Designing a Mixed Carpool Mechanism on the Online Cab Service

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Abstract. In this paper, we proposed a mixed carpool strategy via social interaction mechanism in the online cab service market. Considering other two individual strategies on cab service, we made a comparison to examined under which conditions existed, the mixed carpool strategy dominated the others. We emphasized the impact of two crucial factors, information heterogeneity between informed and less-informed passengers as well as information exchange insufficiency, on the cabdriver’s earning. Finally, we made a suggestion to the ISPs which exerted themselves in the online cab service.

Introduction

On account of economic growth in recent times, which has led to industrialization and urbanization, the scale of cars has expanded rapidly, resulting in worsened traffic congestion in big cities. It has been having a negative impact on air quality, utility of precious time[1], fuel consumption[2] etc. Meanwhile, individual travel dominated all travel ways, where most passenger cars were used to carry one or two individuals causing wastes of resource. So it was conspicuous that considerable work was require to improve utility rate of passenger cars’ seats in order to alleviate traffic congestion problem.

Carpool was an environmental-friendly way based on sharing empty seats of cars, and it was an effective solution to traffic congestion[3]. The crucial advantage of carpool was that it congregated several passengers directing to a similar destination in one rather than several passenger cars, which carried the same numbers of passengers with lower vehicles and fuel consumption. Among all carpool forms, cab carpool service was a promising solutions, where cabs played an important role in residents’ daily commutes in urban areas. However, carpool between strangers required a social interaction mechanism to reach a deal. The advancement of information technology facilitated information exchange among the masses and have created many new chances for Internet service providers (ISPs) to implement innovative selling strategies via social interaction. On cab service field, some ISPs which specialized in offering online reserve cab service, such as Uber and Didi, has aroused great concern in masses. There, it was imperative to study the online reserve cab service based on carpool behavior via social interaction mechanism from the perspective of market strategic competition and game.

This paper contributed to the literature in several ways. First, it added to the literature on cab carpool service. Most prior studies ignored social interaction’s impact on cab carpool service in software design. Some research focused on proposing carpool service system. CarpoolGlobal[4], which was web-based and transmitted carpool information to online community platforms, supplied an interfacing service for drivers and passengers. ShareYourRide[5] added a digital GIS to match travel offers to requests. BlueNet-Ride[6] was a cloud-based architecture for carpool service. Some research focused on tackling with operation problem on cab scheduling[7], novel systems making use of cab mobile traces[8], large-scale cab networks using cloud server[9].

Second, it contributed literature that congregated consumer social interactions into designing company market strategies. For instance, [10] studied how to activate buyers to make after-purchase product referrals. [11] concluded how interactions between distinctively different groups require
seller to adjust its optimal price decision. [12] proposed a monopoly’s pricing determination model in the durable goods market where social interaction acted as a factor on consumer product evaluation. [13] illustrated two kinds of social interactions' impact, word of mouth and observational learning, on consumer purchase decisions. [14] modeled group buying and referral reward’s impact on the profit of online product providers.

In this paper, we proposed a mixed carpool model which embedded a social interaction mechanism to study the ISPs’ strategy on the online cab service market and identified conditions under which mixed carpool was more profitable than individual cab strategies including hail a cab and special cab strategies.

The Basis of Model

We considered two segments including a cabdriver and four passengers who distinguished in their knowledge of cab and its driver’s information. We defined two informed and two less-informed passengers, where the former used online cab service via cab-hailing apps while the latter didn’t. Our aim was to propose a model to illustrate the cabdriver’s earning of a mixed carpool strategy and two individual strategies. Because ISPs extracted a proportion of cabdrivers’ earning to maintain operation and make profit, for the ISPs, helping cabdrivers earn more money was equal to benefit themselves.

Passengers Behavior: The less-informed passengers accepted a travel price $kP_0$, where $k$ denoted government’s regulation on the price; and the informed ones accepted a travel price $P_0 + \alpha I$, where $I \geq 0$ was the information gap between the two types of passengers. It prevented the less-informed passengers from fully appreciating the facility of travel. The $\alpha$ measured the unit information’s important degree. For hail a cab strategy, passengers were lack of added value $I$ brought by information service, so the acceptable price was lower.

Major Strategies. (1) Hail a Cab strategy, under which both informed and less-informed passengers hailed a taxi on the roadside without ordering a schedule via the Internet; (2) Special Cab strategy, under which an informed passenger ordered a special cab via cab-hailing apps and hoped that the special cab picked him up at his desired time; (3) Mixed Carpool strategy. The strategies (2) (3) embodied social interaction mechanism while the strategy (1) didn’t.

Individual cab strategy. Assumed that the informed passengers took special cab strategy, both passengers took hail a cab strategy, the marginal cost was zero. The optimal price $(P^*_S, P^*_H)$ and the corresponding earning $(\pi^*_S, \pi^*_H)$ were shown in Eq.1-Eq.2.

\[
\begin{align*}
\text{Special Cab strategy:} & \quad P^*_S = P_0 + \alpha I \quad \pi^*_S = 2(P_0 + \alpha I) \\
\text{Hail a Cab strategy:} & \quad P^*_H = kP_0 \quad \pi^*_H = 4kP_0
\end{align*}
\]

The Model of Mixed Carpool Mechanism

The carpool strategy meant that informed passengers, as sales agents, disseminated travel information, recruited less-informed passengers to carpool via cab-hailing apps for sharing the travel fare. We put forward a mixed carpool model where passengers could change strategy between carpool and individual strategies. Such a mixed strategy was unable to improve earning for cabdrivers with homogeneous informed passengers where all of them made the same choice.

However, the cabdrivers might have the chance to benefit from accepting a mixed carpool strategy when informed passengers were heterogeneous. We designed a mixed carpool mechanism to study the benefit by allowing the informed passengers to differ in their behavior to delay the order. We assumed one informed passenger who was patient had a higher delay factor than the other informed one who was impatient ($\delta_1, \delta_2$ and $\delta_1 > \delta_2$). In the mixed carpool strategy, the cabdriver
faced the optimal problem to maximize earning showed in Eq.3-Eq.8.

\[
\max_{p_{mc}, p_{ai}} \pi_{mc} = p_1 + \delta p_{mc}
\]  

(3)

\[
s.t. \quad \delta_1 [p_0 + \alpha I - (p_{mc} / 3 + 2\beta \Delta I)] \geq 0
\]  

(4)

\[
\delta_1 (p_0 + \alpha I - p_{mc} / 3) = 0, \quad 0 \leq \Delta I \leq I
\]  

(5)

\[
p_0 + \alpha I - p_1 \geq 0
\]  

(6)

\[
p_0 + \alpha I - p_1 \geq \delta_2 [p_0 + \alpha I - (p_{mc} / 4 + \beta \Delta I / 2)]
\]  

(7)

\[
\delta_1 [p_0 + \alpha I - (p_{mc} / 3 + 2\beta \Delta I)] \geq p_0 + \alpha I - p_1
\]  

(8)

The Eq.3-Eq.8 was described as a principle-agent problem between the cabdriver and the informed passengers. Two informed passengers recruited two less-informed passengers to join a carpool group for their similar destination. The impatient informed one couldn’t wait other passengers for a long time and he transferred carpool strategy into an individual strategy by taking a cab on his own, which left the other three to mix carpool. In the Eq.3, \( p_{mc} \) represented the travel price on mixed carpool strategy and \( p_1 \) represented the travel price on individual strategy. A discount factor \( \delta \in (0,1) \) reflected time delay. For the explanation, it took time for the informed passengers to reach the less-informed passengers and to persuade them to carpool; for cabdriver to negotiate both passengers with travel information (e.g. pick-up location, pick-up time, routes) than individual strategies. \( \delta \) was considered to be opportunity cost for cabdriver which complete more orders on the individual strategies than on the mixed carpool strategy in some time. So a smaller \( \delta \) captured a higher difficult degree of negotiation and a higher opportunity cost for the cabdriver. The mixed carpool strategy was feasible for the two motivations. First, cabdriver could earn more wages than the individual strategies. Second, passengers shared expenditure. To travel at a cheaper price, the informed passengers must interact with the less-informed passengers. The price discount could be partly viewed as compensation to the informed passenger for their interaction effort. The compensation, denoted as \( \beta \Delta I \), increased with the agent’s effort level in information dissemination \( \Delta I \). The information exchange inefficiency \( \beta \in (0,1) \), which measured how difficult it was for the informed passenger to recruit less-informed passengers. The Eq.4 reflected partition for the informed passenger. \( p_{mc} / 3 \) represented each passenger’s expenditure on mixed carpool which must be sufficient low to compensate the informed passenger \( (p_c/3+2\beta \Delta I) \) for taking the effort to recruit others. The informed passenger was stimulated by mixed carpool strategy rather than special cab strategy because of \( p_c/2+\beta \Delta I \leq p_1 \). The Eq.5 reflected incentive compatibility for the informed passenger. The agent’s effort level was not directly observable by the cabdriver, and the information exchange would be implemented only if it was the agent’s best choice. Given a carpool size of three, the agent would choose the minimum \( \Delta I \) that was sufficient to persuade the less-informed passenger to carpool. The Eq.6 described that price of the impatient informed one’s individual strategy was lower than or equal to special cab strategy. Because he recruited less-informed passengers and should get compensation. The Eq.7 described the incentive compatibility for the impatient informed one to choose special cab strategy over carpool, where the right part described the situation of the impatient informed one’s participation in carpool. Here, each passenger payed the price of \( p_{mc} / 4 \), and the compensation for information exchange was \( (\beta/2)\Delta I \) because the two informed passengers shared the task of recruiting one less-informed passenger. The Eq.8
described the incentive compatibility for the patient informed one to choose carpool over special cab strategy, where the left part described the carpool strategy without the impatient informed one, so each passenger payed the price of $P_{MC}/3$.

**Comparison**

Lemma 1. The optimal solutions of the three cab strategies were given in the following table.

<table>
<thead>
<tr>
<th>Traveling Strategy</th>
<th>Price</th>
<th>Passengers</th>
<th>Earning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Special Cab</td>
<td>$P_s^* = P_0 + \alpha I$</td>
<td>2</td>
<td>$\pi_s^* = 2(P_0 + \alpha I)$</td>
</tr>
<tr>
<td>Mixed Carpool</td>
<td>$P_{MC}^* = 3[P_0 + \alpha^2 I/(\alpha + 2\beta)]$</td>
<td>4</td>
<td>$\pi_{MC}^* = P_1^* + \delta P_{MC}^*$</td>
</tr>
<tr>
<td>Hail a Cab</td>
<td>$P_{h}^* = kP_0$</td>
<td>4</td>
<td>$\pi_{h}^* = 4kP_0$</td>
</tr>
</tbody>
</table>

The Proposition 1 showed a formal comparison of the three maximum earnings, which stated the conditions under which each strategy dominated the others.

Proposition 1. (a) The mixed carpool dominated the two strategies by two factors, passenger information gap($I$) and the inefficiency of disseminating information($\beta$), under which was $\beta < \beta_1$ or $I > \max(I_1, I_2)$ or $\beta_1 < \beta < \beta_2$, $I_1 < I < I_2$; (b) The different time delay for informed passenger provided a motivation for the cabdriver to adopt a mixed carpool strategy, namely offering passengers both carpool and individual options; (c) The mixed carpool had more probability to dominate the pure carpool when the gap between the informed and less-informed passengers increased, $\partial[\pi_{MC}^* - \pi_{h}^*]/\partial[I_1 - I_2] \geq 0$. (Notations were defined in the appendix)

Proposition 1 revealed that the mixed carpool strategy was more profitable than the other strategies when two situation occurred: (1) passengers had a mid-range of information heterogeneity, so as the information dissemination efficiency, (2) passengers’ information gap was large and information dissemination was sufficiently efficient. A mid-range information gap and indicated heterogeneity between passengers didn’t differ greatly, so expanding the market became more attractive. Therefore, mixed carpool strategy dominated the market.

Information exchange inefficiency affected the optimal of mixed carpool strategy in several ways. First, Mixed carpool strategy can’t be beneficial when $\beta$ was too large. Carpool depended on informed passengers to expand the market through interpersonal communication, and the attraction of this strategy relied on how much incentive the cost sharing compensated the information exchange effort. The higher inefficiency indicated higher information exchange costs, and it was less attractive for cabdrivers to expand the market via mixed carpool strategy. Second, the information gap became wider as $\beta$ descened. Third, when interpersonal interaction became really efficient, the optimal of mixed carpool strategy was no longer limited by an upper bound of the information gap. The results revealed that a higher information exchange inefficiency weakened the cabdrivers’ desires to take mixed carpool strategy but strengthened their desires to take individual strategies.

Mixed carpool strategy introduced an additional money-making format of the carpool channel, which was that made full use of the heterogeneity among the informed passengers to create an opportunity for price discrimination, where impatient one payed a higher individual price while patient one payed a lower carpool price. To realize the price discrimination earning for cabdrivers, also for themselves, the designers of taxi-hailing apps should descend the mixed carpool rate compared with the pure carpool. For the reason, first, there were fewer sales agents under mixed carpool because the impatient one took a cab individually, and a lower carpool price should be set to motivate informed ones to take the same task of recruiting less-informed ones. Second, the patient informed ones faced more choices, which either took a cab individually or joined the carpool group, so the designers of ISPs should offer additional information compensation by means of lowering
carpool price to prevent him from taking a cab individually. As presented in Proposition 1, when heterogeneity($\delta_1 - \delta_2$) among the informed passengers was more larger, the cabdriver might be better off taking advantage of the price discrimination benefit by adding a carpool order to the existing individual order.

**Conclusion**

The paper put forward a mixed carpool model via social interaction mechanism on the cab service market in order to increased utility rate of passenger cars. Our effort provided a few valuable perspectives and guidelines, which were hoped to be useful for realizing cab carpool service commercially in the related ISPs. In specification, First, we discussed the impact of two crucial factors, information gap and information dissemination inefficiency, on the travel price and cabdrivers’ earning. Second, we made a comparison under which conditions occurred, mixed carpool strategy dominated other two individual strategies which were common on the cab service market. The discussion made enlightenment for those ISPs which designed cab-hailing apps. First, we designed a mixed carpool mechanism which customized a possible situation to satisfied personalized travel experience as a commercial mode for those ISPs’s reference. Second, when the ISPs designed the cab-hailing apps, they should measure all parameters by market investigation and operational practice, made full exploitation of the first-hand original data and the pricing methods to calculate the dominating strategy in the distinctive conditions, which was beneficial for them to find out right market orientation and to elaborate right strategic decision in designing market strategies embodied in pricing models of the cab-hailing apps.

**Appendix**

**Proof of Lemma 1**

The optimal Mixed carpool strategy. First, we considered the Eq.3-Eq.5, the cabdriver’s maximum earning which got from the carpool group containing two informed and two less-informed passengers was $P_{mc} = 3[P_0 + \alpha^2 I/(\alpha + 2\beta)]$, where $\Delta I = \alpha I/(\alpha + 2\beta)$. Second, we discussed the Eq.6-Eq.8 affected the cabdriver’s choice of the optimal effort level and the total earning. From the Eq.7 and Eq.4, we got $P_1 = (1 - \delta_2 / 4)P_0 + (1 - \delta_2)\alpha I + \delta_2(3\alpha / 4 + \beta / 2)\Delta I$. Therefore, the cabdriver’s total earning from individual cab service and the carpool group would ascended with $\Delta I$ until it reached the summit. Substituting $P_1$ into the Eq.6, we got $\Delta I \leq \alpha I/(1.5\alpha + \beta)$. Substituting $P_1$ and $P_{mc} = 3[P_0 + \alpha^2 I/(\alpha + 2\beta)]$ into the Eq.8, we got $\Delta I \leq (\delta_1 - \delta_2)\alpha I/[2(\delta_1 - \delta_2)\alpha + (4\delta_1 - \delta_2)\beta] \leq \alpha I/(\alpha + 2\beta)$. Thus, the optimal information gap level

$$\Delta I = \min\left[\frac{2}{1.5\alpha + \beta}, \frac{\alpha}{\alpha + 2\beta}, \frac{(\delta_1 - \delta_2)\alpha}{2(\delta_1 - \delta_2)\alpha + (4\delta_1 - \delta_2)\beta} \right] = \frac{(\delta_1 - \delta_2)\alpha}{2(\delta_1 - \delta_2)\alpha + (4\delta_1 - \delta_2)\beta}.$$

So the optimal solution was $P_{mc}^* = 3P_0 + (3(\delta_1 - \delta_2)\alpha^2 I/[2(\delta_1 - \delta_2)\alpha + (4\delta_1 - \delta_2)\beta])\alpha I$ $P^*_1 = (1 - \delta_2 / 4)P_0 + (1 - \delta_2^* + \delta_2(3\alpha + 2\beta)(\delta_1 - \delta_2)/\{8(\delta_1 - \delta_2)\alpha + (16\delta_1 - 4\delta_2)\beta]\} \alpha I$ $\pi_{mc}^* = P^*_1 + \delta P_{mc}^* = (1 + 3\delta - \delta_2 / 4)P_0 + (1 - \delta_2)\alpha I + [(3\delta + 3/4\delta_2)\alpha + \delta_2 \beta / 2]D^*$

**Proof of Proposition 1**

(1) The optimal Pure carpool strategy. With this strategy, under the assumption that there was no method to differentiate the two informed passengers. The cabdriver would ask these two passengers to share the task of recruiting two less-informed passengers to achieve a carpool price $P_C$. The strategy could be described similarly as in the model.

Target: $\max P_C: \pi_C = \delta P_C$; s.t. $\delta_1[P_0 + \alpha I - (P_C / 4 + \beta\Delta I)] \geq 0$, $\delta_2[P_0 + \alpha I - (P_C / 4 + \beta\Delta I)] \geq 0$, $\delta(P_0 + \alpha\Delta I - P_C / 4) = 0$, $0 \leq \Delta I \leq 1$, $\delta \in (1/4, 1)$

The optimal solution of the model were $P_C^* = 4(P_0 + \alpha^2 I/(\alpha + \beta))$, $\pi_C^* = 4\delta(P_0 + \alpha^2 I/(\alpha + \beta))$
(II) The comparison among Mixed carpool strategy and Individual strategies.

(1) Mixed carpool strategy vs. Hail a Cab strategy.

$$\pi_{MC}^* - \pi_{H}^* = \frac{(1 + 3\delta - \delta_2 / 4 - 4k)P_0 + (1 - \delta_2)\alpha + \{(3\delta + 3 / 4\delta_2)\alpha + \delta_2\beta / 2\}^\Delta I}{(2 + 3\delta - 5\delta_2 / 4)\delta_2 - \delta_2^2 / 2 + (4\delta_1 - \delta_2)(1 - \delta_2)\alpha^2}$$

Thus, $$\pi_{MC}^* > \pi_{H}^*$$ if $$I > I_0$$ \(22201/21/3311\) \(1 / P_{14 / 3}\) if $1 \beta_2 < \beta_1$, \(I_2 \), or $2$ $\beta > \beta_1$, \(I_2 < I_0\), where $\beta_1 = (\delta_1 - \delta_2)(3\delta - 3 - \delta_2 / 4)\alpha \cdot I_2 = \frac{[(2(1 - \delta_2)\alpha + (4\delta_1 - \delta_2)\beta)(3\delta - 1 - \delta_2 / 4)P_0}{(7\delta_2 / 2 - 4\delta_1 + \delta_1 + \delta_2 / 2)\beta - (\delta_1 - \delta_2)(3\delta - 2 - 5\delta_2 / 4)\alpha}^\Delta I_2$.

In general, $$\pi_{MC}^* > (\pi_{S}^*, \pi_{H}^*)$$ if $1$ $\beta_2 < \beta_1$, \(I > \max(I_1, I_2)\), or $2$ $\beta_1 < \beta_2 = (\delta_1 - \delta_2)(3\delta - 2 - 5\delta_2 / 4)\alpha^2 / [(7\delta_2 / 2 - 4\delta_1 + \delta_1 + \delta_2 / 2)\beta - (\delta_1 - \delta_2)(3\delta - 2 - 5\delta_2 / 4)\alpha] I_2$. $I_1 < I < I_2$.

(III) The comparison between Mixed and Pure carpool strategies. The proposition 1(c) was proofed directly based on static analysis. \(\partial\pi_{MC}^* / \partial\delta_1 = \partial\pi_{MC}^* / \partial\delta_2 = 0\), \(\partial\pi_{MC}^* / \partial\delta_1 \geq 0\), \(\partial\pi_{MC}^* / \partial\delta_2 \leq 0\). The fluctuation of the $\pi_{MC}^*$ was not related with $\delta_1$ and $\delta_2$, while $\delta_1$ and $\delta_2$ had reverse impacts on the $\pi_{MC}^*$. So $\partial\pi_{MC}^* / \partial(\delta_1 - \delta_2) > 0$, then derived the result.

References


