# A Future of Shared Mobility

P. Santi[1,2], C. Ratti[1]

[1] *Senseable City Lab, Massachusetts Institute of Technology, Cambridge, MA, USA*
[2] *Istituto di Informatica e Telematica del CNR, Pisa, ITALY*

**Abstract**

Shared mobility is transforming the way we move around in cities and is challenging consolidated transport modes such as the private car, taxi, and public transit. While shared mobility has an immense potential to improve the efficiency of personal transportation and, hence, reducing emissions, this paper makes the case that shared mobility *per-se* is not sufficient to achieve this important goal. Rather, shared mobility services should be designed and integrated with other transport modes having carbon emission reduction as an explicit optimization goal. This observation prompts a call for the development of accurate models and analytical tools for the estimation of the city-level benefits of different forms of shared mobility, and of their integration. Examples of these tools are briefly reviewed and discussed in this paper.

*Keywords:* urban mobility, shared economy, vehicle sharing, ride sharing, shared mobility models.

**Introduction**

Mobility is a fundamental dimension of urban life, and one of the main driving forces that have kept cities alive since more than 7,000 years [1]. Without mobility, many of the acknowledged advantages of living in a city – better access to job, education, and entertainment, economic prosperity, etc. – would not exist [2]. The aforementioned advantages are drawing an increasingly larger amount of the world population into cities – with the number of urban dwellers having recently surpassed the number of rural inhabitants according to the United Nations [3], which predict that about 2/3 of the world population will live in cities by 2050.

Urban mobility has also well-know downsides: traffic congestion accounts for about 23% of world greenhouse gas emissions [4], it negatively impacts the quality of urban life and imposes enormous health costs to the society. Furthermore, it reduces productivity due to the significant amount of time daily spent in traffic. These trends could even worsen in light of the predicted growth of urban population, unless substantial actions and policies are implemented to reduce the impact of traffic in cities.

As a matter of fact, urban mobility systems are still largely inefficient today. Mobility options are silo-ed into a few modes that are either carrying a massive number of passengers along fixed routes with fixed schedules – public transit –, or otherwise transporting a very limited number of passengers (typically, only one) along flexible routes with flexible schedules – taxi and private vehicle. These latter mobility options are very inefficient from a capacity and carbon footprint perspective: for instance, cars are idle 95% of the time and, when they operate, are mostly empty [5]. Hence, taxi and private vehicles are an ideal candidate for the sharing economy that can substantially improve their efficiency .

Lack of flexibility and coverage – which is also related to cost factors – limits the ability of public transit to accommodate the entire mobility demand in a city, resulting in a very significant part of urban mobility still being served by carbon inefficient transport modes such as private vehicle and taxi. This is the root cause of traffic congestion that is still rising in many cities worldwide.

The emerging phenomenon of the sharing economy [*6*, *7*] promises to improve the efficiency of individual, on-demand transportation. Bridging the gap between shared but inflexible public transportation and flexible but not shared private transportation, novel services such as those provided by Uber™, Lyft™, and ZipCar™ can significantly contribute to reducing road congestion and emissions. In this article, we discuss the potential advantages of shared mobility in urban environments, and present challenges still to be addressed to turn potential advantages into actual benefits for the urban community.

**Shared mobility**

The idea of sharing mobility resources is not new, as it dates back at least to the 1970s when the oil crisis raised public attention to the problem of improving the efficiency of personal transportation.

Since then, several forms of shared transportation have been proposed, and have recently been revived by the widespread smartphone and ubiquitous connectivity technologies that allow easy connection between mobility demand and offered services. In the following we briefly review the main models of shared mobility.

In ride-sharing, a ride – typically provided by a professional taxi driver, or, more recently, by an informal UBER/Lyft driver – is shared between a number of passengers who accept lower levels of comfort as well as travel delay in exchange for a lower ride price.

A special type of ride-sharing is carpooling, in which one of the riders is also the driver and the car owner. A challenge facing carpooling is that the economic benefit of sharing a ride, which is immediately evident in the case of ride-sharing, might not be apparent to the driver who should make her car available for pooling. For this reason, carpooling typically finds application in two contexts: in long, extra-urban trips, and in home/work commuting. In the former case, the length of the ride and the implied gas consumption render the benefit of pooling evident to the driver. This is the model adopted by successful start-up companies like BlaBlaCar. In the latter case, it is the repeated nature of the trips, possibly coupled with incentives provided by the employer, that provide a clear motivation for the driver to share her car.

Vehicle-sharing is another form of shared mobility in which the same vehicle is used to serve multiple trips which do not overlap in time. Different mobility services belong to this category, such as car-sharing services where cars must be picked up and returned at specific locations (e.g., Zipcar), or at any point (e.g., Car2Go). Also, traditional taxi services can be considered as a form of vehicle-sharing in which the professional driver "connects" multiple trips by driving from a drop-off point to the next pick-up location.

Vehicle- and ride-sharing can also be combined. This combination is manifested in recently introduced on-demand mobility services such as UBERPool and Lyft Line.

It is important to note that shared mobility per-se does not imply improved carbon efficiency with respect to the use of private vehicle. An example referring to ride-sharing is reported in Figure 1. Two trips can potentially be shared. However, if the distance covered to combine the two trips into a single ride (C+B+D) is larger than the sum of the single trip distances (A+B), then the total traveled kilometers of the shared ride would exceed those of the two single rides, actually *worsening* the carbon footprint of the shared ride. Similarly, vehicle sharing typically implies an increase in total traveled distance due to the need of “connecting” two trips and to serve them with a single vehicle instead of two. Thus, the widely reported benefit of reducing carbon footprint and traffic associated to shared mobility – which is also extensively used by online shared mobility platforms to market their services – can be accomplished also if rides are matched according to well-designed, carbon emission-aware algorithms.

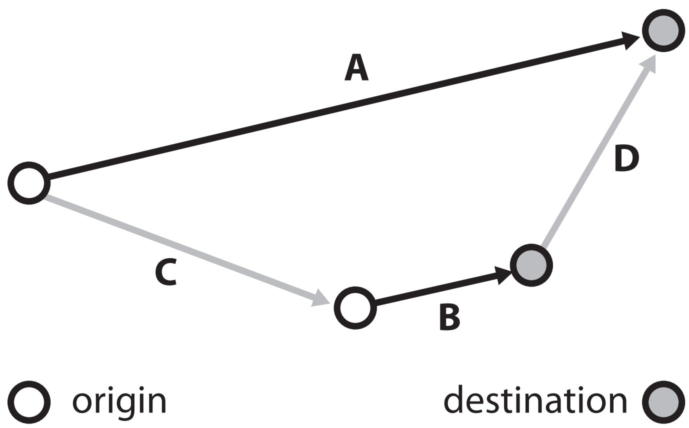


*Figure 1*. Sharing a ride is not always convenient from carbon footprint viewpoint. Black arrows represent original trips; gray arrows represent detour trips needed to pickup the second passenger.

**The need for quantitative tools**

As the example presented in the previous section has shown, understanding whether the current trends towards shared mobility will result in actual benefits in terms of traffic and emission reductions is not straightforward, and requires the development of adequate algorithms, models, and analytical tools that allow quantifying the effect of sharing trips at the urban scale. The resulting quantitative toolkit could be used to better inform the city planning and political decision-making process in the challenging endeavor of re-designing urban regulations, policies, and developing social actions to accommodate these new forms of mobility, and to suitably integrate them with existing mobility systems. This is likely the best strategy to take full advantage of the opportunities presented by shared mobility and to draw an environmentally sustainable path for the predicted growth of urban population.

Developing accurate, city-level quantitative tools for shared mobility systems is, however, very difficult. Considering for instance the problem of how to optimally match rides at the city scale – with the objective of, e.g., minimizing total traveled distance and, hence, emissions –, the challenge comes from the very large number of possible combinations between potentially shareable trips to consider. For example, the average daily number of taxi trips in New York City is about 450,000 [8], implying that the number of possible combinations to consider is in the order of $10^{12}$.

Traditional approaches to the problem of optimizing shared rides are based on so-called dynamic pickup and delivery" problems [9,10], in which a number of goods or customers must be picked up and delivered efficiently at specific locations within well-defined time windows. Such problems are typically solved by means of linear programming, in which a function of the system variables is optimized subject to a set of equations that describe the constraints. Whereas linear programming tasks can be solved with standard approaches of Operations Research or with constraint programming [11], their computational feasibility heavily depends on the number of variables and equations, e.g., the pickup and delivery time windows of each customer, used to describe the problem at hand. Most shared mobility studies have therefore focused on small-scale routing problems, such as within airport perimeters [12,13]. As we have seen, large urban mobility systems, in contrast, involve thousands of vehicles performing hundreds of thousands of trips per day.

Recently, an innovative, network-science based approach to tackle city-level shared mobility modeling has been introduced by a research team lead by MIT Senseable City Lab [14]. The key idea is expressing sharing opportunities between trips through a network called *shareability network*, which is pictorially represented in Figure 2 and we briefly describe below.

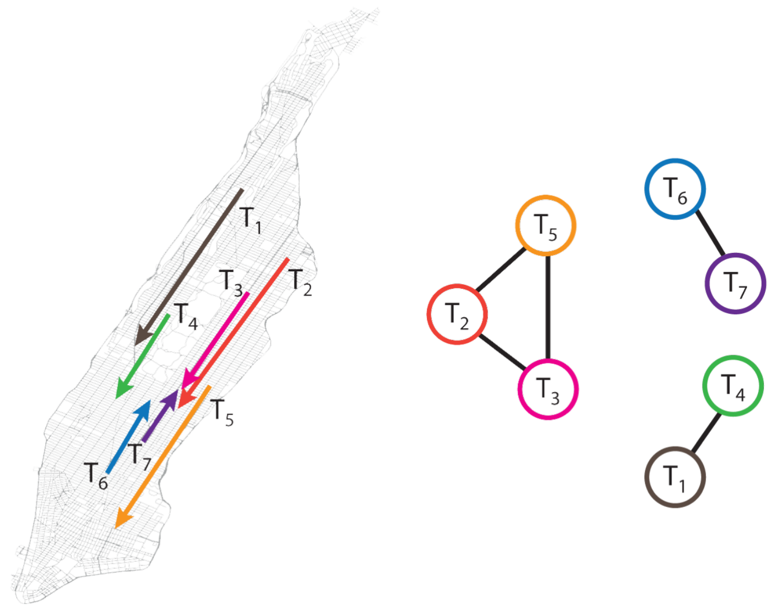


*Figure 2*. From taxi trips (left) to shareability networks (right).

Consider any two trips $T_i$ and $T_j$ characterized by a starting time *t*, an origin *o*, and a destination *d*. Observe that, if we were to combine the two trips into a shared ride, a certain sharing delay $\delta_i$ might be incurred by the passenger of $T_i$ due to the likely detour needed to get the passenger of trip $T_j$ on board, or vice-versa (recall Figure 1). The sharing delay can be used as a parameter to determine whether trips $T_i$ and $T_j$ can potentially be combined into a shared ride: if it is possible to find a route touching the four endpoints of the trips (e.g., $o_i$, $o_j$, $d_j$, $d_i$) such that both passengers arrive at their respective destination with delays $\delta_i$, $\delta_j$ not larger than $\Delta$, where $\Delta$ is a parameter set, say, to 5 *min*, the two trips are considered shareable and a link is added between the corresponding nodes in the shareability network. This is the case, for instance, of trips $T_2$ and $T_3$ in Figure 2. On the other hand, if for all possible routes the sharing delay incurred by passengers exceeds $\Delta$, then the corresponding trips are not considered as candidate for ride sharing, and no link is added in the shareability network. See, for instance, trips $T_1$ and $T_3$ in Figure 2.

By considering all possible trip pairs[1], it is possible to build the shareability network representing ride sharing opportunities in the city. Then, maximum matching algorithms [15] can be used to efficiently determine the best possible way of pairing trips according to the chosen criteria - e.g., minimizing total traveled miles.

The above described approach has been used in [14] to show that, with a passenger delay of at most 5 minutes, more than 95% of taxi trips in New York can be shared, with a resulting 30% reduction of total travel time, and, consequently, emissions, needed to accommodate all taxi requests. The quantitative study has been recently extended to three other cities (Singapore, Vienna, and San Francisco) [16], and has found that the impressive benefits implied by sharing taxi rides in the city of New York occur in a similar way in the other cities. Motivated by this observation, the authors of [16] have derived a *predictive* mathematical model that, given a few urban parameters (city area, trip demand density, and average traffic speed), accurately estimates the fraction of rides that can be shared. This is an important result as it shows that, starting by effective shareability models fed with real-world data, and by characterizing the resulting optimal sharing solution, it is possible to discover shareability trends conducive to the definition of a "general law of ride sharing" that applies to a multitude of cities. This is an example of the kind of analytical tools needed to inform planning, regulation, and political processes related to shared mobility as described at the beginning of this section.

[1] Indeed, optimization based on trip starting time substantially reduces the number of trip pairs to

Other analytical tools will be needed to fully understand the effect of shared mobility at the city scale: for instance, tools that allows characterizing vehicle-sharing benefits, and those resulting from the optimal, carbon footprint-aware integration of ride- and vehicle-sharing mobility models.

## Conclusions

The evolution of personal urban mobility into shared, on-demand, and increasingly autonomous services is challenging not only existing industry and mobility operators, but also urban planners, policy makers, and the society at large. Potentially, ride- and vehicle sharing could transform the way we move and enjoy cities. However, as discussed in this paper, the issues and challenges related to this transformation need to be discussed and addressed. In particular, we have developed some initial tools and ideas to provide accurate shared mobility models. More of these tools, and their integration with human behavioral, microeconomic, and social models are needed to further our understanding of how pervasive shared mobility will evolve in the future – and how it will affect our cities.

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