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# A real-time algorithm to solve the peer-to-peer ride-matching problem in a flexible ridesharing system

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A B S T R A C T

Real-time peer-to-peer ridesharing is a promising mode of transportation that has gained popularity during the recent years thanks to the wide-spread use of smart phones, mobile application development platforms, and online payment systems. An assignment of drivers to riders, known as the ride-matching problem, is a central component of a peer-to-peer ridesharing system. In this paper we discuss the features of a flexible ridesharing system and propose an algorithm to optimally solve the ride-matching problem in a flexible ridesharing system in real-time. We generate random instances of the problem, and perform sensitivity analysis over some of the important parameters in a ridesharing system. Furthermore, we discuss two novel approaches to increase the performance of a ridesharing system.



## 1. Introduction

Congestion in urban transportation networks is one of the common problems faced by many countries around the world. In addition to having a direct impact on travel time and fuel consumption, congestion imposes indirect costs by increasing travel time uncertainty, as well as emission levels which adversely affect human health and ecosystems. Managing congestion by expanding the infrastructure is costly and damaging to the environment. An alternative way is to make more efficient use of the existing transportation infrastructure. Public transportation is a conventional way of using the existing capacity on the roadway network more efficiently.

Transit systems in urban networks mainly include buses and rail services. They typically carry multiple passengers, and therefore can help reduce vehicle miles traveled (VMT) and ease congestion in urban networks. One drawback of transit services is that they operate on fixed routes and schedules, which limits their coverage of the network, both geographically and temporally. Urban transit systems are typically and necessarily designed to satisfy peak period demands. Due to significant peaking behavior of demand, the system capacity is often drastically under-utilized during off-peak periods, which causes significant cost inefficiencies. Government regulations on fares exacerbate the cost concerns. Thus transit services usually fail to act as financially independent entities, and are in need of subsidies.

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Para-transit services were originally introduced to run as supplementary services alongside transit, and as a means to increase the flexibility of public transportation. Para-transit services include all shuttle-like services that serve customers such as airport travelers, employee or student commuters, or the elderly and disabled. Since the passage of the Americans with Disabilities Act of 1990, however, the term para-transit has been used more commonly to refer to the services provided to persons with disabilities, or to the elderly. In this paper, we reserve the term para-transit to refer to such services. These services are demand-responsive, and usually serve multiple passengers at a time, based on spatiotemporal proximity of the requests they receive. Routes and schedules are fairly flexible and demand-dependent.

Although para-transit services can be beneficiary to demographics they target, these demographics are fairly limited. In addition, most services that fall under this category are offered by non-profit organizations that are supported by federal or state funding. Due to the limit on the amount of subsidies, it is not possible to extend these services to the general public. These limitations alongside the desire for more comfortable (and possibly quicker) travel options have resulted in a much higher demand for private sector alternatives, such as taxis.

Taxis are a private form of demand-responsive transportation alternative. They provide door-to-door transportation, but at a higher cost that not everyone can afford. Shared taxi/limousine/shuttle services provide an opportunity for customers to share their trips, cutting the cost of the journey, and potentially reducing the total miles traveled in the network. Over the years, different shared-use mobility services have been designed. Flexible route transit systems (Quadrifoglio et al. 2008; Li and Quadrifoglio 2010; Qiu et al. 2014), and High-Coverage Point-to-Point Transit (HCPPT) (Cortés and Jayakrishnan, 2002) are a few examples. HCPPT is perhaps the first conceptual system that envisaged the option of private drivers offering rides to be shared, and entirely eliminated fixed route transit, though the somewhat misleading word “transit” was used in the name.

In all alternative modes of transportation above, with the exception of HCPPT, drivers work as system employees. Some of the discussed transportation alternatives are more flexible than others in terms of routing and scheduling, and some have the potential to benefit the environment and customers by allowing them to share (parts of) their trips. In the next set of transportation alternatives we discuss, drivers are not employed by the agencies.

A different family of transportation alternatives which has attracted considerable attention during the recent years is founded based on the principle of shared-use mobility (Shaheen and Chan, 2015). These alternatives try to reduce the cost of flexible transportation by reducing (or completely eliminating) the capital investments and operating costs.

Informal carpooling is one of the first and common forms of trip sharing in which a number of individuals share a vehicle for their trips, which typically involve the same origin and/or destination. Examples include parents who take turns in taking their children to school, colleagues who carpool to work, etc. In this form of carpooling drivers own the vehicles and have personal interest in the trips, regardless of whether additional passengers are present in the car. The incentives for informal carpooling may include saving time through use of carpool lanes and not having to drive one’s own vehicle every single day if participants take turns in driving. This form of carpooling is usually pre-arranged, and happens among individuals who share commonalities beyond the time and location of their trips.

Transportation Network Companies (TNC), such as Uber and Lyft, are among the more recent faces of shared-use mobility alternatives. TNCs use private vehicle owners and their personal vehicles to provide flexible and on-demand transportation. These individuals collaborate with the company as independent contractors, and not employees. This substantially reduces the cost of capital and human resources for TNCs while generating revenue for both the company and the drivers. Essentially, the basic services provided by TNCs act as a lower-cost alternative to taxi services, and hence not only do they not address the problem of increasing travel demand and congestion, but they add to it as a result of the empty trips required to pick up passengers. In terms of sustainability, TNCs impose the same cost to the environment as taxi companies do. Recently, two of the more prominent TNCs, Uber and Lyft, have introduced sharing services Uberpool and Lyft Line, respectively. Such services can certainly reduce the cost and environmental impacts of the base services if they can manage to attract a critical mass of participants by incorporating proper design elements (e.g., individual rationality constraints) in their services.

Peer-to-peer (P2P) ridesharing aims at capturing the benefits of TNCs while alleviating their adverse impact on the environment and the transportation infrastructure. Ridesharing systems are founded on the principle of sharing economy. Sharing economy, also known as collaborative consumption, is a fairly old concept that focuses on the benefits obtained from sharing resources (products or services) that would otherwise go unused. This economic model has gained more popularity in the recent years, giving birth to many P2P services in different fields (for examples, refer to Böckmann, 2013). The rapid global spread of the internet during the past decade has extended the domains of sharing economy to global populations, and has highlighted its benefits. Moreover, new platforms allow for easy and quick development of companion mobile applications that facilitate sharing economy.

Similar to TNCs, drivers in a P2P ridesharing system use their personal vehicles to transport passengers, and do not work as agency employees. Contrary to the TNC operations, drivers in a P2P ridesharing system are making trips to perform activities of self interest (as in the case of informal carpooling), i.e., they do not roam around the city only to pick up and drop off passengers. This setting can lead to services that are more environmentally-friendly and cost-efficient compared to the sharing services offered by TNCs. Scoop is an example of P2P ridesharing company which is currently operating in various cities throughout the US.

The overwhelming success and high acceptance rates of TNCs by the public suggest a bright future for the more environmentally-friendly ridesharing systems. Since founded in 2009, Uber has managed to expand its operations in 75 countries and more than 450 cities worldwide. According to BUSINESS INSIDER, in 2014 Uber had more than 160,000 reg-