Slowing down e-commerce deliveries - Empirical findings and results of a stochastic-dynamic solution approach

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Slow logistics is a new logistical concept to reduce logistics costs and to improve eco-efficiency. In e-commerce, this concept can be realized by offering customers the option of accepting an extended delivery time for their online purchases. This enables greater bundling options for a parcel service provider. However, this requires that customers are at all willing, or at least can be motivated, to wait longer for their online orders. The paper presents the results of an online survey in German-speaking countries, which investigates whether customers are willing to wait longer for their online orders or whether certain incentives are required, e.g., savings on shipping costs or information on reducing CO2 emissions, to increase customers' willingness to wait. The empirical findings lead to a new last-mile delivery problem that allows customers to choose from different delivery speeds when placing an order in a stochastic-dynamic order arrival environment. To solve the entire decision problem model, we develop a stochastic-dynamic solution method that solves prize-collecting vehicle routing subproblems. It becomes obvious that a slower delivery option could reduce logistics costs without significantly increasing the waiting times of an average delivery order.

Key words: Last-mile delivery; Sustainability; Consumer behavior; Vehicle routing problem; Stochastic optimization

1. Motivation and problem setting

Parcel deliveries are at an all-time high, amounting for 161 billion parcels worldwide in 2022. This is accompanied by a growing demand for even faster deliveries in the business-to-consumer (B2C) sector. However, short delivery times put tremendous pressure on transportation networks and often lead to less efficient distribution processes. We explore a delivery concept that deliberately slows down the logistics processes involved in parcel delivery, thereby allowing for the consolidation of more shipments over an extended time period. For instance, Amazon already provides a "free no-rush" delivery option in many U.S. regions. Customers who select this option accept a longer delivery time frame and, in return, e.g., receive a discount. Alternatively, customers may be nudged by information highlighting the reduced emissions associated with slower delivery, which could encourage them to accept the potential delay Dietl et al. (2023). We assume the point of view of an e-commerce retailer who operates its own delivery fleet and offers a range of delivery options, including a notably slower *some-day* alternative. Each customer's order is subject to specific delivery date constraints, comprising both an earliest and a latest possible delivery date. The retailer must determine the most cost-effective delivery day for each customer, as well as the clustering and routing. We term this problem setting *some-day delivery problem* (SDDP). Our modeling assumptions align with the broader category of multiple period VRPs (MPVRP) (Archetti et al. 2015). In practice, customer orders arrive continuously throughout the planning period, creating a dynamic setting. While a similar dynamic MPVRP, has been proposed by Wen et al. (2010), our situation differs in that not all relevant information is known in advance but may be available in a stochastic manner.

2. Analysis on customers' willingness to wait (w2w)

Dietl et al. (2023) investigate whether customers in German-speaking countries are willing to wait (w2w) longer for their online orders in the fashion, shoes, and accessories sector when offered incentives in return. The research employed an online survey using a within-subjects design. The study shows that a significant share of participants (49.3 %) would not like to put on the ordered goods until the next week or even not until the next month. This group of customers could be offered an extended delivery period. The control group of the study participants were asked whether they would be w2w 4 to 7 days for the delivery of their order instead of 2 to 3 days. Other randomly selected participants were offered various incentives if they were willing to accept the longer delivery time. Results indicate that incentives significantly extend customers' w2w. Savings on shipping costs and information on the reduction in CO_2 emissions greatly impact customers' patience. Additionally, the research highlights that customers' responses to the incentives vary based on individual characteristics, such as gender, age, environmental awareness, and the urgency of their orders.

3. Stochastic and dynamic solution approach

We use a deterministic model, named SDDP, as the basis for our stochastic-dynamic modeling approach. The deterministic model SDDP is inspired by an MPVRP proposed by Archetti et al. (2015). In its dynamic setting, only a subset of customer orders is known at planning instant, i.e., only customers revealing their demand in the previous period. The customer demands within the following periods are uncertain and stochastic. New orders arrive at the end of each period. A periodic re-planning is carried out each period to account for the newly arrived orders and updated demand forecasts. We define a benefit measure for each known customer indicating the value of serving the customer in the current period rather than postponing. We henceforth call this benefit measure "*prize*." The *prize* combines positive and negative effects on the advantageousness of servicing an order in the current period, including the following aspects: urgency of the order, future capacity utilization, the probabilities of emerging nearby customers in future periods, as well as inventory costs. As intuition, the prize should be high if the order is urgent or we expect a high demand in future periods. Contrary, the prize should be low if we expect nearby customers emerging in future periods. This prize is then used to solve an auxiliary prize-collecting VRP with time windows (PCVRPTW), that decides which customers to deliver in that period and the corresponding routing. The PCVRPTW is solved heuristically with a hybrid adaptive large neighborhood search with granular insertion operators (HALNS-G). The HALNS-G extends the original version Voigt et al. (2022, 2023) with problem-specific operators, in particular granular insertion operators. The concept of granular insertion operators is inspired by the granular tabu search Toth and Vigo (2003). In the granular insertion operators, the insertion positions are confined to customers located in close proximity to the customer being inserted.

4. Sample results and contribution

In our experiments we introduce a simulator based on VRPTW instances with 1,000 customers. In each period, the simulator randomly samples a set of 100 customers from the respective instance. This set is then revealed as the pending customer set for the current planning period. For each instance, we generate 30 periods and calculate several performance measures (e.g., the average costs per customer, the average and maximum number of vehicles used per period). We conduct several experiments to generate managerial insights such as the cost reduction against several benchmark policies, the impact of the length of the delivery interval, and the impact of the share of customers selecting the some-day option. As an exemplary experiment, Table 1 shows the results on varying the length of the delivery interval of the some-day option ($1, 2, \ldots,$ or 5 days). We compare the average costs against the costs achieved with an earliest policy. In this policy, we serve each customer as quickly as possible, i.e., within the period following the order. Compared to the earliest policy, we can reduce costs to 78.9 % with a delivery interval of just 1 day. The costs savings increase with longer delivery intervals but become increasingly marginal, indicating that a moderate interval length of 3 days seems sufficient.

Delivery interval [days]	1	2	3	4	5
Average costs vs. earliest policy [%]	78.9	68.1	61.3	56.8	54.0

Table 1. Average costs for various delivery interval lengths of the some-day option

Contribution The paper contributes by (1) describing a novel slow logistics concept for B2C parcel delivery, (2) reviewing and categorizing MPVRPs with delivery dates, (3) introducing a solution approach for a dynamic MPVRP with stochastic information, (4) implementing a hybrid adaptive large neighborhood search with granular insertion operators for solving prize-collecting VRPTWs, and (5) showing by simulation that a slow delivery option significantly improves costs.

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