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Organizational-based model and agent-based simulation for long-term carpooling

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HIGHLIGHTS

- Design of an organizational model that is mapped to an agent-based simulation model for long-term carpooling.
- It analyzes various effects of agent interaction and behavior adaptation of a set of candidate carpoolers.
- Limit the multi-zonal interactions of agents, to enable communication to trigger the negotiation process.
- A progressive negotiation model on trip start time and driver selection is presented.
- Results in a model for carpooling by dividing the procedure of negotiation and trip execution into separate generic steps.

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ABSTRACT

Modeling the interaction between individual agents becomes progressively important in recent research. Carpooling for commuters is a specific transportation problem where cooperation between agents is essential while executing their daily schedule. Organization-based modeling provides the ability to determine where the relationships between agents exist and how these relationships influence the results. This paper presents both the design of an organizational model that is mapped to an agent-based simulation model and a proof of concept implementation. It analyzes various effects of agent interaction and behavior adaptation for sets of candidate carpoolers. The goal is to limit the interactions of autonomous agents, to enable communication to trigger the negotiation process within social groups. The start of the carpooling process depends on the individuals' objectives and intention to carpool. The success of negotiation highly depends on the trip departure time preference, on the individuals' profile, route optimization and on the effect of constraining activities. In order to cooperate individuals adapt their agenda according to personal preferences and limitations. The carpooling social network was established using results predicted by the FEATHERS operational activity-based model for Flanders (Belgium). From the simulation's discussions, it is possible to portray the real picture of the potential carpoolers throughout their carpooling period. The Janus (multi-agent) platform is used for simulating the interactions of autonomous individuals.

1. Introduction

Modeling the interaction between individual agents becomes progressively important in recent research. Traditional modeling tools have difficulties for handling the complexity of communication, negotiation and coordination that are required in carpooling simulations. A method that is more suited for the interaction of autonomous entities is agent-based modeling (ABM). ABM is an essentially decentralized and individual-centric approach which allows one to understand the interactions of physical particles, and describe many problems of astronomy, biology, ecology and social sciences. ABM has been applied to a broad range of topics in transportation sciences including simulation of vehicles or pedestrian flow, route choice modeling, car-following and lane changing models, and traffic simulation. Organization-based modeling provides the ability to model the relationships between roles played by agents in a system and the contribution of these relationships to the general behavior of the system. It enables a clear representation of structural and strategic concerns and their adaptation to changes in the environment.

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Currently many research areas including transportation behavior need to analyze and model complex interactions between autonomous entities. Carpooling for commuters is a specific transportation problem where cooperation between individuals (agents) is essential. Carpooling is considered to be an effective alternative transportation mode that is eco-friendly and sustainable as it enables commuters to share travel expenses, save on fuel and parking costs, improve mobility options for non-drivers. It also reduces emission and traffic congestion. Change in some factors such as the increase in fuel price, in parking costs, or in the implementation of a new traffic policy, may prove to be an incentive to carpool. In order to commute by carpooling, individuals need to communicate, negotiate and coordinate, and in most cases adapt their daily schedule to enable cooperation. Effective negotiation requires that individuals effectively convey and interpret information to enable carpooling. However, strict timing constraints in the schedule of the day have the opposite effect [1,2].

The aim of this research is to investigate the **effect of time constraints and generalize previous work where cooperating carpoolers were restricted to share the respective home and work areas**. In this case, sets of agents working in a particular traffic analysis zone (TAZ) and living in spatially dispersed zones are considered for co-traveling. Agents' communication, negotiation and coordination in a multiple trip negotiation model are investigated. This is done while taking into account the constraints induced by flexible activity scheduling. The existing studies do not consider the direct interaction between agents in the carpooling except [3] which only allows interactions between agents living in the same TAZ.

In order to observe the effect of limitations to agenda (daily schedule) adaptation, the actions performed by each individual are divided into following steps: (i) decision to carpool, (ii) exploration and communication, (iii) negotiation, (iv) coordination and schedule adaptation, (v) trip execution (carpooling), (vi) negotiation during carpooling and (vii) carpool termination. These steps exemplify a model that represents an extension of the simple but analytically tractable negotiation model for carpooling. The new model is based on an agent-based and organizational-based meta-model [4], in which the role and organization concepts are first class entities. To cooperate on commuting trips, the agents living in mutually different TAZ can interact with others sharing the same work TAZ. A *carpooling social network* is considered. It was established using results predicted by the FEATHERS [5], an operational activity-based model for Flanders (Belgium). The expected travel times between travel analysis zones for the morning peak period, generated by the WIDRS tool [6], are used. The success of negotiation highly depends on the trip departure time decision, on the individuals' profile, on the route optimization and on the effect of constraining activities. Driver selection is based on individual attributes (vehicle ownership and driving-license availability). The ability to carpool for commuting depends on schedule flexibility. The schedule adaptation is limited by the flexibility of the individual schedules. A daily schedule for an individual is a timed sequence of trips and activities of different categories (work activities with fixed or flexible timings). The Janus [7], multi-agent based platform is used: it provides an efficient implementation of agent-based and organizational-based concepts.

1.1. Research objectives

This research presents both the design of an organizational model that is mapped to an agent-based simulation model and a proof of concept implementation. It analyzes various effects of agent interaction and behavior adaptation of a set of candidate carpoolers. The goal is to limit the interactions of autonomous agents, to enable communication to trigger the negotiation process within social groups to find matching partners in order to co-travel. This research results in a model for carpooling by dividing the procedure of negotiation and trip execution into separate generic steps. In this research, a progressive negotiation model on trip start time and driver selection is presented. The purpose of this research is to model (1) how people adapt their daily schedule to enable cooperation and to analyze (2) how the consequent carpooling participation evolves over time. The simulation is aimed to find out what is the share of carpooling among the available transportation modes given behavioral constraints with respect to activity timing.

1.2. Paper's organization

This paper is organized as follows. Section 2 summarizes the related work on agent-based negotiation models, rescheduling activities in a daily schedule, joint activity and trip execution and profile matching in carpooling. Section 3 presents the design of the organization-based model that maps to an agent-based simulation model for the carpooling. This section is divided into two main parts. First, the problem domain is discussed by defining the carpooling process constructed on the bases of individual activity and agendas. The organizational layer and the negotiation model based on trip start times and the vehicle and driver selection are presented in this section. Secondly, the design of an agent domain (solution domain) is presented. The agent's behavior is discussed in detail at the end of Section 3. Section 4 explains the experimental setup and discusses some of the results. Finally, conclusions and future work are presented in Section 5.

2. Related work

In recent years, agent-based simulation has come into the field of transportation science because of its capability to analyze aggregated consequences of individual specific behavior variations. ABM can provide valuable information on the society and the outcomes of social actions or phenomena. The existing works related to the different types of negotiation techniques and models, rescheduling activities in the agenda for a day, joint activity and joint trip execution, and profile matching in carpooling, is presented in this section.

In the first category of the research exertions, the agent-based negotiation models for carpooling are studied. Hussain et al. [8] proposed a single trip negotiation model for carpooling using a simple negotiation mechanism. The authors measured the direct interaction between agents from belonging to a *carpooling social network*. The first implementation used home and work TAZ as well as preferred trip start times and carpool periods determined by uniformly sampling given sets. Hussain et al. [3] extend the single-trip negotiation mechanism into a multiple trip negotiation model (combining the forward and backward commuting trips for a day in a single negotiation) by taking the possibility of *flexible activity scheduling* into account and limit the interaction between agents within small groups based on home and work TAZ. The authors extended the negotiation model by applying constraining activities and by considering the personal daily schedule of each individual. Galland et al., [9] present a conceptual design of an ABM for the carpooling application, that is used for simulating the autonomous agents and to analyze the effects of change in factors of infrastructure, behavior and cost. This model used agents' profiles and social networks to initialize communication and then employs a routing algorithm and a utility function to trigger the negotiation process between agents.

A large body of literature (e.g. Nijland et al. [10] and Guo et al. [11]) has been published about the concept of *rescheduling activities* in a daily schedule of the individuals. This however, considered schedule adaptation to unexpected events as opposed to rescheduling in the context of negotiation to cooperate. Knapen,