On the utilisation of dedicated bus lanes for pooled ride-hailing services

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SHORT SUMMARY

The available capacity in transportation networks is distributed among multiple modes, with some benefiting from an exclusive usage while others competing over the same space. Because the average occupancy of buses is the highest, they are usually allocated dedicated lanes where the speed is larger than in the rest of the network. Private vehicles and ride-hailing drivers use the remaining portion of space which is highly subject to congestion. In this study, we propose to mitigate traffic congestion in the main network by allowing only pooled ride-hailing drivers to use the underutilized capacity in bus lanes. By modeling the accumulation in the system under steady-state using a Macroscopic Fundamental Diagram theory, we show that the optimal strategy that minimizes delays for multi-modal users occurs when a fraction of the pooling vehicles uses the bus network. An adequate pricing discount for pooled trips drives the network towards this system optimum.

Keywords: Multi-modal networks, network delays, public transportation, regulations, ride-splitting services, space allocation.

1. INTRODUCTION

Ride-hailing platforms provide a fast and reliable door-to-door service by picking up passengers from their origins and dropping them off at their desired destinations. Ride-splitting services are fundamentally similar with the exception that two or more passengers are allowed inside the vehicle. This reduces the size of the fleet necessary to satisfy the ride-hailing demand but compels passengers to undertake larger travel distances. Because network spatial availability is becoming more of a concern recently, many regulations are being put forward to target the operation of ride-hailing platforms and to restrict their impacts on traffic congestion. Off-street parking spaces for instance can be efficiently utilized by idling ride-hailing drivers to prevent on-street cruising (Li et al., 2020). Encouraging ride-hailing users to share their rides is one of the possible solutions adopted to address the issue of limited network capacity. Shaheen and Cohen (2019) and Tirachini and Gómez-Lobo (2019) both provide a review of available work on pooling in the context of e-hailing and car-sharing and validate the potential of trip sharing in mitigating congestion and reducing Vehicle Kilometers Traveled (VKT). Ke et al. (2020) used a linear speed-density relationship to compute the maximum achievable ride-hailing and ride-splitting service rates and showed that under specific conditions, pooling decreases the travel time for all network commuters. However, when the origin and destination locations of pooled passengers are not identical, trip sharing comes at the expense of an additional detour. This detour is however lessened as more and more passengers engage in pooling (Ke et al., 2021). This, along with the discount factor that passengers receive for pooling, are the main determinants for the willingness to share (Alonso Gonzalez et al., 2020; Lo & Morseman, 2018).

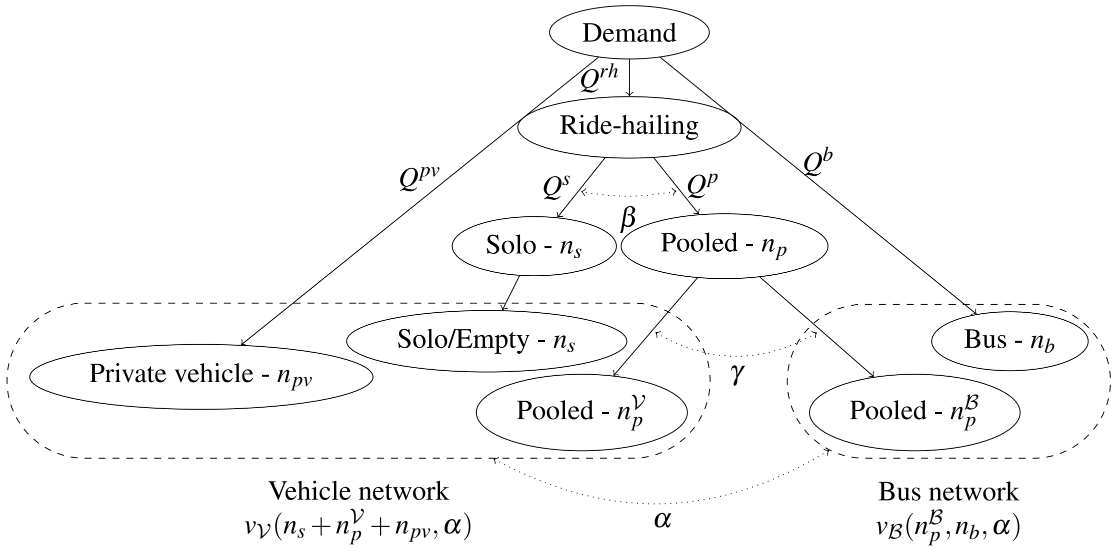


Figure 1: Summary graph of the space allocation strategy and the demand spit over the available network capacity

To improve network conditions by guaranteeing a high pooling engagement level, network regulators have the option to redistribute the existing space over different available modes by granting permission for pooled ride-hailing vehicles to travel on dedicated bus lanes to perform a faster yet longer trip. No solo trips are however allowed in the bus lanes. This serves as an incentive to motivate users to share their rides with other users of the system. The ultimate goal is to mitigate the effect that ride-hailing vehicles have on congestion while guaranteeing that the total delay for all other modes is minimized. The objective of this study is to hence put forward a comprehensive framework for modeling and assessing delays for multi-modal networks under the proposed policy. Once the characteristics of this system optimum are identified, we elaborate on one possible pricing scheme that drives the system towards its minimum point.

2. METHODOLOGY

The following section elaborates on the model that enables us to examine the redistribution of ride-splitting demand in urban space in the existence of other modes of transport. In the network under consideration, travelers perform their trips by one of the set $\mathcal{M}$ of available options: private vehicles pv, buses b, or ride-hailing services rh, such that $\mathcal{M} = \{pv, b, rh\}$. Commuters who opt for ride-hailing have the choice to either travel solo or to pool their trips with other users of the service. We refer to the latter two trips as s and p respectively. Concerning the spatial distribution in the network, buses exclusively utilize dedicated bus lanes to transport passengers, and the remaining fraction of the network that we denote by $\alpha \in [0,1]$ is allocated to private vehicles and the fleet of ride-hailing drivers. When $\alpha = 0$, the full network space is devoted to buses whereas when $\alpha = 1$, the network becomes an exclusive vehicle network. In the event where drivers are matched to a pooled trip, a fraction of the pooled trips is allowed to perform the whole ride in the bus network. Elsewise, all idle, dispatched, and solo-ride drivers travel in the vehicle network in conjunction with private vehicles. For the rest of this study, we will refer to the vehicle network as $\mathcal{V}$, and to the bus network as $\mathcal{B}$.

Let Q^m be the exogenous travel demand for mode $m \in \mathcal{M}$ expressed in passengers per hour, their values remaining unchanged in this study. The split of ride-hailing demand between solo and pool however is assumed to be variable. Therefore, we let $\beta \in [0,1]$ denote the fraction of Q^{rh} that selects a solo trip. In particular, we investigate the optimal value of β that minimizes the total delay for all network commuters. Mainly, when ride-hailing users choose to pool such that

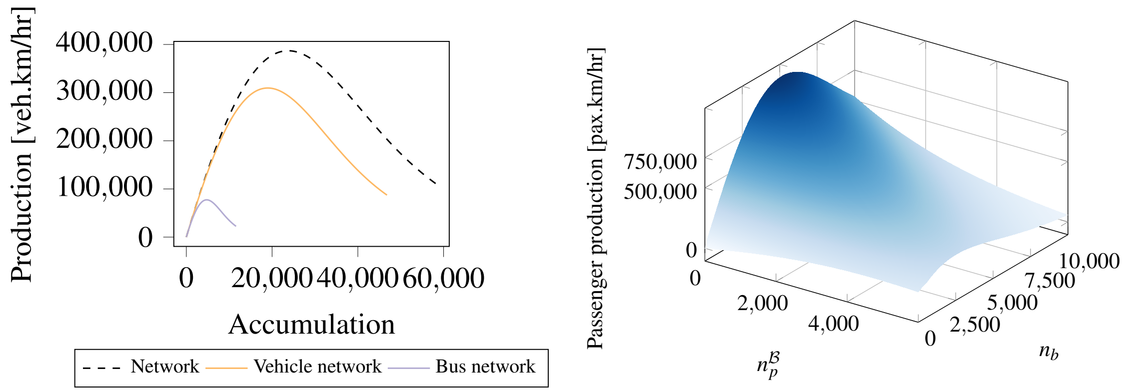
$Q^p = (1-\beta)Q^{rh}$ is the demand for pooling, this portion of the demand interferes with the bus speed causing it to decrease. To avert any disturbance to public transportation, we introduce a parameter $\gamma \in [0,1]$ corresponding to the fractional bound of pooling drivers that are allowed to use the bus lanes. If instead ride-hailing users choose to travel solo such that $Q^s = \beta Q^{rh}$ is the demand for solo trips, they affect the speed in the vehicle network. Another element that has a significant influence on the speed in the bus and vehicle networks is the factor α dictating the size of each one. The larger the value of α, the higher the capacity of the vehicle network, and the lower that of the bus network. Within this context, we additionally investigate in this study how the optimal demand split between solo and pool trips varies with α. The ultimate purpose is to assess how the three variables α, β, and γ affect the quality of the mobility in a network. Figure 1 provides a summary of the previous information including the different modes of transport and the variables defining our model.

To evaluate network delays, a proper estimation of the speeds in the vehicle and bus networks, that we denote by $v_{\mathcal{V}}$ and $v_{\mathcal{B}}$ respectively, is required. According to the model in Figure 1, $v_{\mathcal{V}}$ is function of the accumulation of private vehicles n_{pv}, empty/solo-trip e-hailing vehicles n_s, and the fraction of pooled drivers utilizing the vehicle network $n_p^{\mathcal{V}}$. The accumulation in the bus network is composed of the remaining pooled drivers that we denote by $n_p^{\mathcal{B}}$ and the bus fleet n_b. We point out here that because buses have to repeatedly dwell at bus stops, their influence on speed is not equivalent to that of the pooled vehicles. Moreover, as we previously described, both speed functions are dependent on the fraction α which dictates the space division between the two networks. For us to examine the values of travel times for each individual mode, we resort first to aggregate traffic flow models to define the relationship between speed and accumulation.

Traffic dynamics

In the model we presented, the space-mean speed is a crucial element to evaluate the average trip time for all mode users. Let n be the total accumulation in a network, and $v = v(n)$ its speed. We know that as the accumulation n increases, the network becomes more and more congested and hence the speed in the network decreases with $\partial v/\partial n \leq 0$. Under steady-state conditions, if Q is the total effective trip demand and $\bar{l}$ is the average trip length, then the vehicle production P expressed in vehicle kilometers per unit time is defined by $P(n) = nv(n)$. Hence, when the system is at steady-state, it must hold that $P(n) = Q\bar{l}$.

Under the proposed space allocation strategy, the network infrastructure is segmented into two distinct subnetworks, each having its own production Macroscopic Fundamental Diagram (MFD). Let $n_{\mathcal{V}} = n_s + n_p^{\mathcal{V}} + n_{pv}$ be the total vehicle accumulation in the vehicle network covering a fraction α of the total available space. Having a well-defined production MFD function for the full network makes it possible to derive that of the vehicle network using the spatial fractional split factor α. This corresponds to a rescaling of the full network MFD such that if $P_{\mathcal{V}}$ is the production function for the vehicle network only, then $\alpha P(n) = P_{\mathcal{V}}(\alpha n)$. Similarly, the production in the bus network is related to the full network production by knowing that $(1-\alpha)P(n) = P_{\mathcal{B}}((1-\alpha)n)$. Figure 2(a) shows an example of the production functions used for a value of $\alpha = 0.8$. In contrast however to the vehicle network, simply adding up n_b and $n_p^{\mathcal{B}}$ does not yield a reliable estimation of the vehicle running speed from the production function. This is because an adjustment is required to account for the frequent stops of buses at stations and the resulting hindering of vehicle movements. This effect is observed when translating the bus network MFD to the three-dimensional space where the accumulation of buses and vehicles are dissociated (Geroliminis et al., 2014; Loder et al., 2017; Fu et al., 2020). In this case, looking at the passenger flow instead of the vehicle one is more substantiated because buses have a larger average occupancy compared to pooled vehicles. Figure 2(b) displays an example of the 3D passenger MFD (3D-pMFD) that we use in this work to compute bus passenger delays among others if pooled vehicles traveled on the bus lanes.



(a) Production MFD

(b) Bus network 3D-pMFD

Figure 2: Vehicle production and passenger production MFDs from which speed is derived

Network accumulation

Once all these relationships are established, it becomes possible to convert all demand values into vehicle accumulation under steady-state conditions. For the ride-hailing operator, this is crucial to estimate the fleet size required to satisfy the demand level. Assuming that $\beta = 1$, i.e., no pooling occurs, the fleet size N required to serve the totality of the ride-hailing demand Q^{rh} consists of (i) idling vehicles, (ii) dispatched vehicles on their way to pick up a passenger, and (iii) occupied vehicles, i.e.,

$$N = I + Q^{rh}\frac{d(I)}{v_{\mathcal{V}}} + Q^{rh}\frac{\bar{l}}{v_{\mathcal{V}}}. \tag{1}$$

In Equation (1), I is the number of idle vehicles, d is the dispatched distance from a request's origin location to the nearest idle vehicles. It is itself dependent on the density of unoccupied vehicles such that $\partial d/\partial I < 0$ because the higher this density, the greater the chance of matching the passenger to a neighboring empty vehicle.

In the event of pooling, we accommodate the possibility of sharing a trip with one other ride-hailing user by diving the number of dispatched and occupied vehicles by two. Nevertheless, a pooled trip requires drivers to travel an additional distance Δl_d to perform a supplementary pick-up and drop-off operation. Ideally, the highest pooling benefit is achieved when this distance that we refer to as the driver detour goes to zero, i.e., when two passengers share the same origin and destination. The probability that this occurs is higher when Q^p is large. When the engagement level in pooling is low however, the detour is arbitrary large that the trip becomes unattractive to passengers. In this study, we assume that this function monotonically decreases with Q^p such that $\partial \Delta l_d/\partial Q^p < 0$. Given that the users of the vehicle network consist of solo/empty ride-hailing drivers, a fraction of pooled drivers, and private vehicles, its accumulation $n_{\mathcal{V}}$ is given by

$$n_{\mathcal{V}} = d^{-1}(\tau v_{\mathcal{V}}) + Q^s\tau + \frac{1}{2}Q^p\tau + Q^s\frac{\bar{l}}{v_{\mathcal{V}}} + \frac{1}{2}(1-\gamma)Q^p\left(\frac{\bar{l}+\Delta l_d(Q^p)}{v_{\mathcal{V}}}\right) + Q^{pv}\frac{\bar{l}}{v_{\mathcal{V}}}, \tag{2}$$

where τ is the expected waiting time that the operator aims to achieve. The first term in Equation (2) determines the number of idle vehicles so that the target service level is reached. The second and third terms compute the number of dispatched vehicles for both solo and pooled trips assuming that dispatching occurs in the vehicle network for all types of trip assignments. The fourth and sixth terms return the number of drivers performing a solo trip and the number of private vehicles respectively, each with an identical average trip length $\bar{l}$. Finally, the fifth term is the number of drivers completing a pooled trip in the vehicle network $n_p^{\mathcal{V}}$. In the same manner, the quantity $n_p^{\mathcal{B}}$ for those pooled trips using the bus network is given by

$$n_p^{\mathcal{B}} = \frac{1}{2}\gamma Q^p \left(\frac{\bar{l} + \Delta l_d(Q^p)}{v_{\mathcal{B}}}\right). \quad (3)$$

This category of drivers however travel with a speed of $v_{\mathcal{B}}$ instead of $v_{\mathcal{V}}$.

Similarly, we can compute the number of buses required to serve the total bus demand Q^b while maintaining an average bus occupancy of o_b through

$$n_b = \frac{Q^b \bar{l}_b}{o_b v_b}. \quad (4)$$

In the expression above, $\bar{l}_b$ is the average trip length for bus passengers and it is generally greater than $\bar{l}$. Moreover, v_b is the speed of the buses. Since buses make repetitive stops at stations to board and alight passengers, the running speed in the bus network $v_{\mathcal{B}}$ is reduced by a factor less than or equal to one which depends on the average spacing between stops $\bar{s}$ and dwell time t_d such that

$$v_b = \left(\frac{1}{1 + v_{\mathcal{B}}\frac{t_d}{\bar{s}}}\right) v_{\mathcal{B}}. \quad (5)$$

Both the variables β and γ that we investigate in this study influence the network accumulation and the fleet size. The variable β controls the split of ride-hailing demand between Q^s and Q^p while γ dictates the spatial split of Q^p between the vehicle and bus network. Irrespective of their values however, the results that we obtain are always dependent on a strategic decision related to the network infrastructure modeled here by α. Because this parameter shapes the production functions, it alters the values of speed $v_{\mathcal{V}}$, $v_{\mathcal{B}}$ and v_b.

System optimum

Because the purpose of allowing pooled vehicles to use bus lanes is to decrease the total delays for all commuters in the network, we investigate under a fixed network spatial split α what are the values of β and γ that will minimize the Passengers Hours Traveled (PHT) for all three mode users: buses, private vehicles, and ride-hailing users. The ultimate objective is to mitigate congestion in the vehicle network while simultaneously making sure that disturbances to buses are contained within acceptable ranges. Therefore, we model our objective as the sum of the individual PHT for every category of travelers with the function being expressed as

$$\underset{\beta\in[0,1],\gamma\in[0,1]}{\text{minimize}} \quad Q^{pv}\frac{\bar{l}}{v_{\mathcal{V}}} + Q^s\frac{\bar{l}}{v_{\mathcal{V}}} + (1-\gamma)Q^p\left(\frac{\bar{l} + \Delta l_p(Q^p)}{v_{\mathcal{V}}}\right) + \gamma Q^p\left(\frac{\bar{l} + \Delta l_p(Q^p)}{v_{\mathcal{B}}}\right) + Q^b\frac{\bar{l}_b}{v_b}, \quad (6)$$

where the first, second, and last terms correspond to delays for private vehicles, solo passengers, and bus users respectively. The third term reflects the PHT for pooled passengers using the vehicle network whereas the fourth one assesses delays for pooled passengers on the bus network. Note here that we substitute the driver detour Δl_d with the passenger detour Δl_p to consider the additional distance incurred by passengers compared to a direct trip between their origins and destinations. The behavior of the passenger detour however is assumed to be comparable to that of the driver detour such that they both monotonically decrease with Q^p.

When $\gamma = 1$, the solution to minimizing delays in the network is narrowed down to finding the optimal β given that all pooled passengers use the bus network. We refer to this particular scenario as $\{pv, s\}^{\mathcal{V}}|\{p, b\}^{\mathcal{B}}$ to show that pooled vehicles p exclusively use the bus network. When $\gamma \neq 1$ and $\gamma \neq 0$, we denote this scenario by $\{pv, s, p\}^{\mathcal{V}}|\{p, b\}^{\mathcal{B}}$ where p appears in both networks. Finally, we refer to the scenario where all ride-hailing drivers utilize the vehicle network by $\{pv, s, p\}^{\mathcal{V}}|\{b\}^{\mathcal{B}}$ which indicates that network $\mathcal{B}$ is exclusively dedicated to buses. This corresponds to the scenario where the system behaves without any particular intervention from the

Table 1: Main parameters

Parameter	Symbol	Value	Unit
Demand for private vehicles	Q^{pv}	70000	pax/hr
Demand for buses	Q^{b}	20000	pax/hr
Demand for e-hailing	Q^{rh}	14000	pax/hr
Average vehicle trip length	$\bar{l}$	3.86	km
Average bus trip length	$\bar{l}_b$	5.40	km
Average spacing between bus stops	$\bar{s}$	0.8	km
Dwell time	t_d	40	sec
Platform target waiting time	τ	2	min
Mean bus occupancy	o_b	20	pax
Network area	A	107	km^2

regulator. The decision variable here consists again of solely finding the optimal demand split that minimizes total delays. The reason why the solution does not always yield a value of $\beta = 0$ is because the detour comes into question in this particular setting. Consequently, when the total ride-hailing demand is lower than the critical boundary after which pooling becomes interesting, a scenario where $Q^p = Q^{rh}$ is not necessarily the optimum.

3. RESULTS AND DISCUSSION

In the following section, we present a comprehensive analysis of the influence of β and γ on the network delays, and how these delay values change with the spatial fractional split α. We assess the system optimum from a macroscopic approach for the main three scenarios $\{pv,s\}^{\mathcal{V}}|\{p,b\}^{\mathcal{B}}$, $\{pv,s,p\}^{\mathcal{V}}|\{p,b\}^{\mathcal{B}}$, $\{pv,s,p\}^{\mathcal{V}}|\{b\}^{\mathcal{B}}$ by resorting to a numerical example. The main fixed parameters that we consider in this example are presented in Table 1. We assume that the dispatched distance d as function of the idle drivers is given by $d(I) = 0.63\sqrt{A/I}$. The production function of the entire network under consideration is

$$P(n) = \max\left(\frac{35n}{1+\exp\left((n-22000)/12683\right)} - 0.0001, 0\right), \tag{7}$$

and its shape is shown as the dashed curve in Figure 2(a). The three-dimensional vehicle MFD for the bus network is given by $\max(0.8, -0.2n_b/500+1)(n_p+n_b)v_{\mathcal{B}}$ and is used to compute the running speed in the bus network. With regard to the driver and passenger detour, they are retrieved from the results generated by a matching optimization framework using simulated data taken from Beojone and Geroliminis (2021). The results are then fitted into the following functional from where $\Delta l_d(Q^p)/\bar{l}$ or $\Delta l_p(Q^p)/\bar{l}$ is equal to $(a/Q^{pb})^c$ and $a = 3.72$, $b = 0.32$, and $c = -0.012$ for the passenger detour, and $a = 7.18$, $b = 0.147$, and $c = -1.28$ for the driver detour.

For the scenario where all ride-hailing vehicles are using the vehicle network, the results for the accumulation and PHT as a function of β for a different spatial split of the two networks are presented in Figure 3. First, the network accumulation is naturally the lowest when the full ride-hailing demand is pooling and when α takes the largest value possible while still accommodating the bus demand. This means that a sufficiently high spatial capacity is granted for private vehicles and ride-hailing vehicles, as can be seen from Figure 3(a). However, this does not entail that the minimum for PHT is achieved for the same values of α because as α increases the space available for buses shrinks causing very high delays to travelers on the bus network. This is inferred by looking at Figure 3(b) where the PHTs for different values of β start increasing after reaching the minimum. By comparing the results in Figure 4 to the scenario in Figure 5(a) where pooling

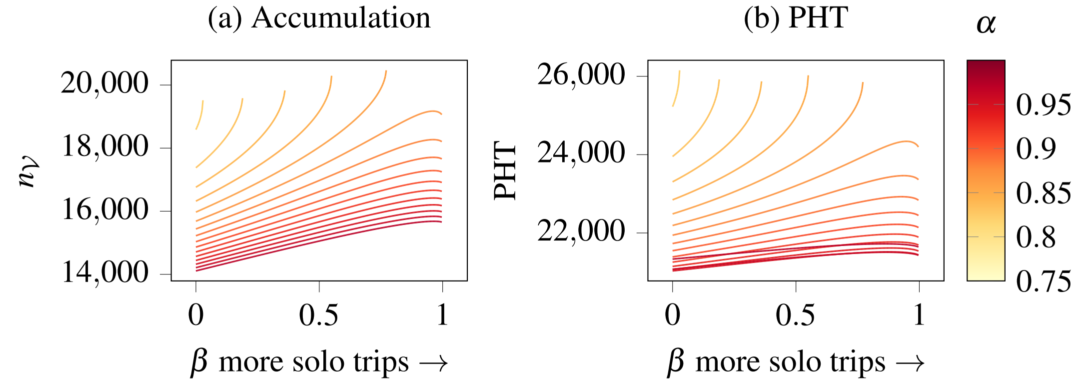


Figure 3: Accumulation and PHT for $\{\mathbf{pv}, \mathbf{s}, \mathbf{p}\}^{\mathcal{V}} | \{\mathbf{b}\}^{\mathcal{B}}$ ($\gamma = \mathbf{0}$)

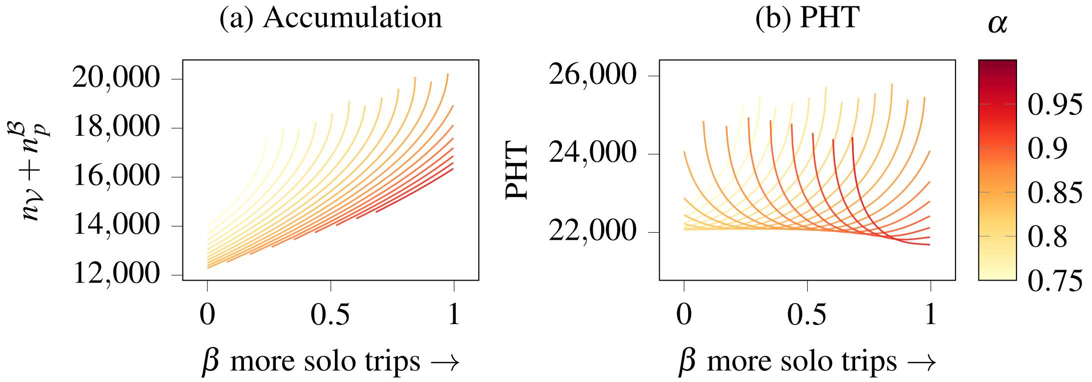


Figure 4: Accumulation and PHT for $\{\mathbf{pv}, \mathbf{s}\}^{\mathcal{V}} | \{\mathbf{p}, \mathbf{b}\}^{\mathcal{B}}$ ($\gamma = \mathbf{1}$)

vehicles exclusively utilize the bus lanes, a significant drop in the accumulation is observed. However, this comes at the expense of an increased PHT particularly for cases where α is high which implies that any addition of vehicles to the bus network severely impacts the delays for bus users as shown in Figure 5(b). What is interesting to note is that, unlike the previous case, we obtain very similar values for the system optimum independently of the value of α.

In Figure 5, we assess the system optimum for the three different strategies proposed for a predetermined network split fraction α. The objective is to evaluate whether by relaxing the constraint that all pooled vehicles must use the bus network, we are able to achieve some improvements by bounding the amount of disruption allowed for the operation of buses. Figures 5(a) and 5(b) show the results of PHT as function of the fraction of pooling vehicles allowed to use the bus lanes for $\alpha = 0.85$ and $\alpha = 0.9$. For high values of β, the value of γ that minimizes the PHTs is equal to 1 because of the low engagement levels in pooling. If all pooled vehicles hence use the bus lanes, the disturbance to buses is naturally limited but the improvements to the vehicle network are still noticeable. Nevertheless, when the number of pooled vehicles is high, the system optimum is achieved for a value of $\gamma < 1$. This is because the delay for buses becomes the factor modulating the objective in this case. The same applies for $\alpha = 0.9$ except that for this case, the best solutions are achieved for high values of β yet lower γ since the potential of exploring the underutilized capacity in the bus lanes is restrained.

Figure 6 summarizes the optimal pooling demand split for different values of α and β. For as long as the bus network capacity allows, Figure 6(a) shows that the optimal γ is equal to 1 if the demand for pooled rides is low. It starts decreasing rapidly however for high values of α indicating that the exploration of the underutilized capacity is not substantiated when the bus network consists of a relatively insignificant fraction of the full network. Moreover, when we look at the speed in both

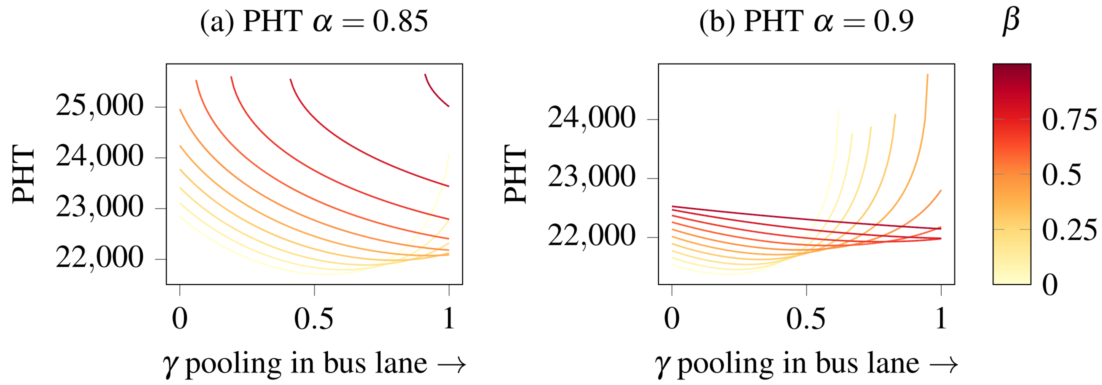


Figure 5: Comparison of best solutions for the three different scenarios

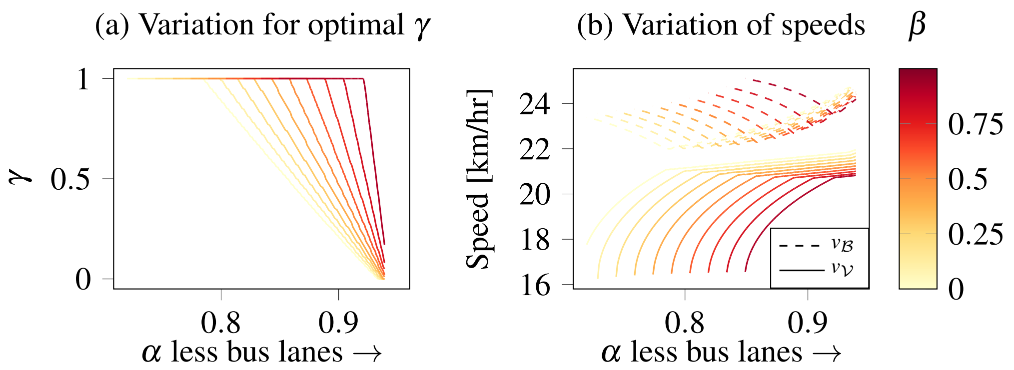


Figure 6: Variation of γ and speed with respect to α

networks for the different values of γ, we notice that these values are set so that the running speed in the bus network continues to be high enough to guarantee that users' delays remain acceptable as shown in Figure 6(b).

To illustrate how the results of this work can potentially be utilized to drive the network into the system optimum, we replicate the choice of ride-hailing users for the following scenario $\{pv, s\}^{\mathcal{V}} | \{p, b\}^{\mathcal{B}}$ as a mode choice model that outputs β^{MC} as a function of the costs for traveling in the vehicle and bus network. The equation for β^{MC} is given by

$$\beta^{MC} = \frac{\exp(-\kappa(F^s + \mu t^s))}{\exp(-\kappa(F^s + \mu t^s)) + \exp(-\kappa(\phi F^s + \mu t^p))} \tag{8}$$

In the above equation, t^s and t^p are the travel time for solo and pooled trips, $\kappa > 0$ is the binary mode choice scale parameter, μ is the monetary value of time, and F^s is the fare for solo rides. To encourage ride-hailing users to share their rides, the service operator introduces a discount factor to F^s that we denote here by ϕ. Combining the obtained results with the choice model, we investigate what should be the discount gap given here by $|\phi - \phi^*|$ to drive the split towards β^* which is the point that minimizes the total PHT. The value ϕ^* in this case is the discount factor that yields a demand split naturally occurring at β^*.

To elaborate more on this approach, we take an example for $\alpha = 0.86$ and display in Figure 7(a) the PHT for the scenario under consideration but also for the other two scenarios for the sake of comparison. If the fraction of passengers opting for a solo ride is greater than 0.45, there is no improvement occurring by allowing only a fraction of the pooling demand to use the bus network, which explains the overlap between the full and dotted lines when $\beta > 0.45$. The gap however starts increasing between the two lines when β is low. Consequently, reducing network delays

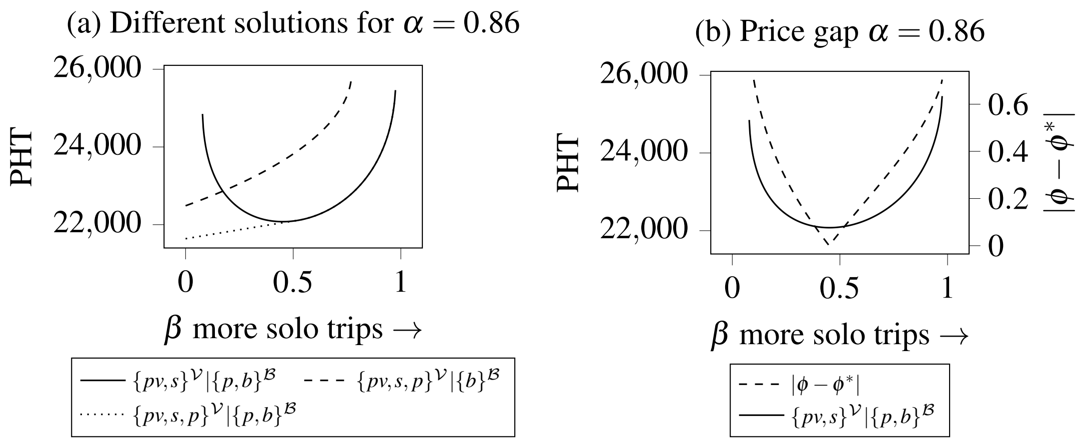


Figure 7: Comparison of the results for three different strategies for the same value of α

by allowing pooled vehicles on bus lanes is beneficial but should be restricted. Otherwise, the delays caused to buses counterbalance all the advantages associated with pooling. Figure 7(b) shows the discount gap in absolute value between the optimal point where the fare of ride-hailing services happens to fall at the minimum of the PHT curve, and between the service pricing for all the remaining range of possible solutions. A relatively low discount leads to solutions coinciding with high values of β which means that passengers are not given enough motivation to pool. Contrarily, a very high discount causes passengers to continue pooling even if the speed in the bus network is low. For these specific settings, instead of penalizing the pooling demand by reducing the discount which from a regulatory point of view is not substantiated, it is possible to improve delays by restricting the access to the bus lanes and hence moving downwards to the dotted curve in Figure 7(a).

4. CONCLUSIONS

In this paper, we have analyzed how, by giving pooled ride-hailing vehicles access to dedicated bus lanes, we can improve the performance of the transportation network under some specific settings. Our results show that when the bus network is relatively large and the pooling demand is low, assigning pooled drivers to bus lanes improves congestion in the vehicle network without causing large disturbances to the flow of buses. When the fraction of pooling demand is high, the bus disturbance becomes more accentuated and an increase in the bus network delays is inevitable. In this case, it is useful to restrict a portion of the pooled vehicles to travel on bus lanes to be able to derive benefits from the proposed policy. Additionally, in this study, we assessed one simple pricing strategy that drives solutions obtained from mode choice models to the system optimum. In the future, we plan to investigate different and more elaborated pricing strategies to help us achieve the same objective. We also plan to introduce a dynamic extension of the model and study how the results can be generalized to other network settings.

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