Dynamic Pricing for Same-Day Delivery Routing

Marlin W. Ulmer

Same-day delivery (SDD) is a powerful tool for online retailers to increase sales. SDD is convenient because customers can order online and do not need to go to the store and wait in lines. Further, customers receive their good within a few hours. Thus, SDD narrows the gap of instant gratification compared to brick and mortar shopping (Anderson 2015). As a result, SDD experiences high two-digit growth rates per year (Yahoo! Finance 2016). Further, the majority of customers is willing to pay delivery fees for SDD dependent on the delivery speed (eMarketer 2015). Many retailers offer a set of SDD options differing in delivery speed and price. Often, SDD is promised within four-hour delivery deadlines but in some cities like Berlin, Amazon already offers two hour delivery and even partially one-hour express delivery dependent on products and customer locations (Benedikt et al. 2016). The combination of SDD and narrow deadlines leads to significant economic challenges for service providers. Delivery time commitments increase the already high last-mile delivery costs and/or reduce the potential of serving many additional customers and gaining additional revenue (Ram 2015). To control customers' delivery choices, service providers can draw on dynamic pricing. In their pricing decisions, service providers have two goals in mind. First, they aim on maximizing the overall obtained delivery fees per day to compensate for the delivery costs. Second, SDD leads to near-instant gratification and may increase the number of orders in the long-term future (Anderson 2015). As a result, the service providers aim on selecting delivery prices leading to both high revenue in delivery fees and a large number of same-day deliveries.

In this research, we consider the dynamic pricing and routing problem for same-day delivery (DPPSDD). In the DPPSDD, a fleet of vehicles delivers goods from a depot to customers during a shift. These customers order dynamically and are unknown before the time of their order. For each ordering customer, a set of SDD deadlines is provided. For every deadline option, the provider presents a price. Based on the customer's (correlated) willingness-to-pay functions, the customer selects an option or rejects SDD (and selects conventional delivery). If the customer selects a SDD-option, a vehicle picks up the ordered good at the depot and delivers it within the according delivery deadline. The objective is to determine a dynamic pricing and routing policy maximizing the expected revenue per shift.

A suitable pricing should consider both the customer's choice and instant revenue as well as the impact of the fleet's flexibility to generate future revenues. This impact is quantified in the *opportunity costs* meaning the difference in future revenue in case the customer accepts an option or not. To determine suitable prices and consider both immediate and future revenue, we combine two pricing systems, a (static) basis price system to account for immediate rewards and an individual (dynamic) pricing based on the opportunity costs. If the opportunity costs of an option are low, we offer the basis price for the delivery option. If they are high, we offer a price with respect to the opportunity costs. To approximate the opportunity costs, we present a value function approximation (VFA, Powell 2011), an offline method of approximate dynamic programming (ADP). For each state and option, we approximate the opportunity costs based on a set of state features. These features reflect the fleet's flexibility to serve future customers in case the option is selected. We compare the VFA with static pricing and conventional pricing methods based on geography and time for a variety of instance settings. Figure 1 shows the average improvement in revenue and number of customers of the

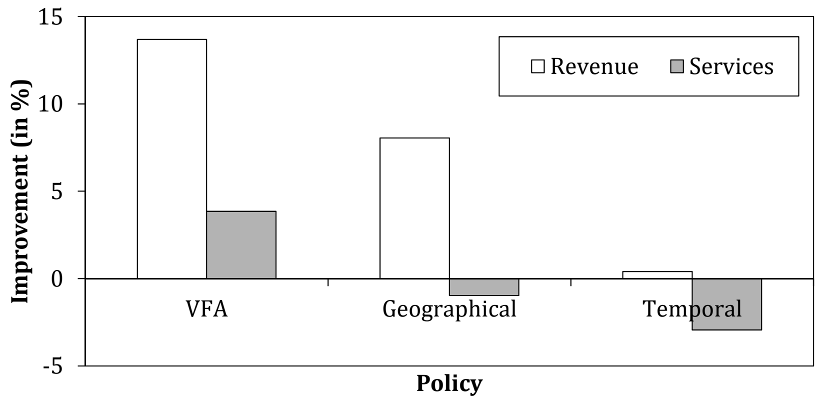

Figure 1: Average Improvement Compared to the Fixed-Price Policy

policies compared to static pricing. The VFA outperforms the benchmark policies significantly with respect to both revenue and number of same-day deliveries per day.

Our contributions are as follows. This work is the first combining dynamic pricing and dynamic delivery routing. The only work combining dynamic pricing with dynamic vehicle routing is presented by Figliozzi et al. (2007) and Topaloglu and Powell (2007). Both of these works do not consider SDD but different routing problems. For the DPPSDD, we present an anticipatory dynamic pricing and routing policy based on offline ADP. Our policy provides suitable prices instantly and achieves excellent results in comparison to conventional pricing methods. Our work further presents the first offline ADP-method for a dynamic vehicle routing problem with temporal commitments, namely, delivery deadlines. The proposed VFA accounts for a fleet's flexibility to efficiently serve future requests. The methodology may therefore be transferable to a variety of related problems with deadlines such as food delivery or dial-a-ride.

References

Anderson, Mae. 2015. Amazon is offering a key benefit of traditional brick-and-mortar stores. *Business Insider* URL `http://www.businessinsider.com/ap-everyone-loves-same-day-delivery-until-they-have-to-pay-2015-11?IR=T`. [Online; accessed 03-January-2017].

Benedikt, Fuest, Stephan Maaß, Max Zimmermann. 2016. So funktioniert das neue Ein-Stunden-Amazon. *Welt* URL `https://www.welt.de/wirtschaft/webwelt/article155266101/So-funktioniert-das-neue-Ein-Stunden-Amazon.html`. [Online; accessed 06-December-2016].

eMarketer. 2015. Do today's on-demand consumers want same-day delivery? *eMarketer* URL `https://www.emarketer.com/Article/Do-Todays-On-Demand-Consumers-Want-Same-Day-Delivery/1012436`. [Online; accessed 15-January-2017].

Figliozzi, Miguel Andres, Hani S Mahmassani, Patrick Jaillet. 2007. Pricing in dynamic vehicle routing problems. *Transportation Science* **41**(3) 302–318.

Powell, Warren B. 2011. *Approximate Dynamic Programming: Solving the Curses of Dimensionality*, *Wiley Series in Probability and Statistics*, vol. 842. John Wiley & Sons, New York.

Ram, Aliya. 2015. Uk retailers face high cost of online deliveries. URL `http://www.ft.com/cms/s/0/516aa75a-a04c-11e5-beba-5e33e2b79e46.html#axzz4CPxX2fjJ`. [Online; accessed 23-June-2016].

Topaloglu, Huseyin, Warren Powell. 2007. Incorporating pricing decisions into the stochastic dynamic fleet management problem. *Transportation Science* **41**(3) 281–301.

Yahoo! Finance. 2016. Increased value-added services expected to boost the same-day delivery market in the US, says Technavio. *Yahoo! Finance* URL `http://finance.yahoo.com/news/increased-value-added-services-expected-204000803.html`. [Online; accessed 14-July-2016].