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Never drive alone: Boosting carpooling with network analysis

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ABSTRACT

Carpooling, i.e., the act where two or more travelers share the same car for a common trip, is one of the possibilities brought forward to reduce traffic and its externalities, but experience shows that it is difficult to boost the adoption of carpooling to significant levels. In our study, we analyze the potential impact of carpooling as a collective phenomenon emerging from people's mobility, by *network analytics*. Based on big mobility data from travelers in a given territory, we construct the *network of potential carpooling*, where nodes correspond to the users and links to possible shared trips, and analyze the structural and topological properties of this network, such as network communities and node ranking, to the purpose of highlighting the subpopulations with higher chances to create a carpooling community, and the propensity of users to be either drivers or passengers in a shared car. Our study is anchored to reality thanks to a large mobility dataset, consisting of the complete one-month-long GPS trajectories of approx. 10% circulating cars in Tuscany. We also analyze the aggregated outcome of carpooling by means of empirical simulations, showing how an assignment policy exploiting the network analytic concepts of communities and node rankings minimizes the number of *single occupancy vehicles* observed after carpooling.

1. Introduction

There is no need to advocate why traffic and its consequences on the environment, our health and quality of life, and the economy is a major problem for our societies. Carpooling, i.e., the act where two or more travellers share the same car for a common trip, is an old idea brought forward, among many others, to reduce traffic and its externalities. If a large proportion of travellers, especially daily commuters, would adopt carpooling, a substantial traffic reduction could indeed take place. However, experiences from many projects internationally, as we discuss in Section 2, have shown that it is extremely difficult to boost the adoption of carpooling to levels that significantly diminish traffic as a whole. There are many reasons why this happens: psychological, organizational, technological. As a matter of fact, we do not know much yet about the real carpooling potential that emerges from people's mobility—a very preliminary step towards designing the right mechanisms and incentives for a successful carpooling system. Nevertheless, we now have access to the data to observe individual mobility at microscopic level and for large populations of travellers, such as the digitized trajectories of vehicular travels recorded by GPS-enabled on-board devices. These forms of *big data* have been used in [1] to discover the mobility profiles of individual travellers, and to understand when two individuals have compatible matching needs, so that they can share part of their travels. In the present work we

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pursue this approach further, to the purpose of understanding the potential impact of carpooling as a collective phenomenon, by adopting a *network analytics* approach. Based on mobility data from a community of travellers in a given territory, we construct the *network of potential carpooling* for that community, where nodes correspond to the users and each link between user u and user v corresponds to the fact that u can take a lift from v, because there is a trip in v's profile that can serve u (u can be a passenger of driver v). By analyzing the structural and topological properties of this network, we can gain a deeper insight of the potential impact of carpooling. We adapt network analysis tools such as community discovery and node ranking to the purpose of highlighting the subpopulations of travellers that have higher chances to create a carpooling community, and who are the users that show a higher propensity to be either a driver or a passenger in a shared car. Also, we can reason about the propensity of geographical units or cities to carpooling, as well as on the impact on externalities such as CO_2 emissions and costs that can be potentially reduced. Our study is anchored to reality thanks to a large mobility dataset, consisting of the complete one-month-long GPS trajectories of more than 150,000 cars observed in Tuscany, the region of central Italy with Florence and Pisa, during the month of May 2011. The population of observed cars is approximately around 10% of all circulating cars. Our analytic observations are therefore referred to real (anonymous) users and real cities, like Florence and Pisa. Remarkably, our method explores the potential of carpooling in *systematic* travels, e.g., home-work commuting, as opposed to ride sharing in occasional trips, which is the approach of several popular apps (see Section 2). Addressing the issue of sharing systematic trips is clearly more challenging and can have a larger impact on traffic reduction. The ultimate contribution of our study is to analyze the potential aggregated outcome of carpooling in the analyzed networks, using several empirical simulations, in terms of expected number of single occupancy vehicles (SOV) that we observe as a result of carpooling matches that take place. We investigate several possible scenarios, and show how a carpooling assignment that exploits the mentioned network analytic concepts of communities and node rankings is the one with the best theoretical performance, because it reduces significantly the expected number of SOV's observed after carpooling. Although much further work is needed to validate in the real world that mining carpooling networks can boost the adoption of ride sharing among communities of commuters, our study is a first in-depth analysis of the potential impact of the approach, which sheds a new, quantitative view on a mechanism that, like all complex social processes, can only be explained in terms of a dynamic network of interacting actors exhibiting an often surprising aggregated behavior.

The rest of this paper is organized as follows. Section 2 contains a detailed overview of related works, addressing carpooling from many different perspectives. The technical background for our study is briefly sketched in Section 3. Section 4 describes the *Never Drive Alone* approach, from the construction of the carpooling network to the assignment method, through the analysis of communities and the ranking measures. Section 5, after illustrating the large mobility dataset used in this study, provides a qualitative and quantitative assessment of the results obtained. Finally, in Section 6, we discuss possible future developments.

2. Related work

The carpooling phenomenon is a subject widely studied in the literature. It has been analyzed form various, very different points of view. Carpooling is the second most popular way of commuting, and maybe one of the least understood – a fact that probably explains the need for such a large corpus of studies in the literature.

Carpooling received wide attention in the theoretical literature, mainly regarding high occupancy vehicle lanes (HOV) [2–7]. Refs. [2,4] develop models to calculate the benefits gained for eliminating traffic congestion by adding HOV lanes, or by converting general purpose lanes into HOV. Ref. [5] shows that there is no increase in ridesharing related with the introduction of new HOV lanes, despite the carpooling rate among commuters increases in some periods. Others, like [3,6], consider tolls related with HOV and how these can influence their use. Ref. [7] is a study about carpooling related with the economy world that examines carpooling and driver responses to fuel price changes. It shows that traffic flows in mainline lanes decrease when fuel prices increase, and this effect is stronger when the presence of a HOV lane provides a substitute to driving alone.

Another approach widely followed in the literature for analyzing carpooling is the agent based model (ABM) [8–13]. A multi-ABM in conjunction with Dikstra's algorithm is used in [8] to efficiently answer real time users' queries. In [9] an ABM is designed to optimize transports by the ride sharing of people who usually cover the same route. The information obtained from this simulator are used to study the functioning of the clearing services and the business models. In [10] the authors face the problem by using a multi-ABM to investigate opportunities among simulated commuters and by providing an online matching for those living and working in close areas. Refs. [11,14,13] present a conceptual design of an ABM for the carpooling application to simulate the interactions of autonomous agents and to analyze the effects of changes in factors related to the infrastructure, behavior and cost. They use agent profile and social networks to initiate the ABM, then employ a route matching algorithm and a utility function to trigger the negotiation process between agents. In [12] the authors define an ABM for the individual mobility behavior during carpooling, the criteria and the function to constitute the carpooling community and a protocol for the negotiation of the details of the carpooling trips.

Many carpooling works are related with the study and analysis of mobility data to understand the carpooling phenomena [15–22]. In [15], for example, the authors deeply describe the characteristics of carpoolers, distinguishing among different types of carpooler, and

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