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TRIP SHARING IN THE ERA OF SELF-DRIVING CARS

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ABSTRACT

Advances in information technologies have increased our participation in “sharing economies”, where technology that allows networked, real-time data exchange facilitates the sharing of living spaces, equipment, or vehicles with others. To quantitatively assess the environmental impact of trip sharing, we recently developed a network-based method which efficiently solves spatio-temporal sharing problems. Using this method and a massive data set of taxi trips in New York City, we found that the cumulative trip length of all taxis in the system can be cut by 40% if passengers are willing to share a cab. Here, we discuss first practical implementations of trip sharing and its possible impacts, blurring the line between individual and mass transportation.

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Quantifying the benefits of trip sharing today

Advances in information technologies have increased our participation in "sharing economies", where technology that allows networked, real-time data exchange facilitates the sharing of living spaces, equipment, or vehicles with others.[1] To quantitatively assess the environmental impact of vehicle sharing in the context of individual trips, we recently developed the method of shareability networks which translates spatio-temporal sharing problems into a graph-theoretic framework that provides efficient solutions[2]. Applying this approach to a data set of over 150 million taxi trips in New York City over a full year, we showed that the cumulative trip length of all taxis in the system can be cut by 40% if passengers are willing to share a cab, while incurring minimal inconvenience. The benefit of sharing comes with reductions in service cost, emissions, and with split fares, hinting toward a wide passenger acceptance of such a shared service if remaining psychological barriers can be overcome.

In our quantitative assessment of trip sharing, we approached the issue from a computational and graph-theoretical perspective. Every trip can be understood as a node in a so-called shareability network, and two nodes are connected if they could potentially be shared, subject to spatial and temporal restrictions. In effect, only trips can be shared that start at similar times and have similar pickup and drop off locations (or where one pickup location lies along the route of the other trip). The solution to the trip sharing problem is then given by the algorithm of maximum matching, which tries to optimally pair up nodes in the shareability network. Extensions include sharing of more than $k = 2$ trips demanding a computationally more intensive maximum matching solution on a hypergraph, or tuning time window parameters allowing a denser solution space but requiring passengers to pre-determine their itineraries in advance or to incur longer delays.

Practical implementations of trip sharing and its impacts

Carpooling has for a long time been a wide-spread, self-organized phenomenon in large parts of the world[3], in the US first motivated by the oil crisis in the 1970s. In most parts of the world where carpooling is common, and during the 1970s in the US, economic incentives outbalanced the psychological barriers on which successful carpooling programs depend: giving up personalized transportation and accepting strangers in the same vehicle. Today, carpooling is experiencing a comeback in the Western world, fueled by the wide penetration of smartphones and real-time apps, by shifts of cultural norms, and possibly by the recent global recession which increases economic incentives to share goods with others. Implementations leveraging mobile technologies and algorithms that *dynamically* bring together strangers on their trips are rather recent, see for example Bandwagon (bandwagon.io), Uberpool (blog.uber.com/uberpool), Lyft Line (www.lyft.com/line), or Ride (www.ride.com). The immediate impact of such dynamic carpooling solutions is not yet clear, however, judging from comparable "disruptive" innovations and their consequences on traditional industries, e.g. Uber and the taxi industry, Airbnb and the hotel industry, or Zipcar and the automotive industry, the impact of trip sharing is potentially as groundshaking and in line with the "gales of creative destruction" expected to naturally occur in non-equilibrium economies[4]. In this view, shocks in the technological ecosystem that arise from innovation lie at the heart of economic growth[5], observed permanently throughout human history, for example, by the automobile abruptly replacing the horse carriage. Impacts on urban life may include:

- **Blurring the line between private and public transportation.** The present cultural move from ownership to accessibility[1] implies a possible dramatic impact on urban life, where cars do not anymore serve single individuals or individual households only, but are shared by communities or the public serving multiple individuals in novel pay-for-use models. This approach, coming with an increased uptime of vehicles and dramatically improved efficiency in their usage, will have significant beneficial effects on our wasteful utilization of public space today, where cars are estimated to spend roughly 95% of their time in parking spaces[6], with unforeseen consequences on urban planning, e.g. re-appropriation or greening of unused spaces, etc.
- **Blurring the line between individual and mass transportation.** For computational reasons, our shareability network approach considered only sharing of up to $k = 3$ passengers per cab[2]. In the case of the New York City taxi system, optimal benefits were achieved for the sharing of $k = 2$ passengers, implying that the overhead for extending vehicle capacities to $k > 2$ might not be justified. However, it is possible to imagine scenarios in which such extensions might be preferable. For example, cities with different topologies or population distributions, specific collective commuting patterns or different trip purposes (commuting, shopping, leisure), might provide increased sharing benefits when more than two passengers can share a trip. In such cases, a multishared taxi service will require vehicles of higher capacity, blurring the line between traditional taxi services and bus services, Fig. 1. Vehicle sizes could be adapted to the particular scenario at hand. To avoid psychological barriers hindering individuals from being seated in the same vehicle, it is possible to imagine vehicles with physically separated, private compartments, extendable in a modular fashion. Alternatively, reputation marketplaces or recommendation networks could facilitate trust between passengers[7].

  It is open to which degree the changing landscape of cities, e.g. increased polycentric and/or dispersed forms of living together[8,9], will facilitate the adoption of dynamic, shared modes of transport. However, there are good reasons to expect that traditional, inflexible forms of mass transit, which sometimes generate higher emissions per traveled mile than individual modes of transport due to low occupancies outside of peak hours, will soon become inadequate.
- **Decreased outdoor air pollution.** The World Health Organization has estimated that over one million deaths per year can be attributed to outdoor air pollution worldwide[10], to a large part caused by road traffic[11]. Less vehicles on the road will mean less deaths through pollution, given we are able to deal with unintended consequences, see section "Dealing with

unintended consequences” below.

- **Economic benefits from reduction of wasted time and fuel.** Due to synchronized mobility patterns and intrinsic emergent features of road traffic that can lead to congestion even under perfect conditions[12], our daily commutes are characterized by traffic jams. Traffic congestion comes at a great monetary cost: The amount of wasted time and fuel caused by congestion has been placed at more than USD 60 billion in the US alone[13]. Reducing urban traffic through trip sharing implies a reduction of traffic jams, hence a reduction of wasted time and fuel.

Figure 1: **Flexible forms of trip sharing blur the line between individual and mass transportation.** The cartoon shows a taxi with different capacities that could be flexibly adjusted to be most efficient for the sharing scenario at hand. These scenarios could depend on the trip purpose (commuting, shopping, leisure), on the topology or on the population distribution of the respective city/region. Vehicles could come with physically separated, private compartments, to avoid psychological barriers hindering individuals from being seated in the same vehicle, that are extendable in a modular fashion. Further, the vehicle on the right would differ from a traditional bus service due to its dynamical, real-time routing capability.

Self-driving technology multiplies the environmental benefits of trip sharing

While our study of trip sharing in the present[2] did not explore the speculative dimension of an imminent world in which driverless technology is ubiquitous, its results are readily applicable to this scenario and have the potential to further multiply environmental benefits in various ways. In fact, due to the missing driver – typically the vehicle’s owner – driverless technology provides an additional motivation to give up ownership, further facilitating the move towards accessibility and the shared use of common goods, including savings of parking space due to increased uptime. While trip sharing has the potential to decrease the number of vehicles needed by up to 40%, self-driving technology – besides motivating to share vehicles – has the potential to multiply these savings due to efficient stacking, requiring no space between cars on the sides or in front.

Moreover, due to their efficient real-time control algorithms, driverless vehicles have the added benefit of not requiring the two-second human reaction time between vehicles, therefore saving additional road space while driving. The saved time and increased environmental benefits are probably most apparent in autonomous intersection controllers that seamlessly merge together traffic streams of autonomous vehicles, allowing traffic to flow smoothly across intersections[14], Fig. 2.

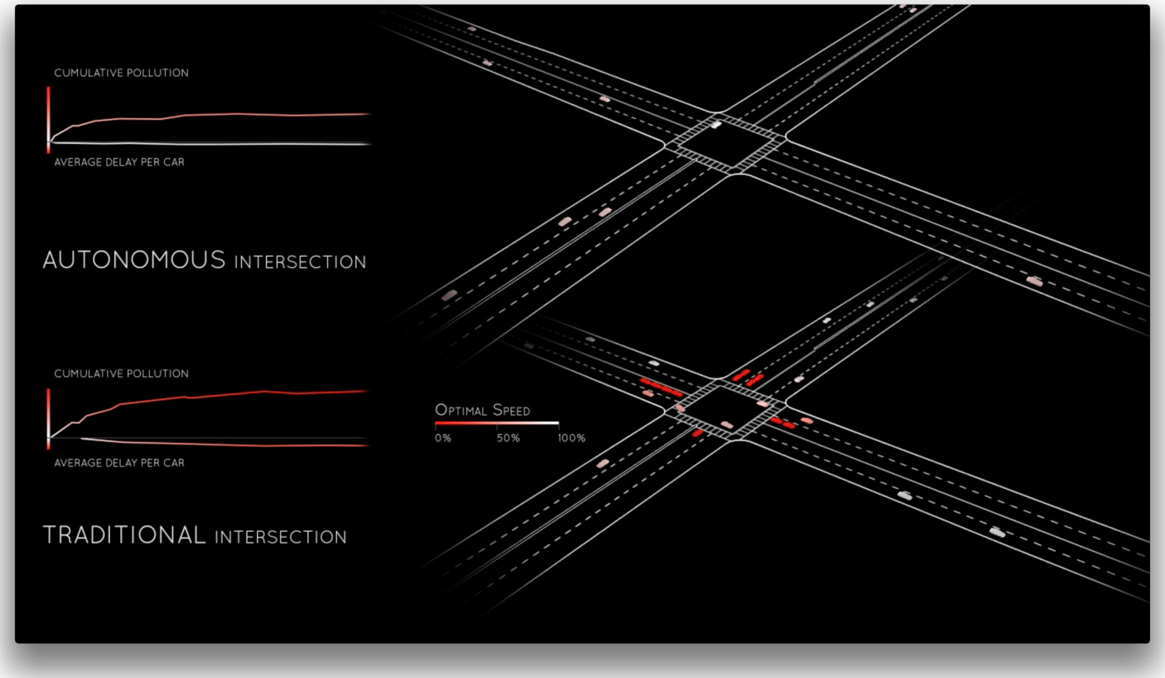

Figure 2: **Autonomous intersections will save considerable time and reduce pollution.** Autonomous vehicles and automated controllers will change the way how cars flow through the city, allowing traffic to flow smoothly across intersections, bringing an end to traffic lights. (Image credit: MIT Senseable City Lab[14])

Dealing with unintended consequences

In our speculations, future plans, and in our policy making decisions, we must always be aware of the complex nature of cities and collective human behavior, by which parameters depend nonlinearly on the system, often leading to unintended, paradoxical consequences when changed[15]. For example, a naively implemented, cheaper shared taxi service might drive away commuters from traditional, more energy-efficient modes of mass transportation, leading to a substitution effect with effectively increased emissions[16]. In such cases, careful investigation of the whole system and adequate policy making could develop a multimodal ride system with the goal of maximizing a city-wide utility function to stipulate “carbon footprint”-optimal fares[17], for example, to ensure environmental sustainability. This function should also consider long-term health benefits and quality of living, for example to convert vehicular road space to biking or walking spaces wherever possible, such as in areas where short trips are dominant.

Further, in contrast to the widely adopted naming convention, we are facing the insight that today’s biggest sharing economies are mostly access economies and often not about sharing at all[18], possibly leading to increased social alienation – which could, for example, be an unintended consequence of our suggestion of physically separated compartments in shared vehicles, Fig. 1 – or to increased wealth inequality if profits and access to opportunities are not passed on fairly[19]. To avoid such undesirable negative consequences, critical and systemic socio-economic monitoring should accompany wide-spread implementations of disruptive innovations to guarantee the improved well-being of the whole of society rather than just of a privileged minority.

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