Ridesourcing markets with a bundled service option

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Extended abstract submitted for presentation at the Conference in Emerging Technologies in Transportation Systems (TRC-30)
September 02-03, 2024, Crete, Greece

April 18, 2024

Keywords: Ride-sourcing markets; Bundled services; Demand allocation; Operating strategies.

1 INTRODUCTION

Advanced information technologies has made ride-sourcing services an increasingly important component of modern urban transportation systems (Wang and Yang 2019; Ke et al., 2020). Companies like Uber, Lyft, Didi, and Grab offer multiple service options to passengers, including non-pooling service (such as UberX), where one vehicle serves one passenger request, and ride-pooling (such as Uber Express Pool), where one vehicle serves two or more passenger requests in a single ride. Recently, ride-sourcing platforms like Didi introduced a bundled option that combines both service modes. With the bundled option, passengers wait in the queue for both non-pooling and ride-pooling service, and the platform assigns them to either one of the two services according to the available vehicle supply. **Figure 1** shows a screenshot of Didi's service options in their app.

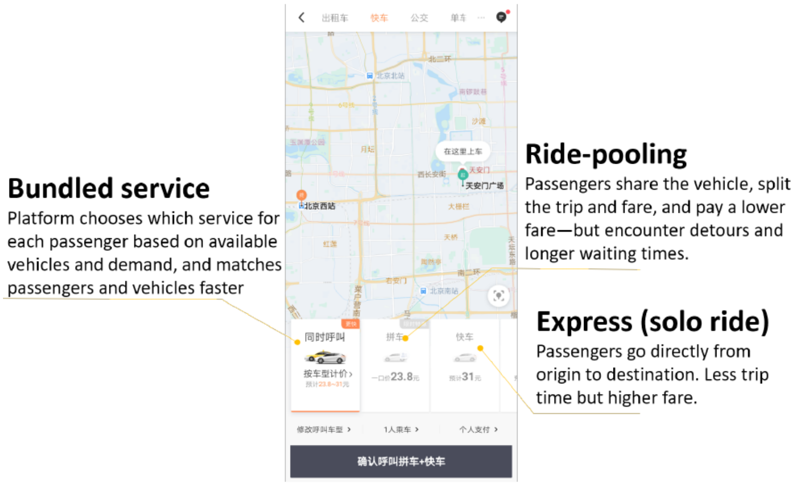

Figure 1. A snapshot of service options, including bundled option, provided by the DiDi App

The bundled option provides benefits for both ride-sourcing platforms and passengers. Platforms can allocate demand for the bundled option to different services based on market supply conditions. In low supply level, platforms can assign more passengers to ride-pooling services to serve more passengers and increase revenue. With enough supply, platforms can assign a larger proportion of passengers to non-pooling services to improve service quality and avoid inconveniences associated with ride-pooling services, such as detours and extra waiting time. Additionally, non-pooling services generally have higher fares, making them more profitable for platforms. Passengers can benefit from the bundled option by experiencing less waiting time and being served as soon as possible, regardless of which service is available. However, the emergence of the bundled option has given rise to managerial and operational problems that have not been examined in the literature. For example, which service should the platform assign to a passenger who selects the bundled option, and what proportion of passengers should be assigned to ride-pooling versus non-pooling? In addition, the platform needs to determine the optimal demand allocation, along with the pool-matching strategy, to improve revenue and service quality. Assigning more passengers to ride-pooling services reduces occupied vehicle hours, resulting in shorter pick-up times, higher service rates, and higher platform revenue. However, passengers assigned to ride-pooling may experience extra detours and waiting time. Identifying the optimal demand allocation strategy to balance these trade-offs is critical. To address these issues, in this work we propose a comprehensive mathematical model that describes the evolution of market fragmentation with service options of ride-pooling, non-pooling, and bundled under various demand-supply levels. The model will be used to describe how the platform should optimally allocate available vehicles to ride-pooling and non-pooling services and how it should determine the demand for bundled options to either service, and price for two services under a certain objective (i.e., profit maximization). We will introduce different components of modelling, such as demand and supply, elucidate the vehicle assignment principle, and introduce a bilateral meeting function to approximate passengers' average waiting time under stationary equilibrium. We expect to theoretically find the optimal allocation of demand for bundled options to ride-pooling and identify critical thresholds over/below which the optimal strategy is to assign all passengers in the bundled service to non-pooling services.

2 METHODOLOGY

In this work, non-pooling ride and solo ride are used interchangeably, which is referred to a regular e-hail trip with only one passenger in a vehicle per ride while a ride-pooling trip is defined as a trip shared by two passengers in one vehicle. Now consider in a monopoly ride-sourcing market, the platform offers three options in their app, solo, ride-pooling and bundled option. Passengers can choose ridesourcing services according to their individual WTP and VOT or leave the system. Throughout this work, we use subscripts n, s and b to denote associating variables with non-pooling, ride-pooling, and bundled option, respectively. A schematic modelling framework is shown in **Figure 2** to explain passengers' choice and characterize platform's vehicle allocation strategies.

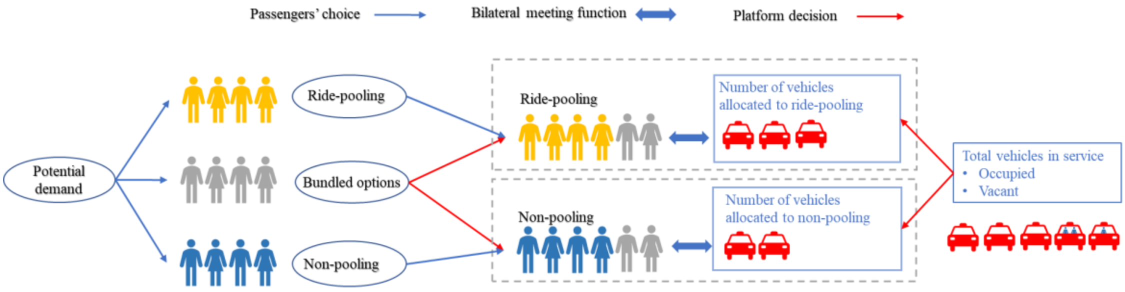

Figure 2. Framework of proposed model

2.1 Passenger Demand

The realized demands for non-pooling, ride-pooling, bundled option are indicated by Q_n, Q_s, Q_b, respectively. Q_n, Q_s, Q_b are determined by generalized cost consisting of willingness to pay (WTP, denoted by ω), value of time (VOT, denoted by β), average waiting time (w_n, w_s, w_b), average trip duration time (t_n, t_s, t_b). Their specific expressions will be discussed later in full version.

2.2 Vehicles Supply

Total supply is provided by the platform corresponding to the demand intensity. It is given exogenously with a fixed fleet size, N. Clearly, total vehicle supply in the network comprises of vacant vehicles and occupied vehicles for ride-pooling, solo ride, respectively.

$$N = N_s^v + N_n^v + N_s^o + N_n^o \tag{1}$$

where at any instant of stationary vehicle movements in the network, we have $N_s^o = 0.5t_s(Q_s + \lambda Q_b)$ with a widely accepted and simplified assumption in the existing literature (Ke, Yang, and Zheng 2021; Zhang and Nie 2021) that every two passengers occupy one vehicle for ride-pooling service while for solo ride, one passenger one vehicle, $N_n^o = t_n[Q_n + (1-\lambda)Q_b]$. And t_s, t_n are the average trip duration time for ridesharing and solo ride service, respectively.

2.3 Allocation Policy of Demand for Bundled Services

Here we introduce a ratio η to decide how to allocate the total vehicles to ride-pooling and solo ride service, i.e., ηN is the number of total vehicles serving for ride-pooling demand, $(1-\eta)N$ stands for the fleet size for solo ride service. η is a decision variable determined by the platform to optimize the supply allocation according to different demand-supply levels. let $\lambda \in [0,1]$ denote the fraction of the customers who choose the bundled options are assigned to ride-pooling service. Accordingly, the leftover $1-\lambda$ of Q_b are allocated to non-pooling service. After the assignment, the realized demand for ride-pooling service now becomes $Q_s + \lambda Q_b$ and accordingly, realized non-pooling demand is $Q_n + (1-\lambda)Q_b$. In some extreme cases, for example, $\lambda = 0$ indicates all customers choosing the bundled option are allotted to non-pooling service. The demand for bundled option will be assigned to ride-pooling or solo service according to the ratio of available vacant vehicles for each service. By this way, the platform can balance the vacant vehicles and thus ensure service quality. We have

$$\lambda = \frac{2N_s^v}{2N_s^v + N_n^v}. \tag{2}$$

2.4 Generalized Cost

Non-pooling ride services $C_n = p_n + \beta(w_n + t_n)$; For ride-pooling services, the generalized cost is $C_s = p_s + \beta(w_s + t_s + \tau)$; For bundled option, $C_b = p_b + \beta(w_b + t_b + \lambda\tau)$. $p_i, i \in \{n, b, s\}$ is the expected monetary fare of service type i. The waiting time of this passenger is a random variable, defined by $W_b = \min\{W_s, W_n\}$, where W_s is a random variable of waiting time to be picked up for ride-pooling service and W_n is a random variable of waiting time to be picked up for non-pooling service. We denote the expected value of three kinds of waiting time by $w_s = E(W_s)$, $w_n = E(W_n)$, $w_b = E(W_b) = E(\min\{W_s, W_n\})$.

2.5 Realized Demand

Let $f_{wv}(\omega, \beta)$ denote the continuous bivariate joint probability density function for a pair of two random variables (WTP, VOT), where $\omega \in [\underline{\omega}, \overline{\omega}]$, $\beta \in [\underline{\beta}, \overline{\beta}]$. the realized demand of three services is given as follows:

$$Q_s = \bar{Q}\int_{\underline{\beta}}^{\beta_2}\int_{p_s+\beta(w_s+t_s+\tau)}^{\overline{\omega}} f_{wv}(\omega,\beta)d\omega d\beta,\ \ Q_b = \bar{Q}\int_{\beta_2}^{\beta_1}\int_{p_b+\beta(w_b+t_b+\lambda\tau)}^{\overline{\omega}} f_{wv}(\omega,\beta)d\omega d\beta,$$

$$Q_n = \bar{Q}\int_{\beta_1}^{\overline{\beta}}\int_{p_n+\beta(w_n+t_n)}^{\overline{\omega}} f_{wv}(\omega,\beta)d\omega d\beta \tag{3}$$

Eqs. (1)-(3) systematically delineates the ridesourcing markets with bundled service option.

2.6 Operating Objectives

A monopoly scenario in which a monopoly ridesourcing platform aims to maximize its profit.

$$\text{(P1)} \max \Pi(\eta, p_s, p_n) = p_s(Q_s + \lambda Q_b) + p_n(Q_n + (1-\lambda)Q_b) \tag{4}$$

3 NUMERICAL RESULTS

We conduct numerical studies to first examine the platform's optimal decisions to maximize its revenue when supply is relatively large where the fleet size is given and fixed as N = 4800 veh. The result is shown in **Figure 3**. It shows that the increase of η indicates the platform assigns more available vehicles to ride-pooling services. Under this condition, we can find the λ is increasing with η. It is interestingly found that the realized demand for bundled service option, first decreases then increases with the increasing η. In the meanwhile, the realized demand for solo ride service and ride-pooling are both increasing at first, then decreasing.

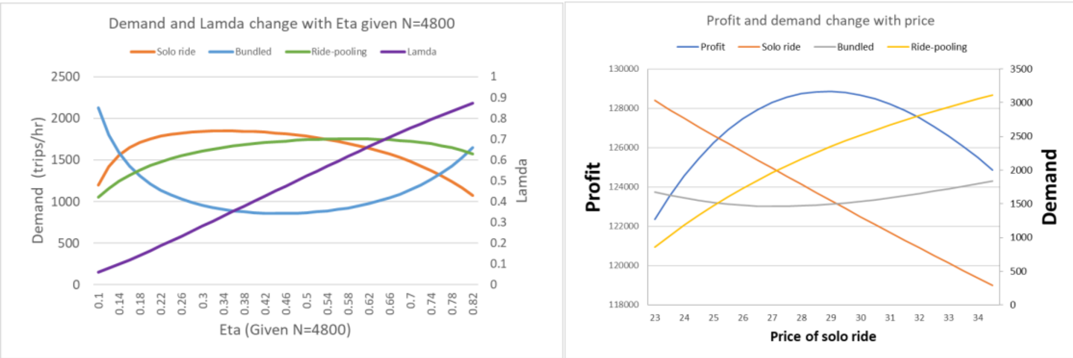

Figure 3. Numerical results when supply is adequate.

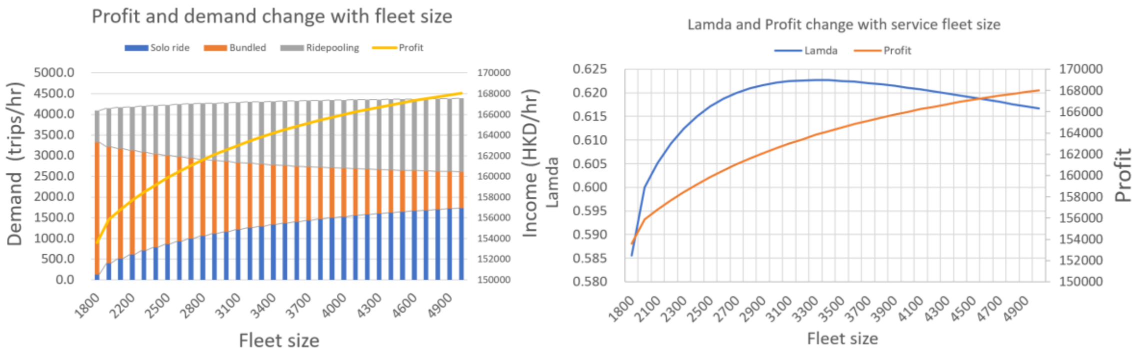

Figure 4. Numerical results of different levels of supply.

And we continue to explore if the fleet size is not fixed, we conduct sensitivity analysis to fleet size. The result is presented as in **Figure 4**. It shows when the potential demand is given and fixed, the platform's income will monotonically increase with the fleet size because here we do not consider the operating cost of fleet size. The served demand will swell with the available vehicles. The ratio to deciding bundled service demand assignment will grow fast when fleet size is small and slow down gently then the fleet size exceeds a threshold relevant with given potential demand.

4 CONCLUSION

We propose a model that helps ride-sourcing platforms determine the best way to manage demand and supply in a market with multiple options, including ride-pooling, non-pooling, and bundled options for passengers. We explore the optimal allocation of vehicles to ride-pooling or non-pooling services, and how the allocation of demand for bundled options can be determined based on supply allocation. We also identify critical thresholds where all passengers who choose the bundled option should be assigned to ride-pooling or non-pooling services. Our findings show that as more passengers choose the bundled option, platforms should allocate a larger proportion to ride-pooling. Our analysis provides insights for the ridsourcing platform to improve their profit and service quality.

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