Time-Dependent Shipment Options and Shipment Fees for E-Commerce Fulfillment Centers

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Given the fast growth of e-commerce, fulfilling online orders faster and cheaper becomes more relevant than ever. In that respect, e-commerce companies increasingly promise same-day shipment. Same-day shipment is a powerful marketing tool to attract and retain customers. Nowadays, customers place orders in the afternoon or evening and expect these products to be shipped immediately so that they arrive the next day. From an operational perspective, however, same-day shipment promises are challenging to fulfill, especially by the end of the day when the time window for same-day shipment becomes tighter. Hence, same-day shipment requires a well-coordinated effort between marketing and operations to ensure a smooth and efficient order fulfillment process.

Companies that sell their products online typically fulfill the orders from so-called fulfillment centers. In these centers, orders are picked from the shelves and subsequently prepared for shipment. At fixed predefined deadlines, typically at the end of the day, the orders are consolidated into large batches and handed over to the external parcel delivery company responsible for the actual delivery of the products (e.g., FedEx or UPS). Meeting these strict deadlines is crucial for the fulfillment process as missing the departure of a delivery vehicle by only a few minutes may result in a delay to the customer of at least one day (Doerr and Gue 2013). In their pursuit of offering increasingly faster service, e-commerce companies might run the risk that they over-promise their shipment services. Indeed, the fulfillment center may not be able to keep up with the inflow of orders that require same-day shipment and need to be ready before the set deadline. This risk is particularly high when companies charge only flat fees for the different shipment options. Under such flat fees, customers cannot be incentivized to choose next-day shipment over same-day shipment when the operations in the fulfillment center would require so.

Time-dependent shipment options and shipment fees

As a natural mitigation strategy to the risk described above, e-commerce companies may want to introduce a time- and fulfillment center load-based dynamic shipment policy. Under such a dynamic shipment policy, the offered shipment options and the corresponding shipment fees can be used as levers to better balance the inflow of orders that require same-day and next-day shipment with the

available capacity and remaining time to do so. While such a dynamic shipment policy has merit from an operational perspective, it may be perceived as unfair by customers (Klein et al. 2019), and it is arguably difficult to implement from a marketing perspective. Static shipment options and corresponding fees that depend only on the remaining time to the set deadline seem to be more appropriate and promising as well, especially as customers are rather sensitive to small price changes (Acimovic and Graves 2017). Such well-targeted static time-dependent shipment options and fees have the potential to influence customers' shipment preferences in order to balance the overall workload and increase the capacity utilization in fulfillment centers, very much akin to a dynamic shipment policy, but without eliciting perceptions of unfairness among customers. Further, static time-dependent shipment options and fees can be easily and transparently communicated to customers on the order website.

In this research, we study the potential of time-dependent shipment options and fees in managing the distribution of customers demanding same-day or next-day shipment. When e-commerce companies operate such time-dependent shipment policies, they need to decide for each moment in time which shipment options they offer as well as the fees that correspond to these shipment options. We study precisely these decisions. Because of its practical appeal, we focus on so-called cutoff-based shipment options under which same-day and next-day shipment are offered to all customers placing their orders until a certain cutoff point while customers ordering after the cutoff point will then only be offered next-day shipment (Mohring et al. 2024). Given the cutoff point decision, shipment fees need to be set for each moment in time. Thus, the following interrelated questions arise:

(1) Cutoff-based shipment options: Until what moment in time should same-day shipment still be offered to customers?

- (2) Shipment fees: How much should the shipment fees be?
- (3) Differentiated fees: When and how should the shipment fees be adapted over time?

Methodology

We build a parsimonious model that provides answers to the questions posed above. We consider a multi-period model, where each period ends with a deadline upon which orders that are due for shipment in that period need to be handed over to the parcel delivery company. Throughout each such period, online customers arrive according to a Poisson process. Customers who complete their online transaction before the cutoff point are offered the choice between same-day or next-day shipment together with their corresponding fees. We assume that customers make this choice by trading off the utility that they derive from both shipment options. Customers that arrive after the cutoff point cannot choose same-day shipment, and hence their products are handed over to the parcel company upon the next deadline at the end of the following period. The processing capacity of the fulfillment center within each period is randomly distributed. If the available capacity is insufficient to process all orders due for shipment in a given period, these orders are then said to be late and carried over for shipment in the subsequent period.

We are interested in finding the optimal time-dependent shipment options and fees such that the long-run average profit consisting of revenue minus costs for late orders is maximized. By developing a discrete-time Markov chain model for the steady-state analysis of the stochastic e-fulfillment centers described above, we provide closed-form expressions for the relevant performance measures as well as structural properties of the optimal time-dependent shipment policy.

Main results and contributions

We are the first to study time-dependent shipment options and fees for stochastic e-fulfillment centers. We characterize how e-commerce companies may derive substantial benefits from introducing a static time-dependent shipment policy. More precisely:

(1) We present an exact analysis of the steady-state performance measures for the stochastic efulfillment centers described above based on the underlying discrete-time periodic Markov chain model.

(2) We show that the optimal time-dependent shipment policy exhibits an intuitive structure: The fee for same-day shipment increases as the time until the cutoff point of the current period decreases.

(3) Motivated by its practical appeal, we numerically study a simple instance of our timedependent shipment policy with a two-level fee structure. We compare this simple time-dependent shipment policy with two benchmark policies prevalent in practice, which rely on static timeindependent fees for both shipment options but differ in whether they include a cutoff point for the same-day shipment option and how they set the shipment fees. We find that (i) including a cutoff point under static shipment fees increases profits substantially, and that additionally (ii) moving to time-dependent shipment fees (i.e., our approach) increases profits by another considerable margin.

The key contribution of this research is that these results provide E-commerce companies with valuable and easily implementable managerial guidelines for the design of shipment options and shipment fees in E-commerce to better balance online demands for same-day or next-day shipment with the available capacity in the fulfillment centers responsible for collecting and shipping those orders.

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