwhile.

Given the significant fulfillment costs and lower gross margins associated with store fulfillment of online orders, researchers have sought methods to maximize the effectiveness and profitability of omni-channel fulfillment strategies that include this channel. Known as online-to-offline (OTO) fulfillment, this fulfillment model forwards online customer orders to traditional (offline) brick-and-mortar retail stores. This necessitates collaborative demand management and order fulfillment (Ishfaq and Raja 2018), since the supply chain is now extended to the retail outlet, consumer's home, or a designed order pickup point (Lang and Bressolles 2013; Yao and Zhang 2012).

Questions concerning fulfillment network design, fulfillment locations, assortment and inventory management, assignment of customer orders, and inventory replenishment and returns must be addressed (Hübner et al. 2022). In addition, logistical challenges increase at the retail site due to unpredictable demand, short delivery timeframes, and the small order sizes characteristic of e-commerce (Campbell and Salvesbergh 2006; Hsiao, 2009). These issues have been addressed by several authors. Alptekinoğlu and Tang (2015) modeled a retail distribution system that incorporated both online and in-store channels and Aksen and Altinkemer (2008) created a retail decision model to determine which stores should fill online orders, based on fixed operating and last-mile delivery costs. Their model took demand from both channels and assigned it to different DCs based on total transportation and inventory costs. Mahar et al. (2012) investigated the fulfillment strategy of filling online orders through retail stores, with orders either pulled from DCs and shipped to stores and pulled directly from in-store inventory. They found that it was best to form subsets of retail stores within a region for online order fulfillment rather than consider all retail stores. Ishfaq and Bawja (2019) determined the effects of fulfillment methods and alternative logistics process structures on retailer's online sales profitability. These works address critical planning decisions with regard to fulfillment locations, inventory management, and customer order assignment.

However, optimal fulfillment network design drives best practices regarding inventory placement and retrieval. Mid-term network design decisions with store fulfillment included has been evaluated as an inventory problem with multiple fulfillment sites and various inventory pick and replenishment policies, with fulfillment cost minimization as the objective (Bendoly 2004; Ma et al. 2017; Chen et al. 2011; Mahar et al 2014; Prabhuram et al 2020)). Other efforts to optimize network design have been undertaken as well. For example, Zhao et al. (2016) modeled a dual-channel supply chain with lateral inventory transshipment allowed to determine the optimal inventory order levels and transshipment price that maximized total profit. Schneider and Klabjan (2013) investigated different inventory control policies for omni-channel retailers to determine optimal base stock and (s, S) inventory policies.

Inventory competition between fulfillment channels may also be introduced with the addition of store fulfillment. Geng and Mallik (2007) utilized a game theoretic model to model inventory stocking decisions between a manufacturer's direct channel and its independent retailer for the same product. They found that an equilibrium condition exists whereby the manufacturer may short a retailer's order even when production capacity exists to fill the order in full, in order to grow total supply chain profit. Difrancesco and Huchzermeier (2020) determined that the refund rate, the values of the return rate, and online order appeal defined the conditions under which a Nash equilibrium exists between competing omni-channel retailers, assuming online order returns (with a restocking fee) but no brick-and-mortar returns. The choice of fulfillment option is also impacted by shipment consolidation opportunities and the resultant decrease in shipping costs via economies of scale. Torabi et al. (2015) built a mixed-integer programming model to optimize customer order fill while minimizing associated logistics costs. Choice of order pick location is a key variable in total fulfillment costs.

Simulation modeling is commonly used by researchers and supply chain managers alike as a tool for order fulfillment optimization. This analytical tool is unique in that it "provides the ability to represent complex interactions within a dynamic supply chain and provides the ability to analyze the impact of stochastic elements that are difficult to analyze either analytically or empirically" (Ojha et al., 2019, p. 534). Difrancesco et al. (2021) used a simulation-based approach, along with exploratory modeling, to determine the optimal policy configuration for omni-channel store fulfillment in terms of the number of packers, number of pickers, and pick cut-off time. They found that the trade-off between customer service level and fulfillment costs is critical, since customer service must be maximized, but at a minimized cost. Ojha et al. (2019) utilized simulation modeling to evaluate how information sharing strategies, along with demand and lead time variability, impact a supply chain's ability to fill new or existing orders quickly and accurately. Simulation modeling is also used to validate analytical models of supply chain systems. Yang et al. (2021) built an analytical model to predict order fulfillment performance for a flow pick strategy within an e-commerce warehouse, then used actual warehouse data coupled with simulation modeling to compare order pick efficiency of batch vs. flow pick strategies. Bendoly (2004) was the first to research the omni-channel fulfillment network problem, combining multiple stores and online order options. He used a combination of simulation and optimization models to evaluate fulfillment priorities (store vs. online customer). Hovelaque et al. (2007) used a similar approach to evaluating an omni-channel fulfillment network, adding drop-shipment as a delivery option to the network. Simulation models, used alone or paired with other analytical tools, provide managers with the ability to optimize complex, stochastic order fulfillment systems that would otherwise be too difficult to evaluate.

Given the complex and stochastic nature of omni-channel order fulfillment, and the recent adoption of store fulfillment by retail organizations, research on operational issues for stores included within OC operations has struggled to keep pace with the rapidly changing retail climate. Academic work on store fulfillment operational and planning issues has focused primarily on the application of operations research analytics, quantitative model development, and managerial decision support. "These approaches cannot be transferred easily to ongoing planning purposes in practice" (Hübner et al. 2022, 815). A research gap exists in the validation of quantitative omni-channel with store fulfillment models, and in the absence of alternative modeling approaches for stochastic systems too complex for a quantitative approach. Simulation modeling can be utilized to fill these gaps. Specifically, simulation can be used to dynamically address the tradeoff between the maximization of customer service and the minimization of order fulfillment cost. In this research, inventory allocation and planning issues are investigated via discrete-event simulation, using order fulfillment cost and cycle time as performance metrics. A case approach is used.

Dual-Channel Retail Distribution with Store Fulfillment

Figure 1, below, provides a framework for a dual-channel retail fulfillment strategy that incorporates store fulfillment. In this framework, online orders can be filled with inventory from either a dedicated direct-to-consumer fulfillment center (DC) or a brick-and-mortar retail store (RS) utilizing 3PL parcel shipping services for final delivery.

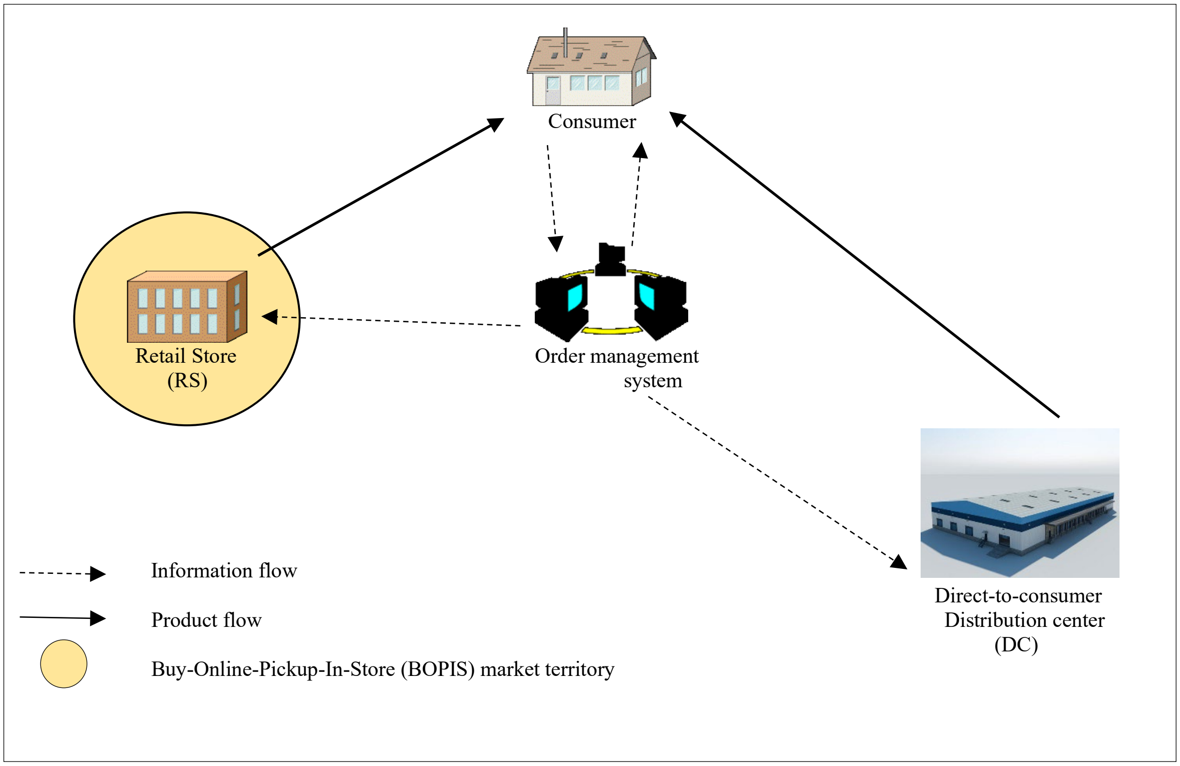

Figure 1: Dual-Channel Retail Fulfillment Framework with Store Fulfillment

An order management system is utilized to process online orders, send fulfillment instructions to participating fulfillment facilities, and communicate order status information back to the customer. Customers that reside within the market territory of the retail store (indicated by the circle in Fig.) may buy-online-pickup-in-store (BOPIS). Fulfillment decisions are based on the proximity of the customer to the retail store (for potential BOPIS fulfillment) and order pick, pack, and ship costs from each facility to the customer's address. Inventory allocation decisions also consider inventory carrying costs, labor costs, and capacity considerations at each facility.

Given the stochastic nature of product demand, order pick and pack time, and shipping time to a customer's address, the dual-channel fulfillment framework described above can best be modeled and optimized using discrete-event simulation. Discrete-event simulation is "the process of codifying the behavior of a complex system as an ordered sequence of well-defined events. Each event occurs at a particular instant in time and marks a change of state in the system" (Kiran 2019, 149). For this research, a case analysis approach is used to determine the optimal inventory allocation between the distribution center and retail store for the online order fulfillment of a given retailer.

Case Analysis

Lawson Clothiers, a regional clothing retailer, operates one brick-and-mortar retail store (RS) and one direct-to-customer distribution center (DC) within a 200 square mile area in the Northern Alabama / Southern Tennessee region. Local online shoppers living within 30 miles of the retail store order online and pickup at the store (BOPIS), while regional online customers outside the 30-mile radius of the store shop order online and have their items shipped directly to them. All regional online customer orders are filled from the DC, if inventory is available, to take advantage of quicker order pick time and lower shipping costs. If inventory is not available there, the retail store inventory is tapped for ship-from-store (SFS) order fulfillment. Local shoppers' online orders are filled from the retail store rack inventory; no additional backroom inventory storage is available. Consequently, local shoppers' online orders are filled by the DC if the retail outlet is out of stock. Only if inventory in unavailable in both locations are shortages recorded for ordered items.

Within the 200-square mile N. Al / S. TN region, the retail store is located at coordinates (34, 50) miles (with the local market region enclosed in the circle) and the distribution center at (100, 150) miles, as shown in Figure 2, below:

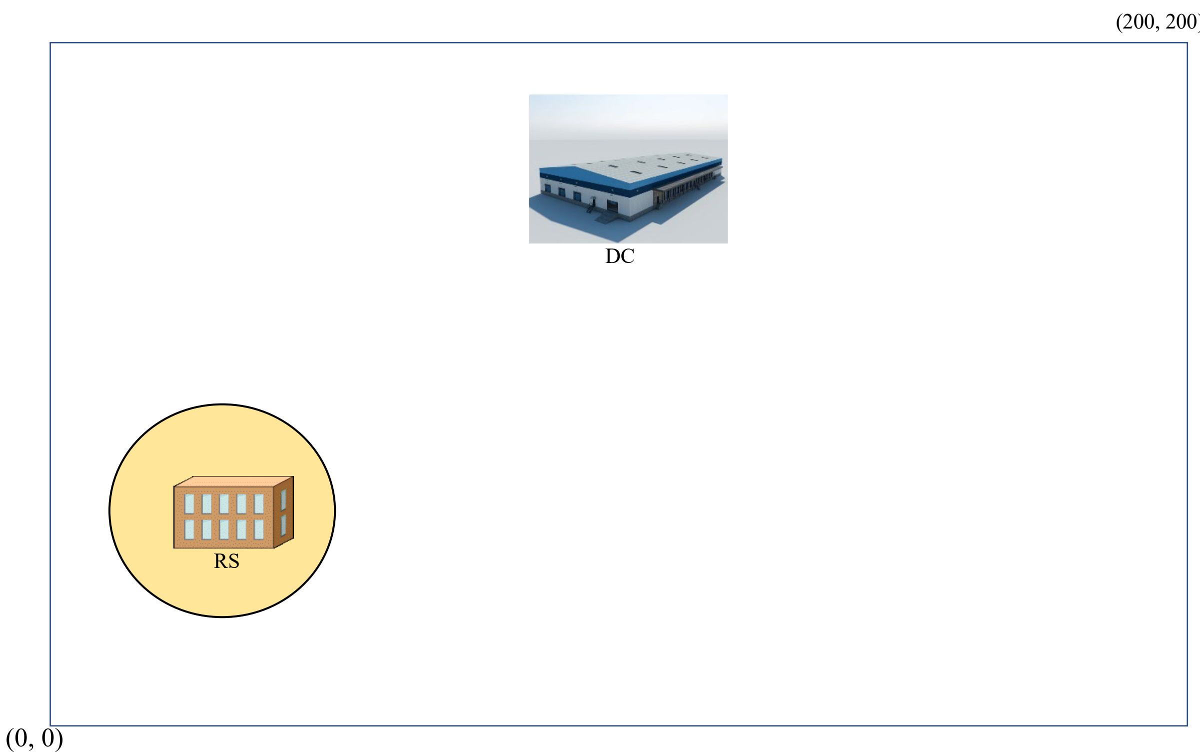

Figure 2: Location of Retail Store and Distribution Center
within 200 Sq. Mile Omni-Channel Fulfillment Region for Lawson Clothiers

Two of the winter season's high-demand items are a particular fleece hoodie jacket and its matching jogger pants, which retail for $60 and $40, respectively, a retail markup of 55% over the cost of merchandise sold (Claypoole 2019; Thomas et al. 1999). One order is placed for the season but shipped in partial segments, with shipments arriving weekly and available for distribution first thing Monday morning. Customers either purchase just the jacket or both the jacket and pants.

The stochastic characteristics of this order fulfillment system at present include the time between orders and the order pick and package times. These characteristics are given in Tables 1 and 2, below.

Item	Time between Orders
Jacket only	Normally distributed, NORM(4, 0.2) hours
Jacket / Pants set	NORM(3, 2) hours

Table 1: Time Between Orders for Order Options

Facility	Garment	Order Pick and Pack (OPP) Time
Retail Store	Jacket	NORM(0.4, 0.1) hrs
	Pants	NORM(0.3, 0.1) hrs
Distribution Center	Jacket	UNIF(0.25,0 .4) hrs
	Pants	UNIF(0.25, 0.4) hrs

Table 2: Order Pick and Pack Time per item for each facility

Order pick and pack (OPP) fees (excluding storage and shipping) are assumed to be $3.13 per item at the distribution center (WarehousingAndFulfillment.com 2023) and $5.92 at the retail store (Fit Small Business 2021). Inventory carrying cost percentages (ICC) for these items are 25% of unit cost at the distribution center and 40% at the retail store (Ganeshan 1999; Fares and Tebbett 2015). Shortage costs are estimated as the gross profit per item short (Lack 2017), which are $21.92 and $14.19 for the jacket and pants, respectively. The fleece hoodie and jacket have a two-month selling season, which is 9 weeks long.

Research Objective 1: Minimize Order Fulfillment Costs, Shipping Cost Not Considered

Lawson management first wants to determine the best inventory replenishment policy for these items at both the retail store and the distribution center to minimize average order fulfillment costs/day, which includes the combined holding, shortage, and order pick costs at the two facilities (Kelton et al. 2015). Shipping costs are not considered, and total shipping time is assumed constant and equal to one business day (15 hours) for both facilities, to all destinations within the region. Order fulfillment costs are calculated as follows:

Avg. order fulfillment cost / day = Avg. order pick cost/day + Avg. holding cost/day + Avg. shortage cost/day, (1)

where

Avg. order pick cost/day = Avg. number of orders filled/day × order pick cost/order

$$= OPC_{DC}(n_{J,DC} + n_{P,DC}) + OPC_{RS}(n_{J,RS} + n_{P,RS}) \quad (2)$$

with

OPC_{DC} ≡ Order pick cost at DC = \$3.13
OPC_{RS} ≡ Order pick cost at RS = \$5.92
$n_{J,DC}$ = avg. number of jacket orders filled/day at DC
$n_{J,RS}$ = avg. number of jacket orders filled/day at RS
$n_{P,DC}$ = avg. number of pants orders filled/day at DC
$n_{P,RS}$ = avg. number of pants orders filled/day at RS

and

Avg. inventory carrying cost / day =

$$= ICC_{J,RS}(\mu_{J,RS}) + ICC_{J,DC}(\mu_{J,DC}) + ICC_{P,RS}(\mu_{P,RS}) + ICC_{P,DC}(\mu_{P,DC}) \quad (3)$$

with

$ICC_{J,RS}$ ≡ unit holding cost/day for jacket at RS = $0.40(\$60/1.55) = \$15.48$
$ICC_{J,DC}$ ≡ unit holding cost/day for jacket at DC= $0.25(\$60/1.55) = \$9.68$
$ICC_{P,RS}$ ≡ unit holding cost/day for pants at RS= $0.40(\$40/1.55) = \$10.32$
$ICC_{P,DC}$ ≡ unit holding cost/day for pants at DC= $0.25(\$40/1.55) = \$6.45$
$\mu_{J,RS}$ ≡ Time-persistent inventory level for jacket at retail store
$\mu_{J,DC}$ ≡ Time-persistent inventory level for jacket at DC
$\mu_{P,RS}$ ≡ Time-persistent inventory level for pants at retail store
$\mu_{P,DC}$ ≡ Time-persistent inventory level for pants at DC

and

Avg. shortage cost / day = $SC_j \times \mu_{SL,J} + SC_P \times \mu_{SL,P}$ (4)

with

SC_j ≡ unit shortage cost/day for jacket = \$21.72
SC_p ≡ unit shortage cost/day for pants = \$14.19
$\mu_{SL,J}$ ≡ time-persistent jacket shortage level
$\mu_{SL,P}$ ≡ time-persistent pants shortage level

To determine the optimal inventory allocation for this organization, a discrete-event simulation model was built using Arena © simulation software to model daily order fulfillment activities. A total of 10,000 replications of the two-month selling season for these garments were run for each inventory allocation strategy tested. Each facility (retail store and distribution center) was assumed to be open for online orders 7 days per week, 15 hours per day, and all shipping occurs during these hours. The details of the simulation model are provided in Appendix A.

The model parameters (independent variables) varied for cost minimization purposes in Research Objective 1 include the weekly inventory allocation of each garment during the 9-week season in both facilities: Number of jackets at the retail store (J RS), number of pants at the retail store (P RS), number of jacket at the distribution center (J DC), and the number of pants at the distribution center (P DC).

The results of the simulation trials for Research Objective 1 are shown in Tables 3 through 5. Decisions about candidate inventory allocation levels were made between trials and based upon the total order fulfillment cost shown in Table 3, as well as the average inventory levels shown in Table 4.

	Inventory Holding Cost / Day				Shortage Cost / Day		OPP Cost / Day		Total
Inventory Allocation (J RS, P RS, J DC, P DC)	J, RS	P, RS	J, DC	P, DC	J	P	RS	DC	Avg Order Fulfillment Cost / Day
(16, 12, 49, 26)	$487.64	$339.92	$201.60	$67.26	$0.03	$0.84	$10.84	$24.82	$1132.95
(12, 7, 49, 28)	221.96	154.02	201.55	78.17	0.48	1.15	9.71	25.73	692.76
(5, 4, 39, 18)	43.70	13.52	127.72	31.43	51.84	32.30	6.52	18.51	325.54
(5, 4, 31, 16)	36.89	11.66	80.78	24.87	111.26	41.92	6.78	15.49	329.65
(5, 4, 34, 18)	39.57	13.53	97.18	31.47	86.13	32.35	6.75	17.19	324.18
(5, 4, 36, 18)	41.26	13.43	108.90	31.45	71.38	32.46	6.63	17.72	323.21
(5, 4, 37, 18)	42.05	13.47	114.99	31.44	64.56	32.34	6.60	17.98	323.44

Table 3: Avg. Daily Order Fulfillment Costs for Given Inventory Allocation Strategies

Inventory Allocation (J RS, P RS, J DC, P DC)	$\mu_{J,RS}$	$\mu_{P,RS}$	$\mu_{J,DC}$	$\mu_{P,DC}$	Avg. Jacket Shortage Level	Avg. Pants Shortage Level
(16, 12, 49, 26)	31.50	32.94	20.83	10.43	0.0012	0.0592
(12, 7, 49, 28)	14.34	14.92	20.82	12.12	0.022	0.081
(5, 4, 39, 18)	2.82	1.31	13.19	4.87	2.36	2.28
(5, 4, 31, 16)	2.38	1.13	8.35	3.86	5.076	2.951
(5, 4, 34, 18)	2.56	1.31	10.04	4.88	3.930	2.28
(5, 4, 36, 18)	2.67	1.30	11.25	4.88	3.26	2.29
(5, 4, 37, 18)	2.72	1.30	11.88	4.87	2.95	2.28

Table 4: Time-Persistent Inventory Levels at Four Inventory Allocation Points

Inventory Allocation (J RS, P RS, J DC, P DC)	J RS BOPIS CT	J RS SFS CT	J DC CT	J and P RS BOPIS CT	J and P RS SFS CT	P DC CT
(16, 12, 49, 26)	0.900	15.399	15..324	1.198	15.699	15.324
(12, 7, 49, 28)	0.900	15.399	15.324	1.197	15.699	15.324
(5, 4, 39, 18)	0.899	15.399	15.324	1.138	15.700	15.324
(5, 4, 31, 16)	0.899	15.399	15.324	1.104	15.693	15.324
(5, 4, 34, 18)	0.900	15.399	15.324	1.134	15.696	15.324
(5, 4, 36, 18)	0.899	15.399	15.324	1.137	15.698	15.324
(5, 4, 37, 18)	0.899	15.399	15.324	1.133	15.700	15.324

Table 5: Order Fulfillment Cycle Time for all Fulfillment Points

The results of these simulation trials showed that the best weekly inventory allocation strategy for (J RS, P RS, J DC, P DC) was (5, 4, 36, 18), with an average daily fulfillment cost of $323.21. Further inventory allocation strategies modeled resulted in higher daily fulfillment costs. Table 5 shows that order fulfillment cycle time remained consistent for each inventory allocation strategy modeled, with slight variation seen in order fulfillment options when two items were purchased.

Research Objective 2: Minimize order fulfillment cycle time, with stochastic shipping time

Lawson management is also interested in minimizing order fulfillment cycle time, which is defined here as the time from order placement to order receipt or delivery. The current order pick and package times (with current staffing levels and packaging facilities) were given in Table 2 and the cycle times for the Research Objective 1 simulation trials were shown in Table 5.

In Research Objective 1, it was assumed that shipping time was constant and exactly equal to 15 hours for each facility. Constant ship time resulted in high consistency in the cycle times for each fulfillment portal in Table 5, but it does not reflect true shipping operating conditions. For Research Objective 2, this assumption is relaxed, with shipping time now assumed to vary with the last mile delivery distance and set parcel pickup times at each facility. It is now assumed that parcel pickup occurs every hour at the DC and every 2 hours at the RS. The assumed shipping times are now defined as

$$CT_{RS} = WT_{PPU,RS} + DT_{RS,Cust}$$

where

CT_{RS} ≡ Delivery cycle time from retail store
$WT_{PPU,RS}$ ≡ Wait Time for parcel pickup at retail store = 2 hours
$DT_{RS,Cust}$ ≡ Delivery time to customer = Distance to customer × 45 mph

and

$$CT_{DC} = WT_{PPU,DC} + DT_{DC,Cust}$$

where

CT_{DC} ≡ Delivery cycle time from distribution center
$WT_{PPU,DC}$ ≡ Wait Time for parcel pickup at distribution center = 1 hour
$DT_{DC,Cust}$ ≡ Delivery time to customer = Distance to customer × vehicle speed

The optimal inventory allocation strategy of (J RS, P RS, J DC, P DC) = (5, 4, 36, 18) was used for Research Objective 2 optimization via simulation. Table 6 contains the simulated cycle time results for five different average vehicle speeds.

Vehicle Speed	J RS BOPIS CT	J RS SFS CT	J DC CT	P DC CT	J and P RS BOPIS CT	J and P RS SFS CT
40	0.909	5.754	4.081	5.082	1.109	6.060
45	0.852	5.381	3.775	4.776	1.052	5.687
50	0.807	5.083	3.530	4.531	1.016	5.388
55	0.770	4.840	3.330	4.330	0.982	5.144
60	0.739	4.636	3.163	4.163	0.954	4.940

Table 6: Average Order Fulfillment Cycle Time Results (in hours) for Various Delivery Vehicle Speeds and Set Parcel Pickup Times for the Retail Store and Distribution

Table 6 illustrates the customer advantage of utilizing BOPIS options for online order fulfillment speed. For example, local customers who purchase a jacket from the retail store and elect to utilize curbside pickup would, on average, receive their order almost four hours before a delivered item would arrive. Even for local customers, delivery must follow the pickup and delivery schedule of the parcel service utilized.

The cycle time predictive capabilities of the model could be further enhanced by using stochastic delivery time that incorporates traffic delays impacted by urban density. Total order fulfillment in that case would incorporate both stochastic order pick and pack time and stochastic ship time. Order fulfillment times, from both facilities, could then be compared for individual customers at specific locations.

Opportunities for Further Research

Discrete-event simulation provides a valuable tool for evaluating order fulfillment strategies in omni-channel retailing. For the Lawson Clothiers case, the lowest-cost inventory allocation strategy can be determined for the independent variables defining fulfillment costs, order pick and pack times, and order ship time. If per-unit fulfillment or inventory costs change, a new inventory allocation strategy could easily be determined using the model.

The simulation model for Lawson Clothiers could also be utilized to evaluate other factors in total order fulfillment cost. For example, labor costs for order pick and pack could be added to the total cost of fulfillment, with additional labor cost incurred to lower order pick and pack time. Backroom storage could be added to the retail store, with associated costs, to increase customer service to local customers in densely populated areas. Shipping costs, and the associated value of parcel delivery contracts, could be considered within the total cost framework as well, especially in decisions regarding point of fulfillment (RS or DC). With the model in place, any number of fulfillment options could be considered, with the costs, cycle times, and any other performance metric of interest, tracked for optimization purposes.

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Conclusion

The rapidly changing retail landscape has brick-and-mortar retailers rethinking their approach to demand fulfillment and the idea of what constitutes a retail shopping experience. Now that omni-channel fulfillment has been fully embraced by consumers, retailers must find low-cost ways to meet customer demand with high customer service. Simulation modeling provides a valuable tool to assess omni-channel fulfillment strategies in the presence of every-changing demand patterns and customer preferences.

By incorporating store fulfillment within the list of fulfillment options, traditional brick-and-mortar retailing may remain a viable shopping option long into the future.

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Appendix A

Discrete-Event Simulation Model Details

Arena © simulation software was used to create the discrete-event simulation model for the Lawson Clothiers case dual-channel fulfillment process. Inventory arrival for the jacket and pants items, at both the retail store and the distribution center, was modeled via Create flowchart modules to describe interarrival times, as detailed in Table 1, and the number of entities per arrival, which defined the replenishment strategies (number of sourced items arriving at a time) tested for the case. Assign modules were used to reset the global Shortage Level value to 0 before inventory was stored. The subsequent storage of these items in inventory was modeled by Hold modules, and the time-persistent average number in the queue of each Hold was used to reflect average inventory levels for both items in each facility. The inventory loops used for this purpose in the model are shown in Figure 3.

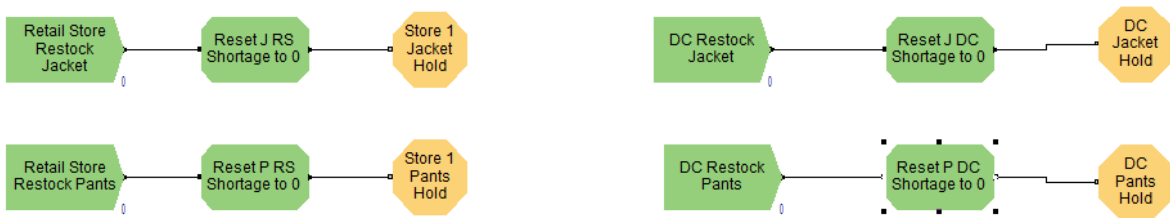

Figure 3: Screenshot of Inventory Replenishment Hold section of model

A second section of the model represented customer arrival, determination of order fulfillment point, removal of inventory for order, and shipment/pickup of order. Two create modules begin this section, each creating a customer for either a jacket-only or jacket-and-pants order. Upon arrival, each customer was randomly assigned an address within the 200 x 200 sq. mile region, then the distances to the retail store and the distribution center were calculated using Manhattan distance (Jaggia et al. 2021), which is defined as

$$\text{Manhattan distance to Retail Store} = |(x_i - x_{RS})| + |(y_i - y_{RS})|$$

and

$$\text{Manhattan distance to Distribution Center} = |(x_i - x_{DC})| + |(y_i - y_{DC})|$$

where (x_i, y_i) represents the location of customer i, and (x_{RS}, y_{RS}) and (x_{DC}, y_{DC}) represent the locations of the retail store and distribution center, respectively. Since one "customer" is created for each item purchased, customer purchase sets were batched per order before assigning addresses and distances to each order. The model section for customer arrival and attribute assignment is shown in Figure 4.

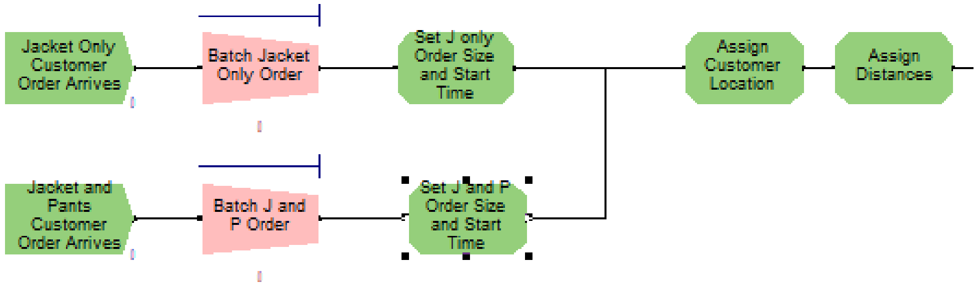

Figure 4: Customer Arrival and Attribute Assignment

After customer arrival and attribute assignment, orders are sent to different sections of the model based on order size. In each section, orders for customers within 30 miles of the retail store are assumed to be filled there, with customers buying online then driving to the retail store for pickup. Inventory is first checked at the retail store; if inventory is available, the purchased items are removed from the appropriate Hold inventories and time is allotted for order pick and pack and customer travel time. If retail store inventory is not available, inventory at the DC is checked; if inventory is available, the order is picked and packed for shipment, then time is allotted for shipment to the customer. All inventory checks are accomplished by assessing the current number in the queue in the appropriate Hold module, which represents the inventory of the given item at the facility being considered for fulfillment. Figure 5, below, shows the basic structure of the order fulfillment section of the model as it appears for jacket-only orders. The code structure is repeated in other sections of the model for jacket-and-pants orders, with code modifications included for split order fills between the retail store and the distribution center. Decision points are also incorporated based on customer distance to the retail store and the availability of the requested inventory at each location.

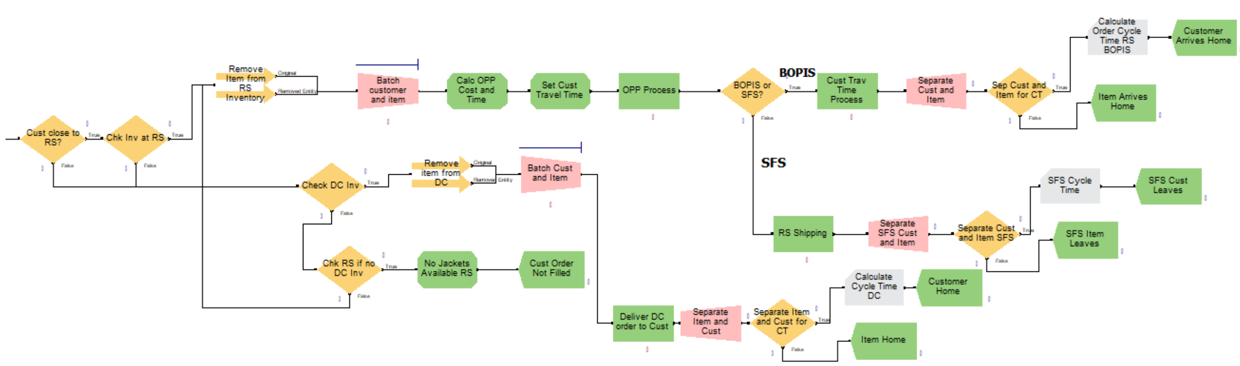

Figure 5: Order Fulfillment for Jacket-Only Orders

Model Results

A total of 10,000 replications of each candidate model structure were run, with summary statistics calculated automatically by Arena for entities, queues, resources, and user-defined statistics. For the Lawson Clothiers model, time-persistent statistics were also defined for inventory holding and storage costs at each location. Furthermore, output statistics were also defined for order pick and pack (OPP) costs at each facility and total order fulfillment costs.

Cycle times were calculated through the insertion of Record modules in the model. Cycle times were recorded for each possible fulfillment option within the dual-fulfillment strategy used by Lawson.

Evaluation of Research Objectives

Research Objective 1 focused on minimizing order fulfillment costs, with the independent variables defined as the restock quantity of each item at the two locations. Candidate restock quantities were evaluated methodically by observing the input costs and inventory levels (defined by the average number in the queue of each Hold inventory module) associated with total order fulfillment costs. Based upon the candidate replenishment strategies presented in Table 3 (and others run as part of this optimization effort), the lowest fulfillment cost strategy was found to be (J RS, P RS, J DC, P DC) = (5, 4, 36, 18). The cycle times for each order fulfillment point was found to be consistent, due to an assumed constant ship time of 15 hours (one business day).

For Research Objective 2, the assumption of constant shipping time was relaxed and changes in total cycle times were observed. The lowest fulfillment cost inventory replenishment strategy from RO 1 was used for inventory restock levels. In the model, shipping time was changed in the Ship Time variable used within the shipping Process modules in the model.