Models and Methods for Omni-Channel Fulfillment

Omni-channel retailing, the combination of online and traditional store channels, advocates the use of traditional stores as shipping centers for originating online orders, customer pickup points for online orders, or even as transshipment points for re-balancing stock. We study a new set of research questions related to acceptance and fulfillment of orders in omni-channel retail operations. Our models focus on the order acceptance and fulfillment decisions for online channels, taking into consideration the total costs of fulfilment including shipping costs when they are satisfied and the possibility of canceling some of the accepted online orders. We tackle the problem of omni-channel fulfillment from a stochastic inventory theory perspective where inventory is held at physical stores and shared between in-store demand and online demand. Physical retail stores, however, are not designed for online fulfillment, and these inventory pooling arrangements often lead to cancelled orders. A major driver of order cancellations is that the required inventory for an online order can be listed in the retailer’s inventory database when the order is placed but, even when the inventory count was initially accurate, is then depleted by an in-store sale before the item is picked for shipment. Our analytical models optimize the trade-off between policies that fill many online orders, yielding additional revenue, and the penalties incurred from cancelling online orders if too many are accepted. Our models, and data testing, are based on close collaboration with a startup that provides omni-channel fulfillment software to several retailers (such as Saks Fifth Avenue and Dick’s Sporting Goods).

Other aspects of omni-channel retailing, such as the costs and benefits of “buy online and pick up in store” policies [Gao and Su 2016] and information sharing [Gao and Su 2016] have been studied by the Operations Management community, but this is the first attempt to formulate and study analytical models of cancellations caused by omni-channel fulfillment. Our analyses use
techniques that have been successful in other areas within Operations Management including
transshipment problems [Herer et al., 2006], sensitivity analysis [Glasserman and Tayur 1995],
and Sample Average Approximation [Levi et al., 2007].

Our models consider a single product and assume that online and in-store demand are drawn
from fixed probability distributions. The core omni-channel problem is to determine under what
inventory conditions of the two demand streams must the online store be kept open. A crucial
consideration for this decision is that if the online store is kept open despite having a low
inventory count the retailer becomes exposed to the risk of needing to cancel some accepted
online orders, incurring a cancellation cost. Conversely, closing the online store when sufficient
inventory is available results in lost sales through the online sales channel. The resulting problem
is setting the optimal reserve threshold at each physical location to trigger the opening and
closing of the online sales channel. We allow for multiple physical stores with differing starting
inventory levels, and in these scenarios the retailer must also determine a fulfillment policy to
ship online orders to their recipients.

We first investigate a single-store, known demand distribution setting. Access to the CDFs of the
demand distributions allows us to compute a closed form solution that maximizes expected
retailer profits. With only a single physical location, the fulfillment problem for accepted online
orders is straightforward, and we are able to prove optimal reserve thresholds in a similar manner
to the the analysis of the classical Newsvendor problem. We also consider a single-store setting
where the demand distribution is unknown. In this setting, we draw from Sample Average
Approximation (SAA) analysis methods and prove sample complexity bounds obtained from
solving the SAA problem using samples from the demand distributions. The retailer estimates
the online and physical demand distributions with the empirical distributions from an observed
sample and follows the policy we established in the single-store known demand setting. We reason about the rate at which the empirical distributions converge to the true demand distributions to establish sample complexity bounds.

Next, we generalize to a multiple-store, unknown demand setting. In addition to determining conditions to open and close the online sales channel, the retailer must now also set a fulfillment policy to ship the accepted online orders to their destinations. Given a fixed reserve threshold policy, we show that the fulfillment problem can be solved as a network flow problem. Furthermore, we can examine certain dual values of the network flow linear program to compute unbiased estimates of the derivative of the reserve thresholds with respect to the retailer’s expected profit. This implies an Infinitesimal Perturbation Analysis (IPA) algorithm that will converge on the optimal reserve threshold policy for the retailer.

References:


