Piggyback on Idle Ride-Hailing Drivers for Integrated On-Demand and Flexible Parcel Delivery Services

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1 INTRODUCTION

The rapid growth of e-commerce worldwide has led to a surge in demand for delivery services over recent years, particularly in the context of short-distance intracity parcel delivery. While long-haul trucks have been used for intercity delivery, logistics companies face significant challenges in short-distance intracity parcel delivery. Maintaining a fleet of vans or trucks for delivery is costly due to dispersed customer demand, stringent driver requirements, and high fuel consumption. These challenges often result in slower delivery speeds and negative externalities for city residents, such as traffic congestion and accidents caused by large delivery vehicles.

To overcome these challenges, a co-modality model has been proposed and implemented, which integrates ride-sourcing services and parcel delivery services on the same platform (Uber (2020)). This model capitalizes on the complementary nature of these services, allowing logistics companies to access a large pool of for-hire drivers already working on ride-sourcing platforms. The model takes advantage of the idle time experienced by ride-sourcing drivers and allow them to perform parcel deliveries, which optimizes the drivers' time and generates additional income.

Despite the aforementioned benefits, existing studies have overlooked crucial factors in the integrated business model such as demand flexibility and idle time utilization. This paper aims to fill this research gap by investigating the integration of ride-sourcing and parcel delivery service utilizing the idle time of ride-sourcing drivers. In particular, we consider an integrated platform that provides on-demand ride-sourcing services and multiple modes of delivery services, including: (1) *on-demand delivery*, where drivers immediately pick up and deliver parcels upon receiving a delivery request; and (2) *flexible delivery*, where drivers pick up (or drop off) parcels only when they are idle and waiting for the next ride-sourcing order. In this context, the on-demand package delivery services offers immediate responses to customer request, and can be used to deliver time-sensitive parcel, whereas flexible delivery services allows the drivers to pick up or drop off the package during their idle time, enabling better integrating with ride-sourcing services and significantly lowering delivery fees for customers. To assess the economic impacts of this integrated platform, we develop a mathematical model that characterizes the interactions between ride-sourcing and parcel delivery services. We also validate the proposed model through a comprehensive case study of San Francisco, which indicates that ride-sourcing and parcel delivery services exert both complementary and competitive effects on each other.

2 PROBLEM FORMULATION

Consider a city divided into M zones, and denote the transportation network of the city as a graph $\mathcal{G}(\mathcal{N}, \mathcal{A})$. On the transportation network, an integrated platform offers both ride-sourcing services to transport passengers and delivery services to transport parcels, using the same fleet of for-hire drivers. Ride-sourcing services are on-demand, which has to be served immediately. However, delivery services can be either on-demand or flexible: in the case of *on-demand delivery*, drivers need to immediately pick up and deliver the goods when the order is dispatched; while in the case of *flexible delivery*, drivers can pick up (or drop off) the goods only when they are idle and close to the origin (or destination), and carry them along with the on-demand orders. The flexible delivery service has lower priority, and may be interrupted by ride-sourcing or on-demand delivery service. The rest of this section will present a mathematical model that captures the market equilibrium under the profit-maximizing platform.

2.1 Profit Maximization of the Platform

The integrated platform determines the ride fare r_i^r for each zone i, the delivery fare $r_{ij}^{d_f}$ for flexible delivery services from zone i to zone j, and the driver wage q, in order to maximize the profits subject to the market equilibrium constraints. This can be formulated as the following optimization problem:

$$\max_{\mathbf{r}^r, \mathbf{r}^{d_f}, q} \quad \sum_{i=1}^{M} \sum_{j=1}^{M} r_i^r t_{ij} (\lambda_{ij}^r + \lambda_{ij}^{d_o}) + r_{ij}^{d_f} \lambda_{ij}^{d_f} - N_0 F_d(q) q \tag{1}$$

$$\begin{cases}
\lambda_{ij}^r = \lambda_{ij}^{r,0} F_r \left(\alpha_r w_i^r (N_i^I) + r_i^r t_{ij} \right) & \text{(2a)} \\
\lambda_{ij}^{d_f} = \lambda_{ij}^{d,0} F_d^1 (\alpha_d w_i^{d_f} (\bar{N}_i^I) + p_d(t_{ij}^{d_f}) + r_{ij}^{d_f}, \alpha_d w_i^r (N_i^I) + p_d(t_{ij}) + r_i^r t_{ij}) & \text{(2b)} \\
\lambda_{ij}^{d_o} = \lambda_{ij}^{d,0} F_d^2 (\alpha_d w_i^{d_f} + p_d(t_{ij}^{d_f}) + r_{ij}^{d_f}, \alpha_d w_i^r (N_i^I) + p_d(t_{ij}) + r_i^r t_{ij}) & \text{(2c)} \\
w_i^r (N_i^I) \leq w_{max} & \text{(2d)} \\
N_i^I = w_i^I \sum_{j=1}^{M} (\lambda_{ij}^r + \lambda_{ij}^{d_o}) & \text{(2e)} \\
N_0 F_d(q) = \sum_{i=1}^{M} \sum_{j=1}^{M} (\lambda_{ij}^r + \lambda_{ij}^{d_o}) t_{ij} + \sum_{i=1}^{M} \sum_{j=1}^{M} w_i^r (\lambda_{ij}^r + \lambda_{ij}^{d_o}) + \sum_{i=1}^{M} \sum_{j=1}^{M} w_i^I (\lambda_{ij}^r + \lambda_{ij}^{d_o}) & \text{(2f)} \\
\text{Matching constraints} & \text{(2g)}
\end{cases}$$

The decision variables are the ride fare per unit of time charged to passengers $\mathbf{r}^r$, the average delivery fare of flexible delivery parcels under different O-D pairs $\mathbf{r}^{d_f}$, and the average wages paid to drivers per unit of time q. The objective function (1) captures the platform profits which equals the total revenues from ride-sourcing services ($\sum_{i=1}^{M} \sum_{j=1}^{M} r_i^r t_{ij} \lambda_{ij}^r$) and both types of delivery services ($\sum_{i=1}^{M} \sum_{j=1}^{M} r_i^r t_{ij} \lambda_{ij}^{d_o} + r_{ij}^{d_f} \lambda_{ij}^{d_f}$) minus the total wages paid to the drivers $N_0 F_d(q) q$. Constraints (2a)-(2c) specify the demand of ride-sourcing passengers, flexible delivery customers, and on-demand delivery customers, respectively. The choices of passengers/delivery customers depend on the comparison between the generalized costs, including waiting time, delivery time, and service fare. Constraint (2d) imposes an upper bound on the waiting time for on-demand customers to guarantee that each zone can maintain good service quality. Constraint (2e) captures the number of idle drivers for on-demand services. Constraints (2f) ensure that the driver supply is consistent with the sum of drivers in each operating mode. Constraints (2g) capture the matching processes between drivers and flexible delivery customers, shedding light on the waiting time and delivery time for flexible delivery services. Given that ride-sourcing services and delivery services utilize the same pool of for-hire drivers but have distinct priorities, the matching between drivers and passengers becomes closely intertwined with the matching between drivers and delivery customers. Additional details on the matching constraints are presented in the following subsection.

2.2 Matching between Flexible Parcels and Drivers

In this subsection, we model the matching between flexible parcels and drivers to delineate the dependence of waiting time $w_i^{d_f}$ and the delivery time $t_{ij}^{d_f}$ for flexible delivery services on other endogenous variables. Since flexible parcel has a lower priority compared to on-demand service requests, idle drivers dispatched to a flexible delivery order may be interrupted by another on-demand request. Therefore, whether a driver can successfully pick up or drop off a flexible order depends on pick-up/drop-off time, driver's idle time, and vehicle carrying capacity.

To evaluate the impact of the capacity limit, we utilize a Semi-Markov process (SMP) to model the driver's position and the number of packages they carry. The SMP's states represent the driver's current zone and the number of packages being carried. Transitions between zones are determined by the driver's movement, primarily driven by on-demand orders. Transitions between package numbers depend on whether the driver successfully pick up/drop off a flexible package or not by comparing the pickup/drop-off time with the driver's idle time. The limiting probabilities of the SMP are crucial for calculating the average number of idle drivers available for flexible delivery orders, which is used to estimate $w_i^{d_f}$ by Cobb-Douglas matching functions.

The delivery time $t_{ij}^{d_f}$ depends on the probabilities for a driver to arrives at zone j, and the probabilities for him/her to successfully drop off the flexible parcel without being interrupted by other on-demand orders. It is given by $t_{ij}^{d_f} = \mathbb{E}[T_{ij}] + \frac{1-p_{j,drop}^{succ}}{p_{j,drop}^{succ}}\mathbb{E}[T_{jj}]$, where $\mathbb{E}[T_{ij}]$ captures the average time for a driver in i to arrive at zone j for the first time, which depends on the destinations of on-demand orders he/she received, and $p_{j,drop}^{succ}$ is the probability for a driver in zone j that can successfully drop off a flexible parcel before matching with next on-demand order.

3 CASE STUDY

This section introduces a case study conducted in San Francisco to assess the effectiveness of our proposed model. We consider a service area consisting of 11 zones within the city, partitioned according to zip code. We evaluate the proposed model and algorithm using real ride-sourcing demand data and synthesized parcel delivery data. To assess the influence of the integrated business model and examine the interplay between different services in the integrated platform, we normalize the delivery demand relative to the ride-sourcing demand, designating the ratio of the total potential demand between these two sectors as γ, i.e., $\sum_{i,j} \lambda_{ij}^{g0} = \gamma \sum_{i,j} \lambda_{ij}^{p0}$.

To evaluate the impacts of the integrated business model on the ride-sourcing market, we fix the ride-sourcing demand and perturb the value of γ from 0 to 2. The corresponding platform profits, total number of drivers on the platform, and total arrival rate of ride-sourcing passengers are presented in Figure 1. As the potential delivery demand increases, both the platform profit and the number of drivers significantly increase. However, the ride-sourcing passenger will benefit from the integration when the delivery demand is relatively low, but will suffer from the integration when the delivery demand is high. The reason is that there is both competition and complementarity between delivery services and ride-sourcing services, and the complementarity effect diminishes as the delivery demand increases.

Next, we discuss the outcomes of the parcel delivery market for the integrated platform. Figure 2 shows the attraction of on-demand/flexible delivery orders in each zone of the city. It indicates that when the potential delivery demand is low, the platform will give up serving flexible orders that are sent to the areas where ride-sourcing demand is low (i.e., zone 4, 5, 10 and 11). Since vehicle movement is largely driven by on-demand ride-sourcing orders, the few drivers dispatched to low ride-sourcing demand areas result in longer delivery times for flexible orders sent to these areas. As γ increases, flexible delivery services gradually become accessible

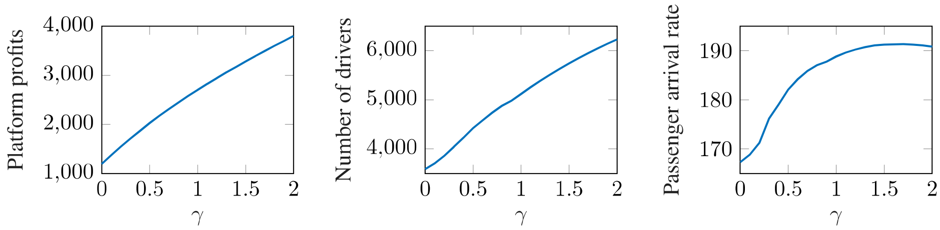

Figure 1 – *The platform profits ($/min), total number of drivers on the platform, and total arrival rate of ride-sourcing passengers (/min) under different level of delivery demand.*

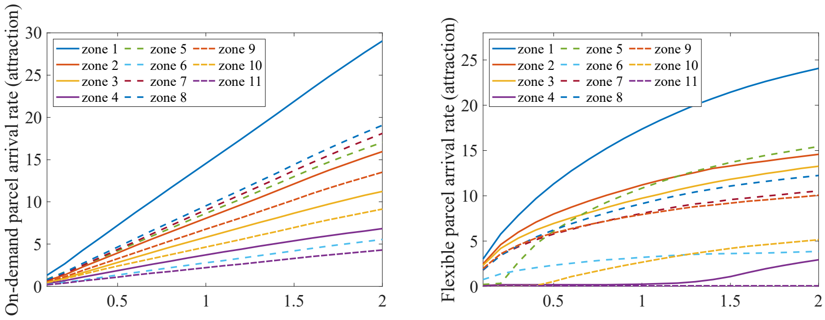

Figure 2 – *The arrival rate of delivery customers (/min) attracted to each zone under different level of delivery demand*

to customers wishing to send parcels to these areas. The reason is that with the increase of γ, the on-demand delivery orders sent to areas with low ride-sourcing demand also increase. This shift redistributes idle drivers, raising the probability of their presence in the aforementioned zones and consequently shortening the delivery time for flexible orders. This finding highlights the interplay between the flexible delivery services and on-demand delivery services.

4 CONCLUSIONS

This paper investigates the optimal pricing and fleet management strategies for an integrated platform to provide integrated ride-sourcing and intracity package delivery services over a transportation network utilizing the idle time of ride-sourcing drivers. We consider an integration of ride-sourcing services and two modes of parcel delivery services on a single platform, including on-demand delivery and flexible delivery offered at distinct prices. A semi-Markov process (SMP) model is proposed to capture passenger and parcel movement in a network with limited vehicle capacity. The platform's profit maximization problem is formulated as an optimization problem considering market economic equilibrium. The model is validated through a case study in San Francisco, providing insights into the relationship between ride-sourcing services and parcel delivery services.

Possible extensions of this work include incorporating temporal dynamics for demand and supply, developing specific strategies for different times of the day. Additionally, extending the study to a multi-modal transportation network that includes public transit and other shared mobility options.

References

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