Temporal capacity allocation and tolling schemes for morning commute with carpooling

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1. Introduction

This study investigates temporal road capacity allocation and toll schemes for carpooling vehicles in the morning commute. Specifically, during a designed period, we assign road capacity to the designed classes of vehicles, where the road bottleneck capacity can be exclusively used by carpooling vehicles and other vehicles can only pass the bottleneck outside the designed period. We then introduce tolling schemes to further manage the carpooling behaviours and improve system traffic efficiency. We also analytically examine the efficiency of the proposed temporal road capacity allocation and toll schemes and provide efficiency bounds.

Different from many studies focusing on two-person carpooling or average ridesharing ratio (Ma and Zhang, 2017), this study explicitly models and analyses the cases with two-person carpooling, three-person carpooling, four-person carpooling, and m-person carpooling similar to the shuttle bus. With more carpoolers in one vehicle, the number of vehicles on road is reduced, while the inconvenience incurred by carpoolers increases. We model this trade-off and explore how to optimize it. It is noteworthy that under the proposed temporal road capacity allocation schemes, braking or tactical waiting behaviours may arise (Lindsey et al., 2012; Xiao et al., 2012). This is due to the cost discontinuity in the inconvenience costs between vehicles with different numbers of carpoolers.

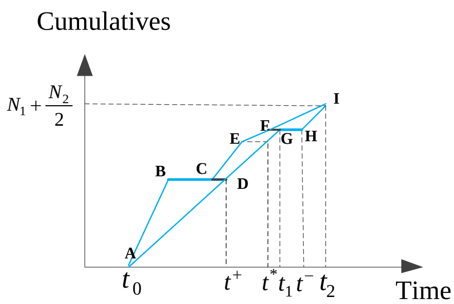
2. Methodology

2.1 Equilibrium under the temporal capacity allocation scheme

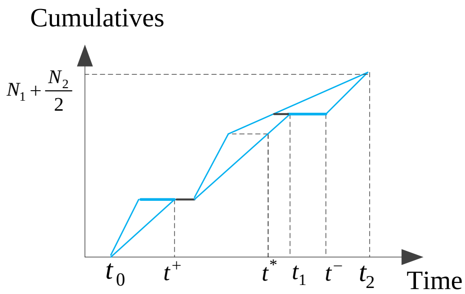
There is a road with bottleneck linking the home and workplace, and the commuters need to pass the bottleneck and make a trade-off between the travel time cost related to queue length and schedule delay cost. When carpooling is considered, commuters also need to consider the inconvenience incurred. The bottleneck model has been utilized to generate analytical insights for commuting problems (Arnott et al., 1990). N is the total number of commuters and s is the fixed bottleneck capacity. t^* is the work starting time. $\alpha, \beta\ and\ \gamma$ represent the value of unit travel time, and schedule penalties for unit time of early arrival and late arrival, respectively.

Within an allocated time period $[t^+, t^-]$ (we consider t^+ is before t^* while t^- is after t^*) only two-person carpooling vehicles can be allowed to pass the bottleneck, while before t^+ and after t^-, solo-driving vehicles may pass the bottleneck. This capacity allocation scheme is abbreviated as 1-2-1 according to the order of travel period for different travel modes, where 1 and 2 represent the solo-driving and two-person carpooling, respectively. Therefore, the allocation scheme divides the peak period $[t_0, t_2]$ into three time periods, i.e., $[t_0, t^+]$, $[t^+, t^-]$ and $[t^-,\ t_2]$.

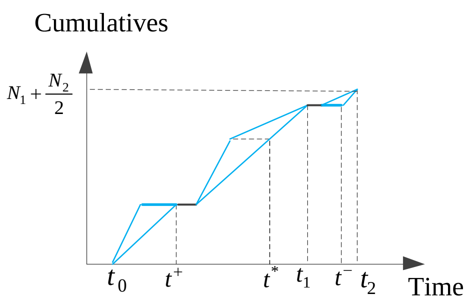
We first discuss the departure/arrival equilibrium profiles under the temporal capacity allocation scheme only considering two-person carpooling and solo-driving as in Fig. 1. There are four possible patterns, which depend on how we set $[t^+, t^-]$. In the two-dimensional domain of (t^+, t^-), we display the occurrence of the four patterns in Fig. 2(a) shows. It can be shown that at the point O in Fig. 2, the total system cost TC is minimized, where the departure/arrival equilibrium profile is depicted in Fig. 2(b). It is noteworthy that when comparing to the bottleneck model with solo-driving vehicles only, the peak period with carpooling is reduced as carpooling decreases the total number of vehicles while the total number of commuters is fixed. However, the carpooling will bring about inconvenience cost.



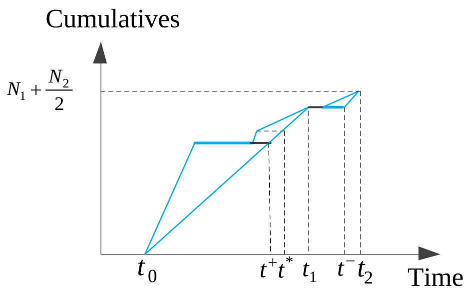
(a) Profile 1: with queue at both t^+, t^-



(b) Profile 2: with capacity waste at t^+, with queue at t^-

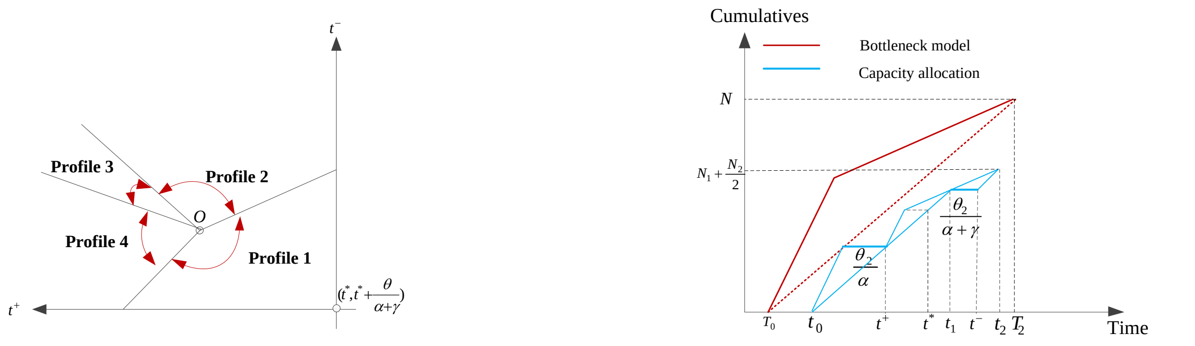


(c) Profile 3: with capacity waste at both t^+, t^-



(d) Profile 4: with queue at t^+, with capacity waste at t^-

Fig. 1. Different departure/arrival profiles under capacity allocation schemes



(a) Traffic profiles in (t^+, t^-) space **(b) Optimal user equilibrium Profile at time *O***

Fig. 2. Optimal departure/arrival profile

2.2 Capacity allocation and tolling schemes for multi-person carpooling

This study also extends the capacity allocation scheme for two-person carpooling to multi-person carpooling. In particular, we examined the cases with three-person carpooling, four-person carpooling, and m-person carpooling, where capacity is allocated to m-person carpooling vehicles, four-person carpooling vehicles, three-person carpooling vehicles, two-person carpooling vehicles and solo-driving vehicles differently.

Furthermore, this study also investigates the coarse tolling strategy combined with the capacity allocation scheme. Specifically, the different coarse tolls are imposed on the commuters during the allocated time periods, which could optimize the numbers distribution for commuters choosing different travel modes to achieve the second-optimal TSC. And the system performance efficiency is also measured.

3. Results

We examine the departure/arrival equilibrium profiles with two-person carpooling, three-person carpooling, 4-person carpooling, and multi-person carpooling. We evaluate a number of efficiency metrics including the total system cost and bound the cost reduction of the proposed capacity allocation and tolling schemes. The detailed results will be provided in the full paper.

4. Conclusion

This study proposes the temporal capacity allocation and tolling scheme for multi-person carpooling. We have explicitly considered two-person, three-person, four-person, and m-person carpooling rather than an average carpooling ratio or two-person ridesharing only. Future studies may further examine heterogenous commuters.

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