Journal of Transport Geography 72 (2018) 131–138

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

Collaborative activity-based ridesharing

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ARTICLE INFO

Keyword:
Ridesharing algorithm
Collaborative travel
Social networks
Time geography
Spatio-temporal index

ABSTRACT

A new ridesharing model called *collaborative activity-based ridesharing* is proposed to enhance not only overall matching rates but also the matches between preferred ride partners. By coalescing the merits of two recently suggested innovative ridesharing models – the *social network-based ridesharing* and the *activity-based ridesharing* – the new model leverages people's preference to their social networks and the space-time flexibility of daily activities to improve the matching outcome. The capabilities and advantages of the proposed model are justified by a group of agent-based simulations in a realistic study area. The influence of geography on the match outcome is discussed in particular.

1. Introduction

Ridesharing, defined in the scope of this paper, is a transport mode that harnesses both private cars and taxis to combine two (groups) of travellers into the same vehicle in an ad-hoc manner, if all or part of the two groups' travels are overlapped in space and time. The ad-hoc manner means rides are matched on variable demands from day to day, or strictly speaking, on real-time demands instead of by pre-arrangement. With its potentials of reducing traffic volume, energy consumption, and travel cost compared to private cars, ridesharing arguably is promising to become popular among the public (Ferreira and D'Orey, 2015). Despite being an attractive concept, ridesharing does not guarantee to encourage uptake.

The challenges of switching to ridesharing are many folds (Amey, 2010), including economic, behavioural, institutional, and technological aspects. Ferguson (1997) analysed the reasons why carpool suddenly declined in the US in the 1980's. He summarised physical (urban form), sociodemographic (auto availability, real marginal cost of motor fuel, age and education, and gender and lifestyle) and economic (fuel cost) factors. While some of the factors still play a role, the story for the internet age seems more complicated when technology can make social changes. Population growth, urbanisation, the wealth increase, and the indicated lifestyle and social status beyond rational economic decisions continue retaining auto ownership and making congestion worse.[1] Meanwhile, the internet and shared economy offer the potential to reduce car ownership.[2] While the old factors retaining car owners may still exist, this paper focus on reducing the barriers switching to ridesharing by proposing a refined *technological* solution.

People are reluctant to share with strangers for safety reasons or to sacrifice time for detour (Amey, 2010; Koebler, 2016; Chaube et al., 2010; Wessels, 2009). Consequently, the uptake potential of ridesharing (Santi et al., 2014; Bischoff and Maciejewski, 2016) might be exaggerated. The two issues of concern are trust and spatio-temporal flexibility. Social ties have an impact on peoples ridesharing decisions: higher willingness of ridesharing and higher detour tolerance are granted to closer social acquaintances (Chaube et al., 2010; Wessels, 2009). Relying on real-life social networks for ridesharing, on the other hand, might threaten the match rate by refusing offers from *nearby* strangers. The outcome is contingent on the spatial distributions of travel demands and of social networks (Wang et al., 2017). However, there is a potential to enlarge the candidate choice set. Given that many daily activities (e.g., grocery shopping) are flexible in terms of space and/or time, travel destinations can be chosen flexibly to fit into ridesharing schedules (Bhat and Koppelman, 1999; Miller, 2005). Opening the choices of alternative destinations hence offers a potential way to enhance the rides between friends: if a shared ride with a friend was originally not feasible, an alternative destination can reverse the situation. Even if there is still no feasible ride from a friend, alternative destinations can still potentially increase the overall ridesharing rates by matching more strangers within shorter distance.

The main contribution of this paper is to propose a new solution for ridesharing to tackle trust and detour flexibility at the same time. In particular, the paper addresses the influence of spatial densities and distributions of social network links and of travel demands, as the basis

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[1] https://www.forbes.com/sites/quora/2017/06/22/what-will-car-ownership-look-like-in-the-future

[2] http://www.businessinsider.com/no-one-will-own-a-car-in-the-future-2017-5

https://doi.org/10.1016/j.jtrangeo.2018.08.013
Received 2 August 2017; Received in revised form 20 August 2018; Accepted 23 August 2018
0966-6923/

to reduce detour while pairing people with some social ties. The proposed approach, *Collaborative Activity-based Ridesharing* (CAR), is a combination of two previously suggested innovative ridesharing models: *social network-based ridesharing* (Wang et al., 2017) and *activity-based ridesharing* (Wang et al., 2016). CAR inherits the trust-based strategy of social network-based ridesharing with heterogeneous detour tolerances and willingness to share a ride with friends versus non-friends. Social network contacts are referred to as *friends* hereafter, defined in the sense of ridesharing collaboration rather than the meaning of “friends” in daily life. In terms of flexibility, CAR expands ridesharing opportunities by considering alternative travel destinations for similar travel aims based on given space-time budget in the same manner as activity-based ridesharing. The combination of the two enables a spatio-social dual index to speed up the search for ride matches.

The hypothesis is that CAR can significantly increase the overall matching rate compared with social network-based ridesharing, and significantly increase the number of matches with friends compared with activity-based ridesharing.

Based on realistic travel demand data, an agent-based simulation for ridesharing pre-planning of a day is built to implement the CAR model. The simulation is run with the pre-generated social networks of small world topology embedded into space. Two spatial structures are investigated in the simulation: random distributions and distance-decays. The simulation is run with multiple methods: trip-based ridesharing, social network-based ridesharing, activity-based ridesharing, and CAR. With different geographic configurations of the underlying social network, results from each simulation are compared to investigate which algorithm comes out as the best in terms of detour cost, the numbers of overall matches and of matched friends. A special focus of the discussion is on the geographic characteristics of the study area, of the population distribution, and of the social network distribution. The findings yield implications on how geography affects the performance of CAR.

The paper is structured as follows: Section 2 is a review of the existing ridesharing models and how geography inspires new ridesharing models. Sections 3 and 4 are the model specification and implementation, followed by the results in Section 5 and discussions in Section 6. Major conclusions and future indications are given in Section 7.

2. A review of ridesharing and its potential

According to the review by Furuhata et al. (2013), ridesharing has its origin since last century and has been quickly developed recently. Though acknowledging the ambiguity of the definition, the authors defined *ridesharing* as “*a mode of transportation in which individual travellers share a vehicle for a trip and split travel costs ... with others that have similar itineraries and time schedules*” (p2, (Furuhata et al., 2013)). They foresaw ridesharing to increase its usability by *on-demand* ridesharing, which emphasises the importance of trust and flexibility due to the lack of pre-arrangement of rides. Despite multiple algorithmic improvements for ridesharing, including real-time en-route planning (e.g., Agatz et al. (2011); Ma et al. (2013); Bischoff and Maciejewski (2016)) and multi-hop ridesharing (Drews and Luxen, 2013), the mainstream ridesharing solutions still fall short in two ways: 1) they ignore the riders' socio-psychological preferences and motivation for ridesharing (Chaube et al., 2010; Koebler, 2016; Wessels, 2009), which results in a low rate of ridesharing compared with its full potential (Amey, 2010; Santi et al., 2014; Bischoff and Maciejewski, 2016); and 2) almost all of the applications are trip-based, with specified fixed origin/destination pairs and thus low flexibility for destination choices.

Trust measures in ridesharing nowadays are mainly captured by peer-rating systems widely applied by such platforms as Uber and Airbnb. Such peer economy, however, is confronted with cognitive challenges due to the lack of legitimacy regularity (i.e., formal rules to regulate the business as traditional corporations), which deteriorates as the platforms grow (Witt et al., 2015). While a peer-rating system provides more information for customers decision-making, it does not solve the problem, for example, that people feel unreliable and unpredictable in their ridesharing schedules. Such bad feeling as lack of reliability is exacerbated when people have bad temper with a stranger (Koebler, 2016).

As a technical solution to the issue, several algorithms have incorporated social networks as a constraint in ridesharing matching. For example, Li et al. (2015) proposed a social network-based group query that matches rides *only* among social network connections. Bistaffa et al. (2015) provided a similar solution. However, these applications are exclusive to friends while missing any offer from a stranger. A possible consequence is a lower matching rate due to less opportunities, compared to non-social ridesharing, which was not further investigated by those authors. Since people accept detour costs only to an acceptable limit (Milakis et al., 2015; He et al., 2016), pursuing a ride *only* with friends can be prohibitive. In contrast, the recently proposed *social network-based ridesharing* (Wang et al., 2017) assigns heterogeneous detour tolerances and ridesharing willingness to different ridesharing partners, including not only friends, but also strangers. In this way, matches between strangers remain possible but matches between direct or indirect friends are prioritized even at higher detour costs. Notwithstanding, the chance to increase ridesharing rates still depends on the spatial distribution and the density of these social networks (Wang et al., 2017).

The *activity-based ridesharing* (Wang et al., 2016) based on time geography might be a solution to the low matching rate of ridesharing by offering alternative destinations for the same travel purpose (namely, the activity at the destination (Bhat and Koppelman, 1999)). Time geography is a set of theories to model accessible resources and feasible human travel behaviours subject to given space-time budgets. The concept can be traced back to the 1970’s (Hägerstrand, 1970), and has later been formalised by computational implementation models (e.g., Miller (2005); Song and Miller (2015)). Time geography induces activity-based approaches (Ellegård and Svedin, 2012) by which multiple locations are selected as candidates to perform an activity (Justen et al., 2013; Fang et al., 2011). Many previous studies have concentrated on adopting time geography for joint activities (Arentze, 2015; Miller, 2013). The space-time constraints in finding accessible locations (for activities), however, are only part of the space-time constraints for a bundled travel containing flexible activities between spatially or temporally non-flexible activities. The latter apparently has stronger constraints requiring matches for the whole movement.

Besides the temporal constraints, the spatial distribution of travel demands and social networks affect matching rates. Tachet et al. (2017) found, regardless of specific geographical contexts across multiple cities, a universal mathematical law between the *shareability* (the maximum number of trips to be possibly shared) of rides and a dimensionless quantity composed of detour tolerance and the density of trips. However, their argument falls short in a few aspects: 1) They do not represent the heterogeneity in travel demand distribution in reality, assuming evenly distributed trips in their simulation and investigating only the urban centres of multiple cities (where population spreads evenly and densely). 2) They estimated an optimistic potential of ridesharing but overlooked people's willingness to share rides that varies with social parameters (degrees of friendship, perceived costs of detours). Vanoutrive et al. (2012) investigated the influential factors for carpooling, a pre-organised ridesharing. They found that different travel purposes (e.g., to home versus to workplace) bounded with their corresponding travel direction yield different carpool rates. With social networks weighing in, ridesharing chances are implicitly shaped by the spatial distribution of social networks. For a monocentric urban form, social networks contribute to higher overlap of trips at outskirts than random pairs, while random encounters in city centre might introduce more shared rides with strangers (Wang et al., 2015). The spatial embedment of social networks is also associated with the underlying function of places and thus travel purposes (Xu and Belyi, 2017). The