Design and Evaluation of New Crowdsourced Order-Fulfillment Policies

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1. Motivation

Today's customers expect speed, convenience, and choice. To meet these expectations, companies are providing an omni-channel experience, in which neither customers nor the retailer distinguishes between channels. This research focuses on omni-channel policies where online orders are picked from inventory in brick-and-mortar stores (also known as store fulfillment). Popular examples include reserve-online-pickup-in-store, ship-from-store, and click-and-collect operations. These policies, which connect the retailer's online and physical store channels, have two primary benefits: (1) reduced safety stock by pooling inventory for online and in-store customers, and (2) reduced or eliminated last-mile shipping costs by utilizing inventory physically closer to the customer. However, store fulfillment is more expensive and has lower throughput performance than distribution center order-fulfillment (Hübner, Kuhn, and Wollenburg 2016). This is because a distribution center is designed explicitly for order-fulfillment efficiency, while a retail store for a pleasing in-store shopper experience with opportunities for impulse buys.

Operational designs for store fulfillment have traditionally viewed the presence of in-store shoppers as a constraint (i.e., online orders should be fulfilled in such a way that does not encumber in-store shoppers experiences (Hübner, Kuhn, and Wollenburg 2016)). This research takes a different approach, viewing a shared facility with both in-store shoppers and e-commerce orders as an advantage.

In this research, we explore methods to design and evaluate new demand fulfillment strategies that engage in-store shoppers to fulfill online orders from brick-and-mortar stores.

While omni-channel research is growing (Gao and Su 2016, Jin, Li, and Cheng 2018, Zhang, Xu, and He 2018); the focus has been on facility selection, product assortment, replenishment, pricing and service design. Only limited quantitative work exists on operational considerations

of omni-channel order-fulfillment (MacCarthy, Zhang, and Muyldermans 2019). Moreover, we are not aware of any work that uses in-store shoppers to help fulfill online orders. While routing in warehouse and distributions is a well-studied area (Theys et al. 2010), all of these approaches focus on minimizing travel distances of full-time employees' picking routes. In contrast, crowdsourced in-store shoppers' goals are to minimize their detour distance or extra shopping times beyond what would be required to shop for their personal order.

2. Problem Statement

In-store customers announce their intention to visit the store at least δ minutes before their arrival. They also announce the departments they intend to visit (produce, dairy, bakery, etc.), as well as the maximum time they are willing to spend in the store for their own shopping and possibly taking over some picking tasks in the store. In the meantime, online orders are placed over time. Each order potentially includes multiple items that need to be picked from storage shelves in the store. The online order request must be ready for delivery or pick up from the store's designated station after S minutes of being placed. Upon arrival, the in-store customer announces her arrival on her smartphone. She then receives a notification informing her whether she is assigned any picking tasks. If so, she takes a cart with a designated basket and scans the basket's barcode. A pick path visiting all the storage locations of items in her shopping list in addition to those assigned to her by the store pops up on her smartphone. After picking each assigned item, the in-store customer scans the item's barcode and places it in the basket. Once all the slots on the pick path are visited, the in-store customer drops off the basket at the pick up station. We assume that all the items assigned to an in-store customer belong to the same online order.

The goal is to maximize the number of orders assigned to and picked by in-store customers while minimizing the in-store customers inconvenience by assigning them the set of items requiring the minimum detour and extra extraction time. The detour is calculated w.r.t. the pick path an in-store customer would take if no picking task is assigned to her and she only picks her own groceries. A team of dedicated pickers is available in case the crowdsourced capacity is insufficient to pick the set of active online orders by the deadline. A dedicated picker is dispatched to pick an active order only if that order becomes "urgent" and has not been assigned to any in-store customer.

Assuming each product family is stored in a given slot in the store, let $\mathcal{L} = \{1, \ldots, L\}$ be the set of all the slots available, with $\{0\}$ being the pick up station and $\mathcal{L}_0 = \mathcal{L} \cup \{0\}$. Set $\mathcal{P} = \{1, \ldots, P\}$ represents the set of all product families the store carries. Note that a given product family may contain several similar products of different brands that are stored in the same slot, and therefore, $L = P$. Let $\mathcal{I}^h = \{1, \ldots, I\}$ be the set of unassigned in-store customers at time epoch h. Associated with each in-store customer $i \in \mathcal{I}^h$, there is a set $\mathcal{L}_i \subset \mathcal{L}$, the slots the customer is planning to visit

for her own shopping. For each in-store customer $i \in \mathcal{I}^h$, parameter R_i indicates the maximum time the customer is willing to spend in the store, when her arrival to the store is denoted by τ_i^I. Similarly, let set $\mathcal{O}^h = \{1, \ldots, O^h\}$ be the set of active orders placed by time epoch h. Set $\mathcal{L}_o \subset \mathcal{L}, \forall o \in \mathcal{O}^h$ represents the slots to be visited to be able to pick all items included in order o, when τ_o^O indicates the time order o is placed. The retailer offers a fix service commitment: all orders are ready for pick up after S minutes of being placed.

The picking time associated with a picking task includes the travel time between the corresponding slots and the extraction time of the items. The matrix $\mathbf{T} = \{t_{ll'}\}$ represents the travel time for a crowdsourced or dedicated picker to move from slot l to slot l', when $l, l' \in \mathcal{L}_0$. Similarly, d_l indicates the extraction time of an item stored in slot $l \in \mathcal{L}$. If online order o is assigned to in-store customer i, the set of slots to be visited by the in-store customer is represented by $\mathcal{L}_{io} = \{0\} \cup \mathcal{L}_i \cup \mathcal{L}_o$. The pick up station is a location visited by all in-store customers participating in the crowdsourced picking. That is, every pick path including items from online orders starts at the pick up station. Additionally, once all the assigned items to an in-store customer are picked, she needs to visit the pick up station to drop off the picked order. Assuming the shopping list of an in-store customer is available, her pick path takes the form of a traveling salesman problem (TSP). Any potential online order assigned to an in-store customer would insert new slots into her pick path. Associated with each additional stop is a cost, proportional to the extra travel and extraction times. Let c_{oi} be the cost associated with assigning order o to customer i.

3. Solution Approach

We construct a bipartite graph. On one side we have the set of active online orders and on the other side we have the set of in-store customers willing to participate in order picking. There is an arc a_{oi} between order o and customer i, only if such an assignment is time feasible. Let τ_{oi}^O denote the time customer i can drop off order o at the pick up station. Similarly, let τ_{oi}^I be the time customer i can leave the store after completing her own shopping and picking order o. The assignment of order o to in-store customer i is said to be time feasible if there exists a pick path such that (a) $\tau_{oi}^O \leq \tau_o^O + S$, and (2) $\tau_{oi}^I \leq \tau_o^I + R_i$. The cost of an arc a_{oi} corresponds to the cost of the least cost time-feasible pick path of in-store customer i picking order o. If no such path exists for an in-store customer and an online order, no arc is added to the graph between that order and that in-store customer. There exists an arc between D, the dedicated picker node, and all active orders, with a cost M that is higher than the cost of all other arcs linking in-store customers to online orders. Set $\mathcal{A}$ includes all the arcs of this graph. Let binary variable x_{oi} take on the value 1 iff arc a_{oi} is selected, otherwise it equals 0. Our objective function minimizes the overall cost of picking online orders. Constraints ensure that each customer is assigned at most one online order, and guarantee that all online orders are picked by either an in-store customer or a dedicated picker.

3.1. Pick Path Generation

To identify pick paths, we initially solve a TSP per in-store customer visiting all slots associated with her shopping list. This TSP is then augmented by inserting the slots associated with each online order tentatively assigned to each in-store customer. Each visit to a slot is inserted into the pick path of the customer in the best position (i.e., requiring the minimum detour cost). The drop off of a picked order to the pick up station can happen some time from the pick up of the last item of the order until after the pick up of the last item from the set of items of the online order and those of the customer's shopping list is picked.

3.2. Dynamic Assignment

Online order placements and in-store customer arrivals occur dynamically over time, thus, our decision making approach is of a dynamic nature. We consider a time horizon $\mathcal{H}$ representing the store's operational hours in a given day. Decisions are made at a set of dynamically generated time epochs $h \in \mathcal{H}$ corresponding to arrival of new in-store customers to the store. During the δ minutes before the in-store shoppers arrival, the decision maker may tentatively assign an online order to this in-store customer without committing to that decision. An assignment decision is committed to only upon the customer's arrival to the store and may possibly undergo several changes before then. At any time epoch h, the set $\mathcal{O}^h$ associated with active online orders and set $\mathcal{I}^h$ comprising available in-store customers over the next δ minutes including the in-store customer arriving at time h are updated. Next, the assignment model is solved and the assignment (if any) involving the in-store customer arriving at h is committed to. All other assignments are considered as tentative.

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