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Simulation of city-wide replacement of private cars with autonomous taxis in Berlin

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Abstract

Autonomous taxi (AT) fleets have the potential to take over a significant amount of traffic handled nowadays by conventionally driven vehicles (CDV). In this paper, we simulate a city-wide replacement of private cars with AT fleets of various sizes. The simulation model comprises microscopic demand for all private car trips in Berlin (including incoming and outgoing traffic), out of which the internal ones are exclusively served by ATs. The proposed real-time AT dispatching algorithm was optimized to handle hundreds of thousands of vehicles and millions of requests at low computing times. Simulation results suggest, that a fleet of 100 000 vehicles will be enough to replace the car fleet in Berlin at a high service quality for customers. Based on this, one AT could replace the demand served by ten CDVs in Berlin.

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Keywords: Autonomous vehicles; autonomous taxis; MATSim; fleet size; large-scale taxi simulation

1. Introduction

Ongoing developments of fully autonomous vehicles (AVs) will sooner or later result in commercial autonomous taxi (AT) services. With these becoming available, the attractiveness of driving and owning a car will become substantially lower, making a complete replacement of conventional driven vehicles (CDV) with ATs a possible option for city traffic. Currently, most automakers and several IT companies are developing AVs. Google's self-driving car[1] project may be known best, however, Toyota strives to enter the AT market in a public beta test as early as 2020[2]. Also Uber is doing research in the field[3]. Most recently, General Motors and the ride-sourcing provider Lyft teamed up to develop AT services together[4]. What remains to be seen is the question, when such services will become available, with some people saying it could take decades[5].

The impact of AT fleets has also been part of recent research. It suggests that using AT fleets is beneficial over CDV ownership from the user cost perspective with costs in the US being as low as 0.15$ per mile[6]. In Europe,

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user costs in small to medium-sized cities could be lower than for conventional public transit if some vehicle sharing is conducted[7]. With high annual mileages, ATs are most likely to be fully electric. For the US, this could mean a decrease of green house gas emissions per mile by up to 94%[8]. Albeit hard to quantify, AT fleets will also change the shape of cities, as significantly less room is required to park vehicles.

Determining the fleet size and the number of cars one AT could replace has also been looked at. For Lisbon, a simulation study suggests that each AT could replace ten private cars if rides are shared, and only six otherwise[9]. For Singapore, a study suggest a fleet reduction to one third[10] given that also traditional public transport is converted into AT services, whereas for Ann Harbor, Michigan, a reduction to 15% has been calculated[6]. In another study, carried out for a 'synthetic' mid-size US city of size similar to Austin, a ratio of 1:11 was suggested[11]. Even higher reduction in fleet size was achieved for Stockholm, i.e. between 5% (with ride sharing) to 9% (without ride sharing)[12]. For the Zürich region, up to 90% fleet reduction were calculated[13].

To our knowledge, no simulation research has been conducted combining a large scale (millions of trips) and the microscopic level of detail, including the movement of individual ATs embedded into overall traffic and real-time fleet management.

2. Methodology

In order to evaluate effects of large-scale introduction of ATs, we decided to carry out microscopic simulation of a typical weekday in Berlin. The simulation runs in this study were made with MATSim. The software is open-source and jointly co-developed by TU Berlin and ETH Zürich. MATSim allows a microscopic simulation of agent behaviour at high computational speeds. Thus, it is suitable for large-scale scenarios and has been in use world-wide. It combines a traffic-flow simulation with a sophisticated scoring model for agents as well as co-evolutionary algorithms that can alter daily routines ("plans") of agents. This three-step process is usually applied to some kind of initial synthetic population repeatedly over several iterations until some form of equilibrium has been reached[14].

2.1. Initial scenario

The initial model is based on the BVG-MATSim model for the year 2008–2011[15]. It has been used in several Berlin-related case studies on both public[16] and private transport[17]. The network contains about 98 000 road links and 37 000 nodes. This allows to depict all major and minor roads within the city boundaries as well as all bigger roads in the surroundings. The initial network also contains designated public transit links (used for railway and subway lines).

The synthetic population depicts a typical weekday in Berlin. Agent activities over the day are plentiful. In the original scenario, agents make use of all relevant transport modes. During the course of the day, some 16 million trips are made by all agents. These also include very short trips made by bike or walking.

Traffic flow in the scenario is characterized by a morning peak which is followed by a constant amount of traffic flow during the day leading in a remarkably strong afternoon peak. The split of car and public transit trips (pt) in Berlin is roughly even, with both modes having a share of 35%. This scenario has been validated against car counting stations throughout the city.

2.2. Scenario adaptation

Because this study deals with the issue of replacing private cars with autonomous taxis within Berlin, the scope of the initial scenario was reduced to private cars only. As a result, the network model comprises only links for available for car mode, and non-car trips were not simulated. Also all external trips (i.e. neither starting nor ending in Berlin) trips were removed. All in all, 4.7 million trips are left in the simulation, and out of them, 2.5 million trips are made wholly within the city boundaries. These internal trips were converted into AT trips, resulting in replacing the demand served typically by 1.1 million private cars with a fleet of ATs.

The hourly demand for AT trips over the whole day is presented in Figure 1. As in the original scenario, demand in the is higher than in the morning, which is very specific to Berlin. This figure indicates the afternoon peak hour is critical in terms of the AT fleet size. Figure 2 show the accumulated origins of these converted trips. Over the whole day, most areas of the city have a roughly identical share of incoming and outgoing trips.