



Modelling and Optimization for the Employment of Full-Time and Part-Time Drivers in Ride-Hailing Platforms

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To cite this article:

Chunhui Liu, Yangguang Lu. Modelling and Optimization for the Employment of Full-Time and Part-Time Drivers in Ride-Hailing Platforms. *International Journal of Economics, Finance and Management Sciences*. Vol. 9, No. 6, 2021, pp. 221-224.

doi: 10.11648/j.ijefm.20210906.11

Received: October 18, 2021; **Accepted:** November 5, 2021; **Published:** November 12, 2021

Abstract: The employment strategy is of great significance to improve the performances of the ride-hailing platforms. This paper establishes a nonlinear programming model to characterize the employment problem of a ride-hailing platform where full-time drivers and part-time drivers coexist, facing a month-varied daily market size. The daily online time of the full-time drivers is assumed to be fixed, while the daily online time of the part-time drivers is self-scheduled. The objective of the decision model is to maximize the total effective demand of the ride-hailing platform, and the constraints are to guarantee the minimum income of both the full-time and part-time drivers. By solving the models, we find the decision problem can be simplified as a linear programming model and the optimal numbers of full-time drivers and part-time drivers are derived. Theoretical results show that it is optimal for the ride-hailing platform to employ only part-time drivers if the cap of number of part-time drivers is sufficiently high, and the number of part-time drivers satisfies that the expected income per unit time during the month with the minimum daily market size equals the required minimum income. Otherwise, if the cap of number of part-time drivers is not sufficiently high, full-time drivers and part-time drivers will coexist. Finally, a numerical experiment is conducted to illustrate the theoretical results.

Keywords: Optimization, Employment, Ride-Hailing Platforms

1. Introduction

The 2017 Didi travel platform Employment Research Report shows that the employment of ride-hailing platforms is flexible [1]. Most Didi drivers have their own jobs, and the online time is widely distributed. As shown in Table 1, the part-time drivers who work less than 2 hours a day account for the highest proportion, 50.67%, and the full-time drivers who work more than 6 hours a day account for only 16.76%. For other ride-hailing platforms, e.g., Uber, Hall and Krueger reported that about one-third of Uber drivers work full-time, while others drive part-time to supplement income from other jobs or sources [2].

The employment of full-time drivers and part-time drivers in ride-hailing platforms can significantly affect the welfare of drivers and the travel efficiencies of passengers. In particular, if the proportion of part-time drivers is relatively

high, the supply can be in great insufficiency during peak period, leading to inefficiency of passenger's travel; if the proportion of full-time drivers is relatively high, the demand can be in great insufficiency during low peak period, leading to low income of drivers. Therefore, it is necessary for the ride-hailing platforms to design reasonable employment strategy about the full-time and part-time drivers to improve the matching efficiency between the supply and demand. Based on these facts, this paper is focus on the modelling and optimization of the employment of full-time and part-time drivers in ride-hailing platforms. By establishing a nonlinear programming model, the employment problem of a ride-hailing platform is characterized to derive the optimal numbers of full-time drivers and part-time drivers. The objective of the decision model is to maximize the total effective demand and the full-time/part-time drivers' welfare is taken into account as the constraints.

Table 1. Average daily online time of Didi drivers in 2017 (hours).

Online time (h)	Percentage
0-2	50.67%
2-4	19.66%
4-6	12.91%
6-8	12.91%
8-	8.02%

2. Related works

Related works include the studies on employment/staffing strategies of the ride-hailing platforms and service strategies of the self-scheduled drivers. Benjaafar et al. [3] and Gurvich et al. [4] studied the employment and distribution strategies of service capacity to improve the welfare of drivers in ride-hailing drivers. These studies ensure the salary level of drivers by controlling the upper limit of the number of registered drivers. Zhong and Lin demonstrated the matching between supply and demand of ride-hailing platform when full-time drivers and part-time drivers coexist [5]. Ibrahim assumed that the opportunity cost of service agents is a random variable and made a decision on the number of service agents to maximize the platform revenue [6]. Taylor [7], Bai et al. [8] proposed that the participation constraint of the agents in the ride-hailing platforms is that the expected income per unit time is not less than the opportunity cost per unit time. Chen et al. [8], Farber [9, 10], and Chen and Sheldon [11] empirically studied the drivers' online time decision. Benjaafar et al. [12] and Baron [13] made theoretical analysis on the online time decision of agents in the on-demand platform, taking the cumulative online hours of all agents as the total supply of the platform and considering that the agents make decisions with the goal of maximizing their expected income.

3. Model

This study investigates a ride-hailing platform, employing a population of full-time drivers and a population of part-time drivers facing a month-varied daily market size (potential demand). The daily online time of the full-time driver t_f is assumed to be fixed and exogenous. Part-time drivers are more flexible on the daily online time. Generally, full-time drivers take more time online than part-time drivers. According to the scheduling principle based on service grade, under which the drivers who have served more orders will have higher priority to be assigned, incoming orders are prioritized to full-time drivers. Part-time drivers choose their daily online time $t_{p,i}$ in month i within the limited available time t_a and the participation constraint of the part-time drivers is that the expected income per unit time in the ride-hailing platform is no less than the reserved wage r . In addition, to guarantee the drivers' welfare, the expected income per unit time of the full-time/part-time drivers is no less than a minimum income $\underline{w}_f/\underline{w}_p$, where $\underline{w}_f > \underline{w}_p > r$.

For simplicity, we suppose the service duration including the idle time, the pick-up time and the service time for each order is one unit time, and the total demand and the total supply are uniformly distributed in each day.

Other system parameters will be used in following analysis are defined as below.

n_p The number of part-time drivers employed by the ride-hailing platform

n_f The number of full-time drivers employed by the ride-hailing platform

N_p The cap of number of part-time drivers

N_f The cap of number of full-time drivers

ξ_i The daily market size in month i ($i = 1, 2, \dots, 12$)

T_i The number of days in month i ($i = 1, 2, \dots, 12$)

w Wage for serving one order

First, we analyse the decision problem of the part-time drivers. The part-time drivers can vary their online time as the daily market size fluctuates. In month i , the potential demand is first prioritized to full-time drivers. Since the daily total supply of the full-time drivers is $n_f t_f$, the daily effective demand served by the full-time drivers equals $\min\{n_f t_f, \xi_i\}$. It follows that the daily potential demand assigned to the part-time drivers is

$$\xi_{i,p} = (\xi_i - n_f t_f)^+ = \max\{\xi_i - n_f t_f, 0\}. \quad (1)$$

The daily total supply of the part-time drivers is $n_p t_{p,i}$. As a result, the daily effective demand served by part-time drivers is

$$d_{i,p} = \min\{\xi_{i,p}, n_p t_{p,i}\}. \quad (2)$$

See Yu et al. [14] for similar setting of the demand function. The daily expected online time for part-time drivers $t_{p,i} \leq t_a$ satisfies

$$\frac{d_{i,p}}{n_p t_{p,i}} w \geq r, \quad (3)$$

implying that the expected income per unit time is no less than the reserved wage. Denote $t_{i,p}^E$ and $d_{i,p}^E$ by the equilibrium daily online time and daily effective demand of part-time drivers.

Based on the main assumptions above, the decision problem of the platform is established using a nonlinear programming model.

$$\begin{aligned} & \text{Max}_{n_p, n_f} \sum_{i=1}^{12} T_i d_i \\ & \text{s.t. } \frac{d_{i,p}^E}{n_p t_{i,p}^E} w \geq \underline{w}_p \quad (\text{a}) \\ & \frac{\min\{n_f t_f, \xi_i\}}{n_f t_f} w \geq \underline{w}_f \quad (\text{b}) \\ & d_i = \min\{\xi_i, n_f t_f + n_p t_{i,p}^E\} \quad (\text{c}) \\ & n_p \leq N_p, n_f \leq N_f \quad (\text{d}) \end{aligned} \quad (4)$$

There are some additional explanations for the decision model. The decision objective is to set the numbers of the part-time drivers and the full-time drivers to maximize the platform's total expected effective demand. Note that d_i is the daily effective demand served by the drivers in month

i ($i = 1, 2, \dots, 12$). Inequality (a) is the minimum income constraint of part-time drivers. Inequality (b) is the minimum income constraint of full-time drivers. Constraint (d) indicates that the number of part-time/full-time drivers is no larger than the cap of number of part-time/full-time drivers.

4. Analysis and Solutions

We first solve the part-time driver's daily online time strategy $t_{i,p}^E$ and simplify the decision model of the platform (4). Recall that the participation constraint of part-time drivers is (3), and $d_{i,p}$ is determined by (1) and (2). By solving (1) and (2), we have the effective demand $d_{i,p}$ satisfies

$$d_{i,p} = \begin{cases} 0, & \text{if } n_f \geq \frac{\xi_i}{t_f} \\ n_p t_{p,i}, & \text{if } n_f < \frac{\xi_i}{t_f} \text{ and } t_{p,i} \leq \frac{\xi_i - n_f t_f}{n_p} \\ \xi_i - n_f t_f, & \text{if } n_f < \frac{\xi_i}{t_f} \text{ and } t_{p,i} > \frac{\xi_i - n_f t_f}{n_p} \end{cases} \quad (5)$$

Accordingly, the expected income per unit time of part-time drivers satisfies

$$\frac{d_{i,p}}{n_p t_{p,i}} w = \begin{cases} 0, & \text{if } n_f \geq \frac{\xi_i}{t_f} \\ w, & \text{if } n_f < \frac{\xi_i}{t_f} \text{ and } t_{p,i} \leq \frac{\xi_i - n_f t_f}{n_p} \\ \frac{\xi_i - n_f t_f}{n_p t_{p,i}} w, & \text{if } n_f < \frac{\xi_i}{t_f} \text{ and } t_{p,i} > \frac{\xi_i - n_f t_f}{n_p} \end{cases} \quad (6)$$

Part-time drivers will increase the online time until the expected income per unit time reaches the reserved wage r . Therefore, the part-time driver's daily online time strategy $t_{i,p}^E$ satisfies

$$t_{i,p}^E = \begin{cases} 0, & \text{if } n_f \geq \frac{\xi_i}{t_f} \\ \frac{\xi_i - n_f t_f w}{n_p r}, & \text{if } \frac{\xi_i - t_a n_p r/w}{t_f} < n_f < \frac{\xi_i}{t_f} \\ t_a, & \text{if } n_f \leq \frac{\xi_i - t_a n_p r/w}{t_f} \end{cases} \quad (7)$$

and the resulted daily effective demand and expected income per unit time of part-time drivers satisfy

$$d_{i,p}^E = \begin{cases} 0, & \text{if } n_f \geq \frac{\xi_i}{t_f} \\ \xi_i - n_f t_f, & \text{if } \frac{\xi_i - t_a n_p}{t_f} < n_f < \frac{\xi_i}{t_f} \\ n_p t_a, & \text{if } n_f \leq \frac{\xi_i - t_a n_p}{t_f} \end{cases} \quad (8)$$

$$\frac{d_{i,p}^E}{n_p t_{i,p}^E} w = \begin{cases} 0, & \text{if } n_f \geq \frac{\xi_i}{t_f} \\ r, & \text{if } \frac{\xi_i - t_a n_p r/w}{t_f} < n_f < \frac{\xi_i}{t_f} \\ \frac{\xi_i - n_f t_f}{n_p t_a} w, & \text{if } \frac{\xi_i - t_a n_p}{t_f} < n_f \leq \frac{\xi_i - t_a n_p r/w}{t_f} \\ w, & \text{if } n_f \leq \frac{\xi_i - t_a n_p}{t_f} \end{cases} \quad (9)$$

Taking (9) into constraint (a) yields that $n_f \leq \frac{\xi_i - t_a n_p w/w}{t_f}$.

It follows that the decision model (3) is reduced to (10), where ξ is the minimum market size among 12 months.

$$\begin{aligned} \text{Max}_{n_p, n_f} \sum_{i=1}^{12} T_i \min\{\xi_i, n_f t_f + n_p t_a\} \\ \text{s.t. } n_f \leq \frac{\xi - n_p t_a w/w}{t_f} \\ n_p \leq N_p, n_f \leq N_f \end{aligned} \quad (10)$$

The objective function of (10) is equivalent to $\text{Max}_{n_p, n_f} n_f t_f + n_p t_a$, and constraint $n_f \leq \frac{\xi - n_p t_a w/w}{t_f}$ is equivalent to $n_f t_f + n_p t_a w/w \leq \xi$. Then (10) is further reduced to a linear programming model, and by solving the linear programming model, we have the optimal solution is

$$(n_f^*, n_p^*) = \begin{cases} (0, \frac{\xi w}{t_a w_p}) & \text{if } N_p \geq \frac{\xi w}{t_a w_p} \\ (\frac{\xi - N_p t_a w/w}{t_f}, N_p), & \text{if } \frac{(\xi - N_f t_f)w}{t_a w_p} < N_p < \frac{\xi w}{t_a w_p} \\ (N_f, N_p), & \text{if } N_p \leq \frac{(\xi - N_f t_f)w}{t_a w_p} \end{cases} \quad (11)$$

The explanation for (11) is as follows. Compared with full-time drivers, the minimum income guarantee for part-time drivers is easier to be achieved. Then it is optimal for the platform to employ only part-time drivers if the cap of number of part-time drivers is sufficiently high, and the number of part-time drivers satisfies that the expected income per unit time during the month with the minimum daily market size equals the required minimum income. Otherwise, if the cap of number of part-time drivers is not sufficiently high, full-time drivers and part-time drivers will coexist.

5. Numerical Experiment

In this section, we conduct a numerical experiment to validate the theoretical results. Suppose $N_p = 15000$, $N_f = 2500$, $t_f = 8$, $t_a = 3$, $w = 50$, $w_f = 40$, $w_p = 30$, $\xi = 30000$. According to (11), we can derive the optimal numbers of full-time drivers and part time drivers: $(n_f^*, n_p^*) = (375, 15000)$. The total supply satisfies $n_f^* t_f + n_p^* t_a = 48000$. The expected income per unit time of full-time drivers equals 50. The effective demand and the expected income per unit time of part-time drivers at each month is reported in table 2.

Table 2. The effective demand and the expected income per unit time of part-time drivers under different daily market size.

Month i	Daily market size ξ_i	Effective demand d^*	Expected income per unit time of part-time drivers
1	50000	48000	50
2	30000	30000	30
3	30000	30000	30
4	48000	48000	50
5	50000	48000	50
6	55000	48000	50

Month t	Daily market size ξ_t	Effective demand d^*	Expected income per unit time of part-time drivers
7	70000	48000	50
8	70000	48000	50
9	48000	48000	50
10	42000	42000	43
11	42000	42000	43
12	50000	48000	50

6. Conclusion

The employment strategy significantly affects the efficiencies of the ride-hailing platforms, including the passengers' service experience and the drivers' income. This paper considers a ride-hailing platform where full-time and part-time drivers coexist. A nonlinear programming model is first presented to establish the employment problem of the platform, considering the maximization of the total effective demand as the decision objective and minimum income of full-time/part-time drivers as the constraints. The part-time drivers self-scheduling their online time are also taken into account. Finally, the optimal solution about the numbers of full-time and part-time drivers is obtained.

Further research may look into how traffic congestion affects the theoretical results. Full-time drivers and part-time drivers might be available in different time periods of each day; future work can take this fact into account and study how the employment strategy changes.

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