第Ⅳ部門 Marginal increasing pricing to minimize negative travel behavioral impacts of autonomous vehicles

Kyoto University Student Member 〇Youxi Lai
Kyoto University Member Jan-Dirk Schmöcker
Kyoto University Member Tadashi Yamada

Introduction:

Wide adoption of autonomous vehicles (AVs) are expected in the near future due to the rapid development of this technology and its attractive features. Among various impacts, this study will consider travel behavioral changes that AVs are likely to bring especially resulting from reduced value of time (VOT) when car users do not need to focus on the driving task anymore. As also other literature has suggested, adoption of AVs might hence cause negative impacts on the traffic network including increase of traffic and sprawling activity by AV drivers. Therefore, to control these impacts, this study explores marginal increasing pricing per distance travelled which is thought to be fair and effective given the tendency to travel longer with reduced VOT.

Methodology:

This research models the changes of traffic before and after AVs adoption with and without marginal increasing pricing based on user equilibrium assignment. Following previous research, a VOT decrease of 25% and an increase in trip generation by 5% are thought reasonable. The study is formulated as bi-level framework. In the upper level, the aim is to find the optimal pricing which separately minimizes total costs (1), total system time (2) or accessibility (3) subjected to user equilibrium condition. The pricing structure has three stages of price (F_s) per kilometer and two threshold distances (Z_b), denoted as $[F_1, F_2, F_3]_{Z_1,Z_2}$, where $0 \leq F_1 < F_2 < F_3$, $0 \leq Z_1 < Z_2$. In the lower level, user equilibrium conditions for simultaneous destination and route choice is obtained by the method of successive. In the route choice step, marginal increasing pricing is introduced within the Dijkstra algorithm. Trip distribution (4) is obtained by applying the gravity model (5) which reflects the influence of travel cost on demands, and demand elasticity is also introduced to make the trip distribution more realistic, as well as to investigate how optimal pricing changes depending on it.

Results:

The Sioux Falls network is used as a case study for this model. Before applying marginal increasing pricing, feasibility of this model has been checked by comparing estimated and observed traffic flows; constant price per distance has also been checked and found to be ineffective to optimize the network. Under fully elastic demand ($\varepsilon = 1$), the results of optimal marginal pricing show that activities of AV travelers will be restricted by a high price to be within a short distance of about 8 km when optimizing total costs and total system time, while the pricing which optimizes accessibility does not show such a strict restriction. Optimization of total costs and total system time somehow causes degradation of accessibility. Optimal pricing and corresponding values of objectives are also investigated under lower demand elasticities. Marginal increasing pricing is not effective to minimize total costs when demand elasticity is below 0.5; when demand elasticity is around 0.6~0.8, the optimal pricings which minimizes total costs become simply two-stage and price is reasonable; when

---

Youxi LAI, Jan-Dirk SCHMÖCKER, Tadashi YAMADA
ylai@trans.kuciv.kyoto-u.ac.jp

demand elasticity is close to 1, F_2 increases drastically. When minimizing total system time, optimal pricing are still extreme and restricting activities of AV travelers to be within a short distance at any demand elasticity. When optimizing accessibility, a two stage pricing (i.e. $[F_1, F_2]_{Z_1}$) is sufficient and the price is low when demand elasticity is below 0.75. For all three objectives the objective function improves as demand elasticity increases.

Conclusions and Implications:

Marginal increasing pricing on AVs is effective to restrict activities of AV travelers to be within short distance and can hence support compact city developments. Type of pricing and degree of optimization depend on demand elasticity of the network. This study might give rough idea about how much these objectives should be traded-off against each other. This model is helpful for city planners to develop a city with AVs and manage the use of AVs by pricing, and it will be applicable for real networks with further studies such as investigating impacts of changes in the demand distribution and size of network, additional real case studies, as well as proper upper bound for pricing.

Key references:

[1] T. Litman (2018) "Autonomous Vehicle Implementation Predictions, Implications for Transport Planning," Available from < https://www.vtpi.org/avip.pdf>

[2] L. T.Truong, C. D. Gruyter, G. Currie and A. Delbosc (2017) "Estimating the Trip Generation Impacts of Autonomous Vehicles on Car Travel in Victoria, Australia," Transportation, 44(6), 1279-1292.

[3] A. Soteropoulos, M. Berger and F. Ciari (2019) "Impacts of automated vehicles on travel behavior and land use: an international review of modelling studies," Transport Reviews 39, 29-49.

Appendix:

Key formulations are listed as follows.

Total costs
$$\sum_i \sum_j \sum_{m \in R_{ij}} \frac{c_{ij}^m T_{ij}^m}{\|R_{ij}\|} \tag{1}$$

Total system time
$$\sum_a t_a x_a \tag{2}$$

Accessibility
$$\sum_{ij} t_{ij}^+ \tag{3}$$

Trip distribution
$$T_{ij} = (1-\varepsilon)T_{ij}^b + \varepsilon T_{ij}^g \tag{4}$$

Gravity model
$$T_{ij}^g = \frac{P_i A_j}{W_{ij}^c} \tag{5}$$

c_{ij}^m	: Travel cost from *i* to *j* on path *m*	T_{ij}^g	: Trip distribution obtained from gravity model
$T_{ij}(T_{ij}^m)$	: Trip from *i* to *j* (on path *m*)	P_i	: Trip production
R_{ij}	: Path set used for OD pairs	A_j	: Trip attraction
$\|R_{ij}\|$	: Number of paths for this OD pair (*i,j*)	W_{ij}	: Impedance
t_a, x_a	: Travel time, link flow on link *a*	c	: Weight of impedance in gravity model
x_a	: Flow on link *a*	T_{ij}^b	: Trip distribution in base case
t_{ij}^+	: Travel time from *i* to *j* after AV adoption	ε	: Demand elasticity