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Increasing Shareability in Ride-Pooling Systems

Opportunities and Empirical Studies

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9.1 INTRODUCTION

The last few years have seen a tremendous growth of mobility companies, referred to as Transportation Network Companies (TNCs), such as Uber, Lyft, and Via, that have introduced a variety of on-demand services. TNCs have grown exponentially. It took Uber six years to reach its first billion rides but only six months to reach the next billion [1].

The popularity comes with concerns about the impact of these services on congestion and traffic conditions in general. In 2018, there were 42,201,375 TNC rides starting in the Boston municipality, with an average of 68.3 rides per habitant. According to the Massachusetts Department of Public Utilities (DPU), rides increased by 21 percent from 2017 [2]. The San Francisco County Transportation Authority (SFCTA) reports that TNCs were responsible for half of the increase in congestion in San Francisco from 2010 to 2016 (while employment and population growth contributed the other half). The report also finds that TNC trips account for an estimated 25 percent of the total congestion in the city and 36 percent of delays in the downtown area. On a typical day, they add 170,000 vehicle trips and more than 570,000 vehicle miles traveled (VMT) (20 percent of all local daily VMT). TNCs contribute to congestion at all times of the day, especially in the evenings [3, 4]. Furthermore, in general, the fraction of rides that are actually shared is small, meaning that TNC services are operating, in principle, as taxi services with a ride arranged through apps. This actually adds extra mileage rather than reducing traffic, considering the mileage driving to pick up passengers. Schaller [1] reported that the non-shared ride TNC services (UberX, Lyft) put 2.8 new vehicle miles on the road for each mile of personal driving removed, for an overall 180 percent increase. The increased congestion brings other negative externalities as well, for example, reduced safety. According to a study [5], the rise of TNC services has increased traffic deaths by 2–3 percent in the United States since 2011, equivalent to as many as 1,100 fatalities a year.

TNC services also compete with sustainable modes of travel such as public transport, walking, and biking, while they are, in general, less competitive with personal

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automobiles. The main factors impacting mode-choice, such as price, speed, convenience, and comfort, result in shifting passengers to TNCs from public transport and nonmotorized modes rather than cars. Many surveys show that if TNC services were to disappear, about 60 percent of current TNC users would switch to public transport, walking, and biking (or not make the trip), about 20 percent would use their own car, and 20 percent would use a taxi [1]. Many traditional public transport services have been recently experiencing a reduction in ridership, especially buses. This decline is partially attributed to direct competition from TNCs [6]. The Chicago Transit Authority (CTA), for example, is reporting that the decline in ridership is partly caused by competition from TNCs, like Uber and Lyft. Equally alarming is the decline in student ridership. The Metropolitan Transportation Authority (MTA) in New York reported a 12.7 percent decline in student ridership in buses in 2018 [7].

Despite their popularity and large market, on-demand mobility services are far from profitable. Uber reported an operating loss of $8.5 billion in 2019 after losing more than $3 billion the previous year [8]. This lack of profitability seems to be a characteristic of the on-demand mobility service industry. Currie and Fournier [9] compiled a database of 120 systems, including traditional dial-a-ride, demand-responsive transit (DRT), and Microtransit, from nineteen countries since the 1970s. They found that most of the systems eventually failed (for example, 67 percent in the United Kingdom), and 40 percent lasted fewer than three years. High operating costs are the main contributor to their failure. The use of new technologies, such as apps and the mobile internet that enabled the recent developments, has not helped, with profitability, at least not yet. Results also show that services with simpler operations (for example, "many-to-few" systems, where trips may have many [any] origin locations but all go to one or very few destinations and vice-versa providing economies of scale) have lower failure rates, compared to the complex all-to-all services (where requests can have any origin location and can go to any destination location). Enoch et al. [10] also concluded that systems are often not properly designed and there is a tendency to offer too much flexibility, which increases costs.

Ride-pooling is a strategy that can address all of these concerns, regarding societal impacts (on congestion, traffic, and competition with public transport) and TNC profitability (operating costs and overall efficiency). Using taxi-trip data from New York City, for example, Santi et al. [11] concluded that even if trips are shared by only two passengers, a significant reduction in total VMT can be achieved in dense metropolitan areas, such as Manhattan. Alonso-Mora et al. [12] showed that, if all trips are shared, 25 percent of active taxis in NYC can satisfy 98 percent of the ride requests with an average waiting time of 2.8 minutes and mean trip delay of 3.5 minutes. This represents a significant reduction in required fleet size and hence, improvement in efficiency.

Because of the potential of ride-pooling to improve operating efficiency and, at the same time, reduce the impact of TNCs on congestion, experts have begun developing approaches to increase the number of shared trips. These approaches include alternative operating models on one hand, and long-term strategic partnerships with other service providers, such as public transport operators, on the other, which can result in simpler operations and economies of scale [10].

This chapter discusses opportunities for on-demand mobility services to improve sharing performance as a means to improve not only operating efficiency but also environmental sustainability. It explores, empirically through a large TNC dataset, the potential of these approaches to reduce on-demand mobility impacts, especially from a sustainability point of view using metrics such as VMT (a good surrogate of congestion and environmental impacts). It examines the impact of various factors (such as the fraction of requests known in advance, the percentage of shared requests, and the level of service expectations). It also reports on the experience with field tests and other experiments of coordinated public transport/TNC services and highlights lessons learned.

9.2 BACKGROUND AND DEFINITIONS

The concept of on-demand transportation services is not new. The first experiments were carried out in Atlantic City, New Jersey, in 1916 and some form of on-demand, shared-taxicab services have existed in US communities since at least the 1930s. By 1974 there were approximately twenty systems operating in North America, often referred to as dial-a-ride, demand-responsive, and paratransit systems [13] used to complement regular transit services. Dial-a-ride was introduced as a form of shared transport where passengers make reservations (typically a day in advance). Requests are organized in itineraries satisfying a certain level of service constraints (for example, maximum wait time from desired departure time). Vehicles do not have a fixed route or timetable. Systematic research into dial-a-ride started in the 1960s by researchers at the General Motors Research Laboratories, Massachusetts Institute of Technology (MIT), and Northwestern University. The federally funded project Computer-Aided Routing System (CARS) at MIT focused on all (operating) aspects of dial-a-ride from all points of view, including the development of computerized algorithms for optimal routing and scheduling [14]. Wilson et al. [15] were among the first to explore the potential of computers to plan and control dial-a-ride systems. Their efforts resulted in algorithms to assign requests to the most appropriate vehicles. They also investigated the problem of integrated dial-a-ride and fixed route public transport services and coordinated dial-a-ride systems. They aimed to design effective hybrid systems, in which dial-a-ride serves low volume and short trips, fixed-route public transport serves high volume trips, and a coordinated fixed-route/dial-a-ride system serves long but low-volume trips [15]. Today dial-a-ride, referred to as paratransit or demand responsive, services are mainly offered by public transport agencies in order to comply with the 1990 Americans with Disabilities Act (ADA). Qualified individuals can make reservations through a centralized system to use the service to access medical facilities as well as locations of other activities.

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Today's mobility on-demand services (for example, Uber, Lyft, Via) are fundamentally app-based dial-a-ride services with centralized dispatching and flexible driver arrangements [9], with most of the requests placed in real-time. These new services appear under various names; however, the terminology used to define them is often inconsistent. For this discussion, we mainly use the terminology introduced by the Society of Automotive Engineers, SAE [16] as summarized by:

1. *Shared mobility* refers to the shared use of a vehicle, scooter, bicycle, or other travel modes. Users have short-term access to the travel mode on an as-needed basis [17, 18]
2. *TNC services* (also called *ridesourcing* or *ridehailing* services) are prearranged or on-demand transportation services for compensation, in which drivers and passengers connect via digital apps that support booking, electronic payment, and ratings of the services.
3. *Ridesharing* is the formal or informal sharing of rides between drivers and passengers with similar origin-destination pairs. Ridesharing may include carpooling and vanpooling, where several passengers share the cost of using a vehicle, and in some cases, driving responsibility.
4. *Ride-pooling*, also known as *shared TNC* services that are organized on-demand, enables people to share a vehicle ride with others. UberPool, UberExpressPool, and Lyft Line are examples of ride-pooling services [19].
5. *Microtransit* is a privately or publicly operated, technology-enabled public transport service, that typically uses vans to provide on-demand or fixed-schedule services with either dynamic or fixed routing.
6. *Demand-responsive transit* (DRT), also known as *demand responsive transport*, *flexible transport*, or *Dial-a-Ride Transit* (DART), is a form of public transport where vehicles can alter their routes based on demand rather than using a fixed route or timetable [20].

9.3 INCREASING SHAREABILITY

Recognizing the need for and potential of ride-pooling, TNCs are adjusting their technology and operating models to deliver more shared rides. They increasingly focus on ways to promote ride-pooling, with services such as UberPool, UberExpress, and Lyftline, offered at reduced prices. In the first two months of LyftLine's service in San Francisco, one-third of all Lyft rides were LyftLines [21]. Lyft recently redesigned its app and is developing strategies to improve ride pooling [22]. New operational models to increase ride-pooling opportunities have also been proposed in the literature, such as meeting points at origins and destinations [23] and transfer points to switch vehicles [24].

Studies in the literature also show that coordination and integration of TNC operations and regular public transport services [25–28] has the potential to be beneficial

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to both parties involved. For example, Fan and Zhang [28] concluded that there are financial benefits in the integrated operation of public transport and shared mobility services in Santa Clara, through increased economies of scale. As a result, not only does TNC operating efficiency improve, but also there is a positive impact on the demand for public transport. There is strong evidence that public transport agencies and TNCs are interested in exploring the coordination between public transport and TNCs. Uber and Lyft have recently added public transport directions and fares to their apps [29, 30]. In Denver, riders can purchase public transport tickets via the Uber app [31]. Google has plans to show in Google map the multimodal trip options that combine public transport and TNCs [32]. The service already provides directions to walk or drive to public transport. By adding on-demand services, the app can also support the option of using a ride to a public transport station. At the same time, various public transport agencies, such as the Greater Richmond Transit Company, are pursuing an integrated design of public transport and TNC services that can be mutually beneficial [33].

Although TNCs have been heavily investing in improving and promoting their shared services, such as UberPool, ExpressPool, and LyftLine, the majority of trips are actually singly served. For example, Uber reported that only 20 percent of Uber trips are shared/pooled trips in the major cities where UberPool service is provided. Lyft estimates that 37 percent of the users in cities with a LyftLine option request a LyftLine trip, but the actual rides being shared is substantially lower (22 percent in New York City in February 2018) [1]. Even in a shared ride, some portion of the trip may involve just one passenger (for example, between the first and second pick-up).

Several studies explore the factors impacting the potential for shared trips using real-world data. Tachet et al. [34] present a simple index that measures the potential for ride-pooling as a function of trip generation rates, the amount of trip delay time that is acceptable to passengers, average traffic speed, and city size. They show that various metropolitan areas (New York, San Francisco, Singapore, and Vienna) exhibit similar behavior in terms of shareability potential, indicating that the same operating strategies to increase shared rides could work in different metropolitan areas.

In general, the factors impacting the ability of ride-pooling services to attract and match ride pooling requests are both demand and supply related. Demand-related factors include customers' willingness to share (demand for ride-pooling) and level of service (LOS) expectations (extra ride time, waiting for a vehicle, etc.). They also include spatiotemporal distribution of requests, which determines the opportunity to match ride pooling requests. Supply-related factors include market fragmentation (various mobility service providers operating independently), which impacts the sharing of information and service resources (leading to inability to match requests across TNCs). They also include operating strategies and partnerships to facilitate ride-pooling and take advantage of the available opportunities for pooling requests to the full extent (request matching, vehicle dispatching and rebalancing, etc.). The remainder of this section reviews these factors.

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9.3.1 *Customer Willingness to Share and LOS Expectations*

Passenger willingness to share and tolerance for increased waiting and trip detour times (additional time due to sharing a trip compared to a direct trip) affect ride-pooling opportunities [11, 12, 34–35]. While several existing studies explore the factors affecting the adoption of TNC services and the frequency of use [36–39], studies on the types of TNC services customers use and the factors impacting these choices are rather limited. In a recent TNC survey [40], respondents were asked about their TNC use frequency, the characteristics of their most recent TNC trip, and their willingness to share rides with others, wait for service, walk to a pick-up/drop-off location, and place requests in advance. The results show that 54 percent of the respondents prefer using the pool/shared services (for example, UberPool, LyftLine). Of the responders, 83 percent indicated that they would choose to walk to/from a pick-up/drop-off location for a discount, with 57 percent willing to walk more than 5 minutes. Furthermore, 75 percent of the respondents would also place requests in advance (at least 15 minutes ahead of their desired departure time). Users with higher income, age, and bike and car ownership tend to use TNC services less frequently. They also use pool services less. Lower-income, age, and no bike/car ownership groups, as well as groups with membership in sharing services (car/bike sharing), use TNCs more and also preferred pool services more than other groups [40].

9.3.2 *Spatiotemporal Distribution of Requests*

Current ride-pooling systems aim at pooling passengers with similar origin-destinations (OD) and departure times. In addition to the complexities of assigning a vehicle to several requests and designing a route plan that serves them most efficiently, pooling of trips with similar OD pairs and time frames, at its core, suffers from the spatiotemporal sparseness of real-time requests that could actually be matched [1]. The spatiotemporal distribution of requests for shared rides and their destinations determines the potential that two or more requests could be matched and served efficiently by a single vehicle, given their pickup/drop-off time windows and locations. Requests with similar paths and time windows can be assigned to the same vehicle. Trip origins and destinations are generally spread over numerous OD pairs which makes it difficult to find passengers who have compatible OD pairs. Moreover, potential ride-pooling passengers should also have compatible departure times. The likelihood of finding passengers who are willing to take a shared ride and are heading in the same direction at the same time is rather low and has hindered the effectiveness of real-time ride-pooling. To increase the likelihood of shared rides, the radius of matching passenger origins or destinations could be increased, or the time window of the departure time could be more flexible. In such cases the scheduling of the trips has to be sensitive to the level of service, as passengers may experience longer travel and waiting times. If the level of service deteriorates this

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may discourage passengers from choosing a shared ride in the future and hence, reduces the demand for shared services.

9.3.3 *Market Fragmentation*

Market fragmentation refers to multiple service providers/platforms, typically operating independently (except for some drivers working for multiple platforms). Multiple platforms fragment demand and myopically optimize their systems to serve their own customers. This may potentially result in a higher cost to society (pollution, fuel consumption, congestion), customers (fare, time), and their own services (fleet, crew). Séjourné et al. [41] analyzed the impact of competition among on-demand mobility companies on operating costs. Their analysis sheds light into the benefits of aggregating pickup and drop-off locations, increasing the flexibility of pickup times, and allowing drivers work on multiple platforms (also known as multihoming). Pandey et al. [42], using New York City taxicab data, conclude that competition among service providers degrades the level of service compared to a centralized model. Integrating all service providers is clearly not practical. However, mechanisms such as multihoming partially mitigate the efficiency loss and increase shared trips. Multihoming has the potential to provide a more flexible supply of labor, which not only increases ride pooling opportunities but also reduces costs, for example, by minimizing the need for rebalancing [43].

9.3.4 *Operating Strategies and Partnerships*

Various studies have proposed and evaluated novel service models for the purpose of facilitating trip matching in order to increase its likelihood. These strategies have the potential to provide more opportunities to share rides by seeking broader consolidation opportunities (in terms of space and time) to efficiently group travelers, while maintaining a high level of service. Several examples follow.

Advanced requests [44]. In this scenario, requests are placed ahead of time with desired pickup and drop-off time windows. In general, the service can accommodate passengers with different advanced request intervals and different price sensitivities. Advanced requests are expected to increase the likelihood of sharing trips while reducing operating costs for TNCs. Pricing the service accordingly can be the means of incentivizing passengers to make requests in advance. Uber recently added a similar function to incentivize travelers to depart later than their desired departure times. For example, users can get a $1 Uber cash back if they are willing to depart in ten minutes and $2 if they depart within twenty minutes.

Dynamic waiting [45]. In this scenario, requests are placed in real-time with desired pick-up times. As with advanced bookings, requests wait to be matched to a driver for a period of time (waiting time window). The waiting window is dynamic, depending on market conditions. For example, it increases when the supply of

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vehicles is constrained. The waiting window is used to increase the opportunities to pool together requests whose origin and destination locations are close to each other (within walkable distance).

Meeting points [23]. In this scenario, requests are placed in real-time with desired pick-up times. Passengers walk to pick up locations and share a ride with other passengers. After alighting, passengers may have to walk from the drop-off spot to their destination. The meeting points are determined dynamically, given the request location and expected LOS of passengers already on-board.

Intermediate transfer points [46, 47]. In this scenario, requests are placed in real-time with desired pick-up times. Users that are picked up may change vehicles during their trip. A transfer can occur at pre-specified locations in a static manner or can happen dynamically based on how trips are pooled together. Transfers increase the opportunity of matching rides as users from different origins can be pooled together at the transfer locations to a common destination.

Partnerships with other service providers [48, 49]. In this scenario, on-demand TNCs and public transport agencies work in partnership. For example, hybrid on-demand and public transport services allow passengers to place requests with desired pickup times and origin/destination information. Passengers can be picked up at their origins by on-demand services and dropped off at an "optimal" public transport station. Alternatively, they can take a bus or metro, and then either walk or take another TNC to their destinations, or they can be directly served (door-to-door) by TNC services.

9.4 ASSESSING OPPORTUNITIES

Successful outcomes with respect to increasing shared trips probably require a combination of approaches. We focus the discussion on two promising strategies for their potential to improve shared trips and reduce impacts such as VMT: a) advanced requests and b) partnerships with public transport agencies.

The advanced requests strategy is representative of the first three operating strategies discussed earlier. It relies solely on the TNCs to adopt alternative operating models by adding options to their services. Advanced requests can be viewed as a more formal way to extend some of the current offerings, for example, dynamic waiting. Therefore, from an implementation point of view, it represents incremental changes that are more likely to be adopted by companies and users. By contrast, strategies such as meeting points and intermediate transfer points may require significant changes to the digital infrastructure and deviate quite substantially from the core operating models currently deployed.

The second strategy we focus on, partnerships, is quite different from pure operating strategies, as it requires collaboration between TNCs and traditional public transport agencies. It represents an opportunity to take advantage of natural synergies that exist between TNCs and public transport services and has the potential to

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benefit both stakeholders. Public transport and TNCs both offer shared rides but with different degrees of flexibility. Partnerships between the two help address the weakness of one through the strength of the other.

9.4.1 An Empirical Evaluation of Advanced Requests

Given the on-demand nature of most requests, from a scheduling point of view, the short time between the placing of a request and the initiation of the service limits the ability of customer matching and vehicle scheduling algorithms to take full advantage of the shareability opportunities. A number of studies point out this inefficiency of the on-demand nature of TNC services. Alonso-Mora et al. [35] show that predicting future demand accurately could improve the efficiency of TNC operations. Using TNC ride data from three US cities (San Francisco, New York, and Los Angeles), Chen et al. [50] reported that ride-pooling with approximated future requests can yield significant benefits by reducing total fuel consumption (by 15 percent) and fleet size (by 30 percent). Various surveys indicate that TNC users report optimal waiting times for their ride to be five–eight minutes. In one study [40], it is reported that 68 percent of the TNC users in the survey actually waited more than four minutes for their service to arrive. Even more importantly, 75 percent of the users are willing to place requests more than fifteen minutes in advance, in return for a fare discount.

Given the inefficiency introduced by real-time requests and also the expressed willingness of users to place requests in advance, at the right fare, we examine in detail the potential of an advanced requests operating model for TNCs. Advance knowledge of future requests gives TNCs more flexibility to schedule trips and identify opportunities to match requests. We evaluate the performance of an advanced requests system relative to current practices using a large-scale dataset from the operations of a major on-demand ride-hailing company in China. In addition to the overall potential of such a strategy in reducing VMT (directly related to energy consumption and emissions) and operating efficiently, the impact of various design aspects of the advanced requests system (for example, advanced requests horizon, vehicle capacity) on its cost and performance is also of interest, as well as the sensitivity of the results to user preferences in terms of level of service (time to be served and excess trip time) and willingness to share.

The advanced requests system that we examine follows the one proposed by Ma et al. [44]. Requests are placed ahead of time with desired pick-up time windows. Let H be the advanced reservation horizon (how far ahead requests for service should be placed). Scheduling decisions are made every Δt seconds (decision epoch), with $\Delta t \leq H$. That means every Δt seconds, utilizing all available information on advanced requests and vehicle status, all requests are processed. At each decision epoch, all advanced requests within the advanced reservation horizon H are known. The decisions respect requests that have already been assigned to trips and, either assign pending requests to an existing trip, or start new trips.

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TABLE 9.1 *Experimental design parameters.*

Dimension	Parameter	Settings
Operating model	Advanced requests horizon	$H \in \{0, 5, 15, 30\}$ minutes
	Decision epoch	$\Delta t \in \{30, 60, 120\}$ seconds
	Vehicle capacity	$\{2, 4, 7, 10\}$ passengers per vehicle
User preferences	Willingness to share	% of customers requesting shared service $\in \{0, 25, 50, 75, 100\}$
	LOS	Strict users <=2 min, =5-min> Neutral users <=5 min, =10 min> Flexible users <=7 min, =15 min>
	User groups	All customers are strict All customers are neutral All customers are flexible Mixed <20% strict, 60% neutral, 20% flexible>
Traffic conditions	Travel time	Traffic conditions $\in$ {low congestion, normal congestion, heavy congestion}

The above model is quite general and can represent alternative operating models. For example, for $H = 0$ the model represents existing, on-demand, ride-pooling services, where passengers make requests expecting immediate service. Existing on-demand ride-pooling services are reactive with requests collected during a short time window, for example, thirty seconds, after which they are assigned to different vehicles and the service stops (pickup and drop-off locations) are scheduled accordingly.

We analyze performance metrics with respect to mobility (VMT) and level of service (LOS) that passengers experience (waiting time and trip delay time). We consider different operating characteristics of the ride-pooling service in terms of the advanced requests horizon and the decision epoch. We also consider different user preferences and traffic conditions. The overall experimental design is summarized in Table 9.1.

A large-scale on-demand trip request data set from Chengdu, China from November 01–30, 2016, provided by DiDi Chuxing, a TNC in China, is used in the analysis. To assess the impact of various factors on the performance of ride pooling services, we use requests with pickups and drop-offs within the third ring of the city (20 km × 20 km area, covering 85 percent of all requests). For each trip, the dataset contains a request ID, vehicle ID, and the time of the request and pickup and drop-off locations (approximately 7 million trips). Figure 9.1 shows the heatmap of the distribution of pickups and drop-offs for a morning period (7.30–8:.0 a.m.). The pick-up and drop-off locations are scattered throughout the network, with drop-offs relatively more concentrated in the city center.

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Morning pick-ups Morning drop-offs

FIGURE 9.1 Distribution of TNC pickups and drop-offs for a morning peak period 7.30–8.30 a.m.

We evaluate the performance of the system for all possible combinations of the above experimental design resulting in 2,880 cases. Requests are scheduled with the objective of minimizing vehicle miles traveled (VMT). The scenario with advanced requests horizon $H = 0$ and decision epoch $\Delta t = 30$ sec represents (as close as possible) current operations of various TNC services (for example, Uber, Lyft). For the model with advanced requests, the vehicle schedule is optimized every decision epoch, for example, thirty seconds, given vehicle states and real-time and advanced requests within the time horizon, for example, fifteen minutes. The scheduled requests are kept in the request pool until picked up and can be reassigned if a better schedule is found before pickup. The base case is the scenario where all requests are for single trips. If all requests are for single trips, 30,000 kilometers are required to serve all requests (7,500), for the period 7.30–8.30 a.m.

Figure 9.2 shows the impact on VMT of passengers' willingness to share, for different user types and advanced request horizons. As expected, VMT decreases with the increase of the percentage of passengers willing to share trips. Compared to the base case, VMT is reduced by 14 percent, 25 percent, and 35 percent, when the sharing percentages are 50 percent, 75 percent and 100 percent respectively, for services with an advanced request horizon of fifteen minutes, vehicle capacity of four, and normal traffic conditions. Interestingly, no significant difference is found for the VMT to serve neutral, flexible, and mixed users (given the same settings on other variables in Table 9.1), while it consistently requires more VMT to serve strict users than the other user types. This suggests that, from the perspective of users' preferences, most of the VMT reductions could be achieved if passengers are willing to wait for five minutes maximum or can tolerate a trip delay of ten minutes maximum.

Operating models with advanced requests perform better than operating models with no advanced requests (advanced request horizon 0) from a VMT standpoint without deteriorating the level of service. Advanced requests facilitate a better

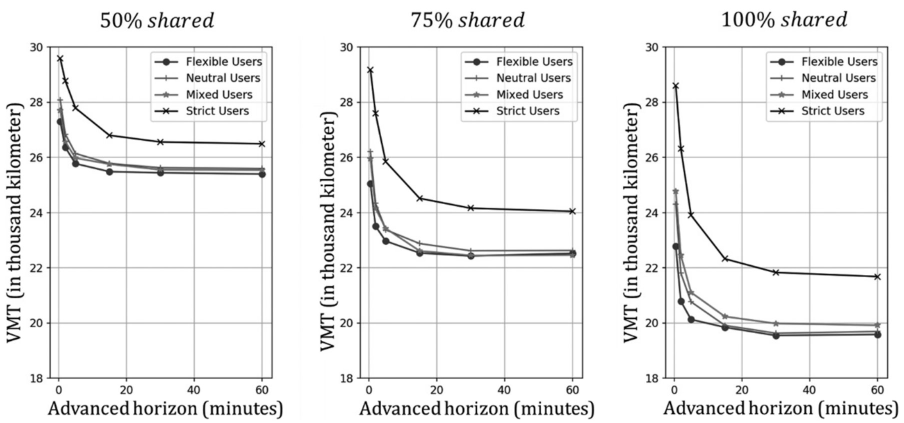

FIGURE 9.2 Impact on VMT of willingness to share (vehicle capacity four, normal traffic).

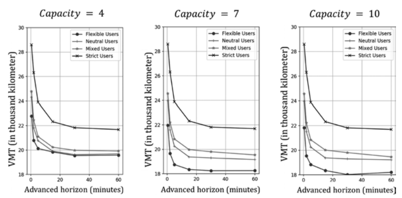

FIGURE 9.3 Impact on VMT of vehicle capacity (all shared, normal traffic).

matching of requests to vehicles as more information is available for decision making. For example, the operating model with an advanced requests horizon of fifteen minutes reduces the base case VMT (all requests are for single trips) by 35 percent, while the current practice model (with no advanced requests) saves 19 percent of the base case VMT if all requests are for shared trips. It is also interesting to note that even a short advanced requests horizon (for example, five to fifteen minutes) provides most of the benefits in terms of VMT reduction.

Figure 9.3 shows the impact on VMT of vehicle capacity for different user types and advanced request horizons. Higher capacity vehicles increase the sharing opportunities as more users can be assigned to the same vehicle and thus decrease the total VMT to serve all the requests. However, there are diminishing returns when the capacity exceeds seven. For example, if all passengers are willing to share, the operating model with advanced requests horizon fifteen minutes saves 35 percent, 40 percent, and 40 percent of the base case VMT for vehicle capacity of four, seven, and ten, respectively. The operating model with no advanced requests reduces the base case VMT by 19 percent, 23 percent, and 24 percent for vehicle capacity of four, seven, and ten, respectively.

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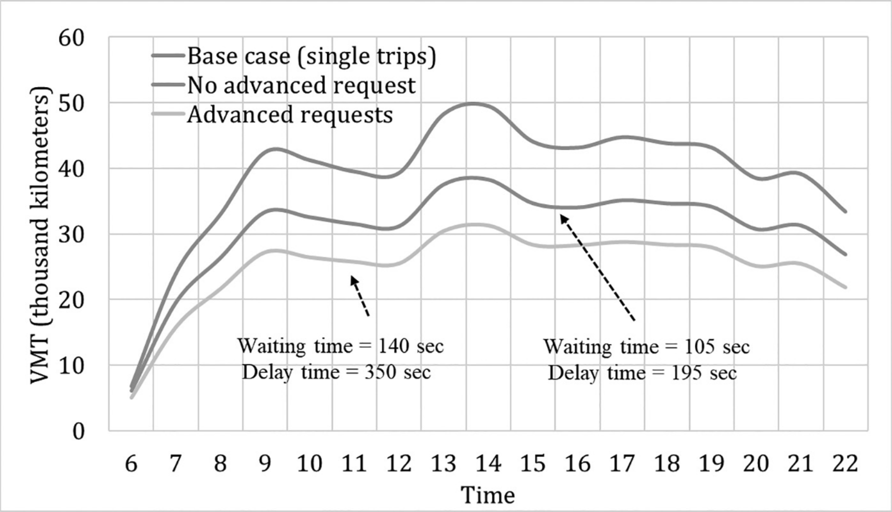

FIGURE 9.4 Comparison of VMT over the course of a day for different operating models: no advanced requests, advanced requests with, H = 15 min 100 percent willingness to share, mixed user preferences, decision epoch thirty sec, vehicle capacity four, and normal traffic.

Figure 9.4 compares the performance of the operating model with advanced requests, assuming a fifteen minutes advanced request horizon and a thirty seconds decision epoch, to the performance of current services (for example, no advanced requests). It is assumed that all passengers are willing to share and have mixed preferences. Vehicle capacity is four and traffic conditions normal. The base case of only single trip requests is also shown. The results are based on the application of the model over the entire day.

The advanced requests operating model performs consistently better than a system with no advanced requests across different time periods of the day. Compared to the base case when all requests are for single trips, on average, if all passengers are willing to share, a system with no advanced requests will reduce VMT by 20 percent, while the operating model with fifteen minutes advanced requests will save 35 percent of the total VMT. The 35 percent VMT reduction represents not only a reduction in congestion but also in environmental impacts. In terms of the LOS for the passengers, the no advanced requests system yields an average waiting time of 1.8 minutes and trip delay time of 3.3 minutes, while the advanced requests model has an average waiting time of 2.3 minutes and trip delay time of 5.8 minutes.

In conclusion, operating strategies based on requests in advance have the potential to improve shared rides and reduce the environmental footprint of TNC services. Even short advance request horizons offer substantial benefits at the cost of a small increase in waiting and travel delays. Furthermore, survey data indicate that users are actually interested in using such services.

9.4.2 *Partnerships with Public Transport*

Recently, there has been a growing interest in exploring partnerships between public transport agencies and TNCs. Such partnerships have the potential to increase shareability opportunities. Many commuting trips for example, take place at the same time and could use the same rail station. This increases the chances of pooling requests that go to the same public transport station (many-to-few case), providing economies of scale for the TNC and also feeding potentially new users to public transport services. In general, public transport agencies may partner with TNCs for various reasons, such as improving mobility where public transport is scarce or cutting down on costs and attracting new customers. TNCs on the other hand, view such partnerships as a means to increase revenue by serving markets with favorable spatio-temporal characteristics. Various studies indeed suggest that TNC and public transport services can be used collaboratively [48]. Uber data, for example show a strong relationship between the origin and destination of the rides and the location of public transport stops. Almost 40 percent of Uber rides in London either start or end near a Tube stop [49]. Uber reported a 22 percent increase in the number of its trips that began within 200 meters of a Tube stop after London launched a limited nighttime Tube service in 2016 [49]. In Portland, Oregon, 25 percent of Uber trips occur within a quarter-mile of a public transport station [51]. Lyft rides follow the same pattern, with 25 percent of Lyft riders using the service to connect to public transport. In Boston, 33 percent of Lyft rides start or end near a public transport (MBTA) stop [52].

The initial partnerships emerged due to safety concerns. The goal of the partnerships was to motivate people to use public transport to attend social and entertainment activities and, later in the night, when public transport services are not available, help them get back home safely with subsidized TNC rides. The Dallas Area Rapid Transit (DART) partnered with Uber on St. Patrick's Day to reduce drunk driving casualties during one of the deadliest holidays [53]. In 2014, the University of Florida proposed a pilot to complement late-night circulatory bus services with subsidized Uber trips to discourage late night-driving [54]. The success of these trials triggered a wider interest in partnerships between TNCs and public transport agencies. The experience with such emerging partnerships however, varies among agencies, ranging from failures such as Bridje in Kansas City, which attracted only a total of 1,452 rides in a year (2016) and was terminated, to the successful Uber partnership with the city of Innisfil, Ontario, with 8,000 rides per month.

In general, three main types of partnerships are observed between public transport and TNCs: First/Last Mile connections, paratransit, and bus route replacement.

First/Last Mile connections: Providing on-demand rides that connect riders to public transport options is the most common partnership. Schwieterman and Livingston [55] reviewed twenty-nine agencies in North America and found that since 2016, at least six offered discounted TNC rides to/from public transport rail

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stations [55]. The Pinellas Suncoast Transit Authority (PSTA), for example, became the first public transport agency in the United States to partner with a TNC to provide first/last mile services. "Direct connect" was a pilot service that used public funds to subsidize Uber rides that would allow riders to get to and from a bus stop. "Direct Connect" replaced underperforming, low-frequency bus routes that were carrying less than five passengers per stop per day [54]. The pilot showed promise to reduce costs and the city allocated additional funds to expand the service to ten times the number of bus stops originally served [54]. European cities are also forming similar partnerships, such as BerlKonig in Berlin, Germany [56], and ViaVan in Espoo, Finland [57].

Some partnerships in this group however, experienced poor results. Centennial, Colorado, terminated a partnership with Lyft that offered free trips to light rail stations (Go Centennial). The city had to spend more (compared to the traditional paratransit service they offered, known as Call-n-Ride service), while serving fewer rides [58]. A report on the "Go Centennial" program blames lack of systematic integration between regional public transport services and the Lyft service for the poor results. Trips were not synchronized with the light rail schedule and alighting riders had to wait for Lyft to arrive. The same report also acknowledges the presence of parallel services (from other demand responsive services) that caused inefficiencies and limited the benefits that come from economies of scale [59].

Paratransit (dial-a-ride): It is typically very expensive to operate traditional paratransit services, which are often mandated by the Americans with Disabilities Act. The Brookings Institute estimates that in 2013, 12.2 percent of the operating costs of public transport agencies (approximately $5.2 billion) went to paratransit. Contracts with TNCs to provide paratransit services are particularly interesting, as agencies are under pressure to find innovative solutions to deal with the ever-growing paratransit costs. The experience from partnerships between public transport and TNCs to offer paratransit services is promising. Agencies, such as in Boston (MBTA) and Las Vegas (RTC), use TNCs as platforms to provide paratransit services that are easier for passengers to use and at a lower cost for the agency [60, 61]. In Boston, the MBTA recently renewed a three-year contract with Uber and Lyft to supplement their paratransit services [62], even though the TNC-based service may have problems serving some wheelchair users who have to be accommodated through other means [63]. In Las Vegas, RTC aimed to reduce the $32 per ride cost for traditional paratransit services by outsourcing the trips to Lyft. The public transport agency estimates that each Lyft ride costs about $15 [64].

Bus route replacement: Another type of collaboration is using TNC services to replace bus routes. The town of Innisfil, Ontario, decided to partially subsidize TNC trips in place of the traditional public transport system operating in the city. The average subsidy of $5.62 per passenger is lower than the subsidy for a typical bus ride [55]. Uber reports that the partnership is saving Innisfil $8 million a year [65].

In Arlington, Texas, the town's entire bus service was replaced by services provided by Via, making Arlington the largest US city without a typical public transport system [66]. The Via rides cost between $3 and $5, depending on distance and origin/destination of the trip. The customer is notified of the expected pickup time but, in general, waiting time is less than ten to twelve minutes, which makes the service particularly attractive. The program has been successful, and the contract was renewed with expanded service from 30 percent coverage to 100 percent coverage [67].

In summary, partnering with TNCs can have benefits for public transport authorities. Connecting riders to public transport, replacing inefficient bus routes, and providing cost-effective paratransit services are the most promising areas of collaboration. Collaboration can also be beneficial to TNCs. As mentioned earlier, TNCs are more cost-effective when trips are concentrated (for example, many-to-few). Partnerships with public transport favor and greatly facilitate such operations. The lessons learned from the current efforts suggest that service design, business models, demand spatio-temporal characteristics, marketing, and demographics are important for the success of public transport-TNC partnerships. The degree of complementarity (TNCs working together with public transport agencies) and substitution (TNC trips replacing public transport trips) between TNCs and public transport varies. The substitution effect is expected to be larger for example, in cities or areas where public transportation LOS is low (for example, high travel times, low frequency of service) compared to places with a strong public transport system.

9.5 CONCLUSION

TNC services have seen significant growth in recent years. While they play an important role in supporting urban mobility, they may also introduce negative externalities. Increasing ride pooling has the potential both to reduce the negative societal impacts and to improve operating efficiency (which is of great concern to TNCs). Although increasing the number of shared trips is a desirable goal, experience suggests that shared trips are currently only a small fraction of all trips. The chapter summarized the factors impacting ride-pooling and synthesized the main approaches that can be deployed to increase ride pooling. Two representative approaches to increase the number of shared trips discussed in detail, operations where requests are required to be known in advance (with short time horizons), and partnerships with public transport agencies for providing multimodal services, have shown promising results.

A case study with data from a large TNC showed that significant benefits (VMT savings) can be realized when advanced requests are combined with an increased willingness to share. Even short, advanced request intervals (five to fifteen minutes) can capture the majority of the benefits of advanced requests. The VMT savings are realized at the expense of a small reduction in LOS.

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Partnerships between public transport and TNCs can be beneficial to both sides, in terms of reducing costs, improving level of service, and potentially increasing demand. Three main types of partnerships are observed: offering first/last mile connections, providing paratransit services, and substituting for unproductive bus routes. The discussion suggests that service design, business models, consumer attitudes, and demographics, are important for achieving increased ride pooling.

However, the success of these strategies depends on many factors that can play a key role in shaping the future role of TNCs as an integral part of a sustainable urban mobility system, especially considering that public transport should and will always be the backbone of urban transportation.

Pricing is an important lever that TNCs can use to drive demand for various services. Pricing, properly differentiated by service type, impacts consumer choices (along with level of service). Currently, prices for the typical TNC service (ride alone) are rather low, set aggressively to increase market share. Fares are subsidized by the venture capital the companies have attracted and do not always reflect the true cost of the trips. As a result, given this low ceiling (price for the single trips), there is currently limited room to set prices appropriately for the other products. Price differentiation is not strong enough to incentivize users to switch to the more sustainable options, such as ride-pooling.

Policy can play an important role in guiding TNCs to offer more sustainable services. A recent study proposes a number of financial instruments, including surcharges to help cities recover TNC-associated costs and externalities (management, curb utilization, congestion, and pollution), fees designed to penalize inefficient routes, and rewards for shared trips and trips that are complementary with public transport [68].

Integrated fare platforms, providing fare bundles for trips involving public transport/TNC connections is a logical next step in the development of partnerships between public transport and TNCs. Such integrated fare platforms eliminate the obstacle and inconvenience of separate payment means for customers, facilitate revenue allocation among stakeholders, and promote multimodal trip searching and recommendations.

Finally, it should be pointed out that, currently, data sharing between TNCs and public transportation agencies and city authorities is rather limited. Data sharing and greater transparency are important to further develop integrated, inclusive, multimodal services that promote sustainable mobility and accessibility in urban areas.

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