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How much is trust: The cost and benefit of ridesharing with friends☆

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ABSTRACT

Ridesharing with social contacts (i.e., 'friends') is substantially more accepted than with strangers. However, limiting ridesharing to friends while rejecting strangers also reduces ride choices and increases detour costs. This work studies, from a theoretical perspective, whether the additional detour costs of limiting shared rides to social network contacts would be prohibitive. It proposes a social network based ridesharing algorithm with heterogeneous detour tolerances for varied social contacts. The theoretical matching rates and detour costs are compared in a simulation for three levels of social connectivity: travelling with direct contacts only, with direct and indirect contacts, or with anyone. The simulation allows for a systematic and comprehensive testing of system behaviour when varying the parameters of social network structure, detour tolerance, and spatial distribution of friendship. Results show that for a clustered friendship – the expected spatial distribution of a social network growing with a ridesharing network – ridesharing with friends does not cause significantly higher costs. Furthermore, the algorithm prioritising friends can substantially increase the matching of friends. An empirical study justifies the findings.

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1. Introduction

The growing amount of cars on the road results in increasing congestion of urban traffic, which then leads to higher fuel consumption, longer average travel time, more environmental pollution, and less patience of people with their daily travel (International Transport Forum, 2013). One known way to reduce the traffic load on the road without harming accessibility is looking for higher occupancy rates per vehicle, i.e., through ridesharing. Trajectory analysis has indicated good chances of ridesharing according to space-time concurrence (Santi et al., 2014). But despite the environmental and economic benefits, there is still a low rate in participation of ridesharing (Amey, 2010; Chaube, Kavanaugh, & Pérez-Quiñones, 2010; Wessels, 2009). The contradiction is partially due to the strong reluctance to share rides with strangers according to some surveys (Chaube et al., 2010; Wessels, 2009). The low willingness for ridesharing with strangers signifies that many of the existing ride opportunities, according to trajectory overlap, are actually inacceptable for a certain person. The preference for travelling with social contacts (a first or second degree socially connected person, hereafter called "friend") seems to be a good reason to limit ridesharing to friends. Realising this argument, Facebook filed recently a patent called "Event-based ridesharing" (Richardson, Petrescu, & Finch, 2016), which allows drivers to select users based on his/her social network connections for an online negotiation on carpooling to an event.

However, a ridesharing system limited to friends has yet to address the impact of missing chances of getting a ride. Ridesharing exclusively with friends while declining offers from strangers may lead to fewer opportunities to get a ride within a given space-time budget and to higher detour costs. This study aims to examine the *theoretical* costs and benefits of ridesharing with friends by systematic and comprehensive variation of parameters in a simulation beyond a particular context. Empirical tests are run as validations. As social networks are gaining attention in travel behaviour research (Arentze & Timmermans, 2008; Hackney & Marchal, 2011), this work helps gain insightful understanding into how spatial structures of social networks affect ridesharing results.

To prove the benefit of ridesharing with friends, two null hypotheses against the objective are to be rejected. The first one is that sharing rides only with friends significantly increases detour cost. The second is that the matching rate is significantly lower with friends than with anyone. These hypotheses are not obvious since detour cost and matching rate are influenced by social similarity and spatial distribution of friends.

The implementation will use an agent-based transport simulation in order to be able to comprehensively vary all relevant parameters and get a theoretical insight into the complex system behaviours. The systematic scenario simulation is necessary for more transferrable findings, because social networks and their spatial distributions vary widely from

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place to place. The theoretical simulation is set up using NetLogo, followed by a validation simulation based on realistic dataset with Repast Simphony (https://repast.github.io/repast_simphony.html) for higher computation efficiency. The model systematically tests different parameter settings; the parameters include the social network structure (average degree of friendship), the spatial distribution of friends (spatially clustered vs. random), and the detour tolerance for different social connectivity levels. Three matching patterns are tested: 1) any driver and passenger must be direct friends, 2) any driver and passenger must be either direct or indirect friends, and 3) no one has to be friends. Two populations of 2000 and 5000 agents, respectively, with small-world social network structures are simulated. Core of the simulation is a proposed algorithm for social network based ridesharing (*SNeRs*). The detour costs and matching patterns will be collected and subjected to statistical analysis.

This paper will be organised with the following sections. Section 2 is a literature review of previous works and findings in ridesharing algorithms and the potential for the inclusion of social network. Section 3 depicts the conceptual framework and Section 4 gives details of both the theoretical and empirical implementations, followed by Section 5 of results and Section 6 of discussions. The major conclusions and future work are given in Section 7.

2. The concern of social network in ridesharing and potential

Ridesharing is a mode of transportation where a driver takes passengers on a non-commercial, e.g., shared cost basis, for accompanied costs such as petrol. Based on trajectory analysis or matching model assumptions (Agatz, Erera, Savelsbergh, & Wang, 2011; Amey, 2010; Dubernet, Rieser-Schüssler, & Axhausen, 2013; He et al., 2012; Santi et al., 2014), a significant portion of inner-urban trips can be merged for ridesharing. For example, Amey (2010) reported a rate of 50% to 77% of the commuting trips to be merged; Dubernet et al. (2013) informed by simulation that about 90% of the trips in Zurich metropolitan area can be matched as 2-person ridesharing. Such observations seem to prove ridesharing a promising transportation mode with potential benefits, such as costs to individuals, reducing traffic amount, and decreasing emissions.

On the other hand, however, the participation rate in ridesharing is known to be a magnitude lower in reality. In the same MIT community, only 8.2% of the community population chooses to share rides (Amey, 2010). Trust (for safety and comfort) is pointed as one of the most influential obstacles for ridesharing (Amey, 2010; Chaube et al., 2010; Wessels, 2009). People are significantly less willing to share a ride with strangers than with direct or indirect friends; and even if they do, they have much lower detour tolerance for strangers. Chaube et al. (2010) reported that 98% of the population of Virginia Tech university community would accept a ride from a friend, 69% accept from a friend of a friend, and only 7% from a stranger. By microsimulation, Dubernet et al. (2013) justified behavioural factor as the most limiting factor of ridesharing, which strongly substantiates the significance of our work. Brereton, Roe, Foth, Bunker, and Buys (2009) also emphasised the necessity of involving social network into ridesharing based on their technology review, but did not give a concrete solution.

In addition and related to matching preferences, the ridesharing demand analysis on the University of Maryland campus points out the significance of service flexibility as a key factor to ridesharing (Erdoğan, Cirillo, & Tremblay, 2014). This is coped in this work as different detour tolerances with varied friends. Wessels (2009) reports the detour tolerance for ridesharing with a friend is about 25% of the shortest possible travel time, while it can be as low as about 6% for a trip with strangers. Thus, despite fewer opportunities for ride choices with friends, the higher tolerance might lead to a substantially higher uptaking rate of ridesharing.

Many ridesharing algorithms have been developed so far. Furuhata et al. (2013) classifies these matching approaches into six categories: dynamic real-time ridesharing, carpooling, long-distance ride-match, one-shot ride-match, bulletin-board, and flexible carpooling. Dynamic real-time ridesharing that addresses short-term matching or even en-route matching (e.g., Agatz et al., 2011; Amey, 2010; Deakin, Frick, & Shively, 2010) has a great advantage of flexibility of routes and time. Avoiding the bottleneck of a central planner for dynamic real-time matching, others have explored peer-to-peer solutions considering short-range radio communication between pedestrians' and car drivers' mobile phone apps (Wu, Guan, & Winter, 2008). However, to our knowledge not sufficient existing matching algorithms have dealt with passengers' experience from the perspective of social psychology. Current social network and ridesharing studies make some progress but still fall short in several ways:

- Some studies recognise the importance of social relationships in ridesharing, but only in an indirect way. Häll, Högberg, and Lundgren (2012) considered the cost of passenger discomfort in their simulation of dial-a-ride system by measuring that inexplicitly with excess of waiting and riding time. Kamar and Horvitz (2009) expected the impact of friendship would make a big difference on their simulation outputs, but only as future work.
- Existing algorithms integrating social networks into ridesharing do not investigate social networks in such a systematic and comprehensive way as this study does, nor do they focus on the spatial distribution of social networks. For instance, Gidofalvi, Pedersen, Risch, and Zeitler (2008) suggested a method to group users into ridesharing groups based on the social network structure, but did not discuss the influence of the *spatial* distribution of social network. An algorithm called *Social-aware Ridesharing Group* (*SaRG*) query (Li, Chen, Chen, & Xu, 2015) implemented a swift strategy querying the matching by different combinations of groups of friends extracted from their social network, and found the best combinations to minimise detour cost by a branch-and-bound optimisation strategy. However, *SaRG* did not take into account potential matching chances with strangers or the competition between social contacts and strangers based on their spatial distributions.
- Cici, Markopoulou, Frias-Martinez, and Laoutaris (2014) conducted a few empirical studies discussing the pros and cons of ridesharing with social network, which is a particular example of this present paper that systematically investigates the influence of a spectrum of social networks on ridesharing outcomes. More complicated but realistic factors, such as congestions, can be considered in ridesharing algorithms as well (e.g., Wang, Dessouky, & Ordonez, 2015). They are, nevertheless, beyond the scope of studying the influence of social networks.

This work is significant in at least two senses. First, none of the aforementioned studies considered heterogeneous detour tolerances with different social contacts, though they introduced grouping strategies. Second, the simulation does a systematic check on the influence of *spatial* distribution of social network on ridesharing results.

This research will model the influence of social network on ridesharing by explicitly quantifying different intensities of social relationships. Though difficult to approximate a realistic or claim a representative social network structure, the small world model (Watts & Strogatz, 1998) is built for simulating social networks of the real world that satisfies small-world phenomena (Milgram, 1967). Small world networks have a higher clustering coefficient than a random network, with more triangles and still a few shortcuts between nodes. They do not have heavy-tail degree distribution as preferential attachment networks (Barabási & Albert, 1999). Small world networks simulate the reality of social networks better because of the limited number of friends a person can hold in reality (Dunbar, 1992). Chaube et al. (2010) suggested three levels (intensities) of social relationships, namely, direct (first degree) friends, indirect (second degree) friends, and strangers. Detour tolerance and willingness to share a ride varies according to different levels of friendship. The spatial distribution of

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