Extended Abstract: Quantifying the Benefits of Autonomous On-Demand Ride-Pooling: A Simulation Study in Munich, Germany

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Keywords: Ride-pooling, Mobility Service, Mobility On-Demand, Traffic Impact, VMT, Detour

With the advancement in communication technology, On-Demand Mobility (ODM) services quickly emerged to a sizeable market share in a very short time. Taking into account the fast advancement in autonomous driving, it will soon be a reality that the largest cost component, the driver, will be removed from the business model and consequently, the fast surge in popularity of ODM services is likely to become even more rapid. Even though these services might be very beneficial for users in terms of convenience, comfort and safety, in most cases there is hardly any benefit on the network system in terms of vehicle miles travelled (VMT), because the occupancy is still one person per vehicle. On the contrary, zero-occupancy trips to pick up customers even increase VMT.

A possible solution to increase the occupancy and decrease the number of vehicles on the streets could be sharing trips or part of the trips between multiple ODM users at the same time, which we denote as on-demand ride-pooling. This mode of transport combines the benefits of public transport, in terms of costs sharing, and the flexibility of a private vehicle, in terms of offering door-to-door transportation.

Considering the before-mentioned benefits of this system, associated with the anticipated increase in market share, on-demand ride-pooling might contribute to an improvement of traffic conditions and therefore, reduction in pollution.

The main goal of this study is to quantify the traffic impacts of an Autonomous On-demand Ride-Pooling system (AODRP). For this reason, we present an agent-based simulation model including a rather realistic customer behavior and customer-operator interaction and a highly efficient and highly effective ride-pooling algorithm. The performance of an AODRP and therefore its impact on VMT is highly dependent on the considered customer behavior and the service model.

We consider a customer model, which is rather restrictive in the sense of its time constraints, but on the other hand guarantees high service for the users of such an AODRP. We take into account an earliest time and two different latest times a customer is allowed to be picked up. The operator first tries to serve the customer within the first latest pickup time and if this is not possible within the larger second latest pickup time. In reality, after a customer sends a request to the operator indicating he wants to use his service, this customer should receive an answer telling if and when he will be picked up. Therefore, in case the operator is able to serve a request, he creates an offer consisting of time interval for ensured pick up. The customer may also decline this offer. This is modelled by a pickup time dependent probability distribution. To facilitate pooling of shareable trips, customers need to accept a certain amount of detour within their trip. The influence of this critical parameter on the performance of the AODRP is observed by variation of this parameter.

This customer model is implemented within an agent-based simulation framework consisting of two agents: on the one side an operator offering the AODRP system by controlling a fleet of vehicles and assigning jobs to these vehicles to serve the customers, and those customers on the other side. The vehicle jobs consist of a sequence of routes to serve a set of requests and thereby satisfy the customer constraints described in the previous paragraph. The operator assigns the jobs in such way, that the fleet operates optimally, measured in our case by maximizing the number of served customers and the driven distance that can be saved by these jobs due to pooling.

The evaluation of all possible jobs and the optimal assignment to the vehicles is a computationally highly complex task. Many algorithms for solving the matching-problem have been proposed, each resulting in a trade-off between complexity and therefore optimality and computational time. In this research we implemented two different algorithms to show their impact on the systems performance. The one algorithm is an advanced, highly effective ride-pooling algorithm considering all of the systems' possibilities combined with a global optimization. The other one is based on a basic insertion heuristic. First results show that the choice of the matching-algorithm is crucial for allowing statements on the impact of an AODRP.

To demonstrate this methodology, a case study in Munich, Germany is considered. Simulation of several scenarios with different demand allow the examination of the performance of such a system and its impacts on VMT. The model's customers are generated from private vehicle trip data with different penetration rate to observe how the traffic state is changed by replacing private vehicle trips with the AODRP system. Simulations are performed on Munich's street network in an operating area defined around Munich's center. Travel times on street sections are precomputed using a micro simulation. Vehicles move on the network corresponding to these deterministic travel times, which are updated every hour of simulation-time to incorporate different traffic states.

We evaluate the impact of the AODRP on the traffic state by comparing the driven distance of the vehicles during one day of simulation and the direct distances of all customers, that have been served by this service. We observe, that even with the strict constraints in our customer model, VMT in the network can be reduced when a certain market penetration is exceeded. This transition between additional VMT due to empty vehicle trips and reduced VMT due to pooling is highly dependent on the allowed detour per customer and on the used matching-algorithm. Moreover, due to the strict constraints to model customer behavior in the AODRP framework, hardly any matches of three or four passengers in a vehicle are observed. Nevertheless, even by matching only two passengers in a vehicle, the VMT in the network can be improved significantly when compared to a system without pooling service.