Equity of a batch-matching on horizon policy for Autonomous Mobility on Demand

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1 Motivation and objectives

While shared mobility solutions are booming, the next generation of e-ride-hailing systems is announced based on self-driving vehicles. Autonomous Mobility on Demand (AMoD) could enhance the level of service thanks to lower repositioning costs and centralized control of compliant vehicles. Private operators, such as Uber, are most likely to be the first to be equipped with large fleets of autonomous vehicles (AVs) able to satisfy urban demand. Their objective relates to profit maximization. It is not necessarily consistent with the objective of public authorities, oriented to social welfare maximization. There is a risk for AMoD operators to focus on the most profitable areas at the expense of equity [1]. AMoD operational policy rules the fleet's behavior and, consequently, the level of service provided city's different zones. A traditional dispatching policy, adopted by Uber and others [3, 2], is batch-matching. Usually, the matching is performed between vehicles and the batch of requests received during the last few minutes. Here, we apply batch-matching on a horizon where demand is known. Our work tackles three questions. First, can a profit-oriented AMoD operator manage the fleet efficiently with a batch-matching on horizon approach? Second, what is the impact of the horizon length and batch-matching rules on system equity? Finally, can we achieve public authorities' equity objective through a pricing scheme addressed to AVs?

2 Methodology

We implemented a batch-matching on horizon algorithm within an agent-based simulation platform. In this platform, traveler agents select a mode and route in a multimodal transportation network to minimize their individual travel costs. Requests addressed to AMoD, characterized by an origin, a destination, and a time window on pick-up, directly come from these choices. The latest pick-up time for a request is assumed to be proportional to the difference between the travel cost on the best route without using AMoD and the travel cost on the best route using AMoD. The more willing a traveler is to wait to be picked up, the more AV-dependent she is.

AMoD agent makes dispatching choices by resolving a binary ILP problem each αH minutes to maximize the sum of utilities $u_{v,r}$ for a match between an AV v and a request r (H is the horizon length and $\alpha \in [0, 1]$). Two definitions of utility are introduced. The *impatient* utility corresponds to the expected profit for v to serve r reduced by a penalty for an early arrival of v at r's pick-up location. The *productivist* utility corresponds to the expected profit for v to serve r divided by the time required to achieve the mission. A vehicle can be matched to at most one request per call of the ILP. The new request is added at the end of the AV service plan. Two matching modes are introduced. In the *permanent* mode, all matches identified in the solution of ILP are permanent. In the *temporary* mode, only requests with an earliest pick-up time within $[t, t + \alpha H]$ are permanently matched. The other requests can be pre-matched with idle AVs only. A pre-match lead to the initiation of repositioning movements. A repositioning AV can be matched with another request at the next call of ILP. Utility definitions and matching modes form four variants of the batch-matching on horizon policy. The ILP problem has been solved with CPLEX 20.1.0.

The regulator agent can define a tax or a subsidy in each city zone. It aims at maximizing the system equity in terms of matches.

We performed a sensitivity analysis of batch-matching variant, horizon length, and fleet size on total profit, order response rate (ORR) per zone, and system equity in a theoretical city network. Equity is evaluated by: (i) the Gini coefficient of ORRs per zone, (ii) the concentration index of the cumulated share of requests being matched over the cumulated share of customers from the less to the most AV-dependent.

We designed two naive pricing schemes. PSC1 provides subsidies in AV-dependent zones and taxes in non-AV-dependent zones. The price value is proportional to zone's AV-dependency score and zone's distance from the city centre. PSC2 provides the same subsidies as PSC1 without taxes.

3 Results

We could highlight the range of H where batch-matching on horizon is relevant. On [0min,25min], extending the horizon leads to a higher profit for AMoD, a higher ORR for customers, and lower inequalities in terms of ORRs per zones. The level of spatial inequalities depends on the policy variant. Under *impatient* utility, AVs tend to look more actively for customers and have a higher total empty distance leading to lower inequalities in our theoretical centralized city. Under *producticist* utility, AVs tend to passively wait for customers in the central zones, leading to higher inequalities. The batch-matching on horizon policy performs better than an event-based *nearest-vehicle/nearest-open-request* dispatching heuristic in terms of profit but worse in equity.

By applying PSC2, equality was reached regarding matches related to AV dependency. PSC1 brings equity with the 40% requesters the more AV-dependent getting 50% of the matches.

4 Perspectives

Several steps are identified to pursue this work. First, the case can be formulated as a bi-level optimization problem where prices optimization stands on the upper level and AMoD dispatching policy stands on the lower level. Results could be compared to the ones obtained with a public AMoD operator having a multi-objective dispatching policy, including efficiency and equity. Finally, we plan to apply the study to a real city.

References

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