Dynamic Pricing of Flexible Time Slots for Attended Home Delivery Services

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Abstract:

Many online grocery retailers offer home delivery within a time slot booked by the customer. Providing narrow time slots improves customer satisfaction but is expensive to provide. To allow more flexibility in the retailer's delivery schedules whilst maintaining customer satisfaction, we propose to apply the concept of so-called flexible products (known in the airline industry) to delivery time slots. The idea is that customers have different preferences, so that some may be willing to accept a wider time window (or, in general, several not necessarily adjacent time windows) in return for a reduced delivery charge. A flexible slot is defined as a set of not necessarily adjacent time slots communicated to the customer as potential delivery times at the time of booking. However, the retailer only needs to make the decision on the specific delivery time on the day of delivery operation. Thereby, flexible products promise to improve the efficiency of the vehicle routes and to accept more profitable orders during the booking horizon.

In our analysis, we focus on managing prices of delivery slots (both regular and flexible ones) over a finite booking horizon for a single delivery day. The set of feasible prices is assumed to have finite cardinality. Customers with random shopping basket sizes arrive randomly over time, observe the offered delivery slot prices and choose a slot (or not to purchase) according to the multinomial logit choice model. The retailer aims to dynamically control slot prices in a way such that the expected profit-to-come over the remaining booking horizon is maximised. At the end of the booking horizon, we generate the final delivery routes to serve all requests using a heuristic for the vehicle routing problem with multiple time windows (due to the flexible slots).

We consider two types of flexible slots: In the first case, *the retailer designs* each flexible slot to consist of a fixed combination of regular slots. We impose constraints to ensure that these flexible slots are dynamically priced cheaper than the regular slots they contain. In the other case, the retailer allows *the customer to decide* which, say, three regular slots (out of all feasible ones) the flexible slot shall contain. In the second case, we assume that all flexible

slots have the same price, however, we need to deal with the large number of potential flexible products that customers can create.

We model the problem as a control problem of a Markov process over a discrete and finite time horizon. The intractable dynamic programming formulation of the problem is approximated by a linear programme (LP). It incorporates information on future expected demand, customer choice behaviour, and estimated vehicle routing cost implications using a very rough decomposition-based heuristic. We solve this LP offline and repeatedly over the booking horizon so as to produce estimates of the opportunity cost associated with accepting an order in a time slot. This opportunity cost in turn is used in an online optimisation that decides in real-time which prices to offer for all feasible time slots. We propose a small linear programme to obtain the optimal prices (given the opportunity cost inputs) in sufficiently short time to enable real-time decision support.

Our contribution lies in introducing two ways of offering flexible slots in attended home delivery services. We specifically focus on a dynamic pricing policy for all regular and flexible time slots aiming to maximise the retailer's profit. Flexible slots are beneficiary because they allow for more flexibility in the generation of the final vehicle routes. The underpinning optimisation problem is highly complex, however, we propose a computationally efficient heuristic approach to control slot prices in real-time. The approach is tested numerically in a simulation study on large-scale instances (up to around 4,000 customers), demonstrating the benefits of using flexible slots.