UPGRADING IN RIDE-SOURCING SERVICES WITH MULTIPLE VEHICLE CLASSES

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1. INTRODUCTION

Over the past decade, the rapid growth of on-demand ride services or ride-sourcing services has made substantial impacts on the traditional taxi industry, on the ways people travel and on the multimodal urban transportation system. Ride-sourcing platforms generally offer different levels of ride-services to passengers with heterogeneous preferences and valuations. For example, Uber's service menu includes UberX (basic service), UberPool (shared rides), Uber Black (luxury rides with professional drivers), Uber Black SUV (premium rides with extra seats), etc. Lyft offers Lyft (basic service), Lyft Lux (sedans with leather-like seats, such as Lexus ES), and Lux Black (luxury sedans, such as BMW 5-series). The luxury ride services are normally provided by drivers with relatively high service ratings. Clearly, passengers who prefer higher service quality will choose high-class services, while passengers who are relatively sensitive to price will opt for low-class services. However, due to the inherent imbalanced distribution of demand, the supply can barely satisfy the demand especially during peak hour for the low-class, the major mode of service, whereas the supply of high-class exceeds its own demand. The surplus high-class vehicle will be wasted if they are impeded to serve low-class vehicles demand. To alleviate this imbalance issue, the platform may upgrade some low-class vehicle requests to high-class ride services without extra charges. This could happen when there is no vacant low-class vehicles but extra vacant high-class vehicles nearby. The motivations for the platform to upgrade a ride service may include: (1) the price difference between the high-class and low-class services is smaller than the cost of operating an idle high-class vehicles during the period of the ride; (2) it can reduce the waiting time and improve the service equality for passengers opting for the low-class services; (3) it will potentially attract some passengers switching from low-class to high-class services in the future; (4) it can avoid the costs of repositioning faraway vacant low-class vehicles.

Of particular interest is the decisions for upgrading, that is, when and where to upgrade ride services. The decision-making majorly depends on the spatial-temporal supply-demand imbalance in different service classes. For example, in the regions with extra low-class demand (passengers opting for low-class ride services wait in a long queue) but with extra high-class supply (vacant vehicles are waiting for new coming passengers), it is intuitively beneficial to upgrade some low-class waiting passengers to high-class ride services to reduce the waiting time of low-class passengers and improve utilization rate of high-class vehicles. An alternative solution is to reposition vacant low-class vehicles from other regions to these regions and to reposition vacant high-class vehicles from these regions to others. It is of immerse interest to compare the costs of these two solutions and assist the platforms in determining whether to upgrade some low-class passenger demand or reposition vacant vehicles in different regions under different supply-demand situations.

Motivated by the aforementioned two strategies to alleviate the demand-supply imbalance problem, we intend to investigate the benefits of upgrading and dispatching under different demand-supply scenarios of high-class and low-class. This study firstly proposes a mathematical equilibrium model to characterize the passenger upgrading and vehicle dispatching in a road network. It is assumed to be a central control platform, which leverages the decision variables of upgrading proportion and the amount of dispatching vacant vehicles on each arc to achieve higher revenue or more served passengers. Without losing generality, we consider the road network with two locations (nodes) and four routes (arcs) in the abstract to in turn derive theoretical decision outcomes. Finally, we verify the effectiveness of the model via numerical examples. In summary, the contributions of this work are as follows:

- As far as we know, it is the first time that the equilibrium model combines the economic concept, upgrading, with the vacant vehicle dispatching of ride-sourcing service in a road network. It will offer support to the platform in determining the appropriate strategy to alleviate the demand-supply imbalance issue;
- The theoretical results are derived and proved in the simplified two-nodes road network, which provide a better understanding of the benefit of upgrading or dispatching decision under different scenarios;
- The effect of these two strategies are investigated theoretically and numerically by comparing with the regimes with or without these strategies.

2. METHODOLOGIES

In the network $G(V,E)$, there are $|V|=m$ zones, where each zone $i,j\in V$. Demand rate from i to j of passengers chosen high-class service and low-class service are respectively denoted by $\overline{Q_{ij}^h}$ and $\overline{Q_{ij}^l}$. The travel time from zone i to j is given by h_{ij}. There are total N^h of high-class vehicles and N^l low-class vehicles operating in the network.

Due to the inevitable cost of the empty cruising, it is reasonable to assume that many vacant vehicles prefer to stay at the same zone waiting for orders instead of cruising to other zones on their own initiative. Therefore, the dispatching of vacant vehicle only happens when the central control platform bears the empty dispatching cost of fully compliant vehicles. In light of the goal of improving the platform revenue and the users' experience (i.e. get matched easily), we assume that the low-class vehicles are able to be dispatched, whereas the high-class vehicles are not. Under the assumptions mentioned above, we introduce two kinds of decision variables, the upgrading proportion $\rho\in[0,1]$ and the dispatching amount of each arc n_{ij} according to our research topic. The former one determines the total volume of high-class vehicles that are assigned to serve low-class passengers; while the later ones define the exact number of vacant low-class vehicles dispatched from one zone to another and serve the low-class passengers there. It is worth noting that in our study, the passenger distribution is not balanced and the low-class passengers are far more than the high-class ones. These environment settings are realistic and thus evoke the issue of upgrading or dispatching for alleviating the imbalance among classes of service as well as demand and supply. Besides, we consider the extreme case that the passengers are so impatient that they will leave the platform immediately if they are pended after generation. Namely, there is no passengers waiting time and the platform can improve the users' experience by augmenting the number of satisfied passengers. Therefore, the served demand rate are within the potential demand rate range and equals to the occupied vehicle movement, i.e. $\overline{Q_{ij}} \geq Q_{ij} = T_{ij}^{o}$, applicable to both high-class and low-class passenger, and we replace all Q_{ij} by T_{ij}^{o} in the following formulae. It is of particular importance to note that for low-class, the equation should take the upgrading vehicles into consideration, i.e. $Q_{ij}^{l} = T_{ij}^{lo} + T_{ij}^{uo}$

Firstly, according to Little's Law, the total number of vehicles in a stationary system is equal to the long-term average effective vehicle arrival rate or movement T multiplied by the average waiting time w or travel time h that a vehicle spend in the system.

$$\sum_{i \in V}\left(T_{i}^{hv} w_{i}^{h} + \sum_{j \in V} T_{ij}^{ho} h_{ij}\right) = (1-\rho) N^{h}$$

$$\sum_{i \in V}\left(T_{i}^{lv} w_{i}^{l} + \sum_{j \in V} T_{ij}^{lo} h_{ij} + \sum_{j \in V} n_{ij} h_{ij} + T_{i}^{uv} w_{i}^{l} + \sum_{j \in V} T_{ij}^{uo} h_{ij}\right) = N^{l} + \rho N^{h}$$

where T_{i}^{hv}, T_{i}^{lv} and T_{i}^{uv} refer to the vacant vehicle movement of high-class, low-class and upgrading at zone i, respectively, while T_{ij}^{ho}, T_{ij}^{lo} and T_{ij}^{uo} denote the occupied vehicle movement of the three types from zone i to zone j, respectively. While the average waiting time or pickup time of high-class and low-class vehicles at zone i are denoted by w_{i}^{h} and w_{i}^{l}, respectively.

Additionally, the network flow balance indicates that for both the two classes, the inflow and outflow should be consistent at each node.

$$\sum_{j \in V} T_{ji}^{ho} = \sum_{j \in V} T_{ij}^{ho}, \quad \forall i \in V$$

$$\sum_{j \in V} (T_{ji}^{lo} + T_{ji}^{uo}) + \sum_{j \in V} n_{ji} = \sum_{j \in V} (T_{ij}^{lo} + T_{ij}^{uo}) + \sum_{j \in V} n_{ij}, \quad \forall i \in V$$

To guarantee the feasibility of dispatching vehicles, we also define that $0 \leq \sum_{j \in V} n_{ij} \leq \sum_{j \in V} (T_{ji}^{lo} + T_{ji}^{uo})$.

As investigated in previous work (Yang et al., 2010; Afeche et al., 2018), at stationary equilibrium status, the number of occupied vehicles to complete services at the riders destination zone must be identical to the number of vacant vehicles available from that destination for a given hour, which can be expressed as $T_{i}^{hv} = \sum_{j} T_{ji}^{ho}$, $\forall i \in V$ for high-class, and the same as low-class and upgrading vehicles.

With the aforementioned equilibrium as constraints, we complete the model by introducing the objective of revenue maximization, which is able to reflect the platform's intention of matching as much customer as possible to avoid customer churn, while reducing the cost of upgrading c_u or dispatching c_d.

$$\pi(p,n) = \sum_{i}\sum_{j} \gamma(\tau_h Q_{ij}^{h} + \tau_l Q_{ij}^{l}) h_{ij} - \sum_{i}\sum_{j} c_d n_{ij} h_{ij} - \sum_{i}\sum_{j} c_u T_{ij}^{uo} h_{ij}$$

3. CONCLUSION

The above section demonstrates one of our scenarios that the vehicle number of high- and low-class are all within the certain range. The rest of our work will focus on completing the theoretical decision set corresponding to the various scenarios (i.e. the optimal decision varies in response to different ranges and combinations of high- and low-class vehicle number.). Moreover, numerical studies will be conducted to illustrate the theoretical analysis and also to produce further insights and policy implications. In particular, the system performance with upgrading will be compared to that of market without the upgrading to quantify the effect of the proposed strategy and the potential efficiency gains.

4. REFERENCES

Afeche, P., Liu, Z. and Maglaras, C., 2018. Ride-hailing networks with strategic drivers: The impact of platform control capabilities on performance. Columbia Business School Research Paper, (18-19), pp.18-19.

Yang, H., Leung, C.W., Wong, S.C. and Bell, M.G., 2010. Equilibria of bilateral taxi–customer searching and meeting on networks. Transportation Research Part B: Methodological, 44(8-9), pp.1067-1083.