Optimized Route Planning for Station-Based Ride-Pooling Services using a Digital Twin

Master‘s Thesis of Akshay Gupta

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Introduction

Exploring the synergy between ride-sharing and **digital twin** technology, the focus is on optimizing route planning for **station-based ride-pooling** services, particularly in Ingolstadt's urban traffic management. Assessment includes **fleet setups**, **station placements**, and route planning methods, aiming to enhance efficiency and sustainability. This involves investigating **user travel time**, **emissions**, and **time loss** due to traffic, providing valuable insights for policymakers and urban planners.

Literature review

Various studies explore route planning algorithms for ride-pooling services, including Wang et al. (2019) and Hasan et al. (2019), highlighting potential efficiency and sustainability improvements. Station-based ride-pooling impacts traffic simulation, as seen in works by Zwick et al. (2021) and Salman et al. (2023). Wilkes et al. (2021) present fleet simulation models showing ridesharing's potential to replace private cars efficiently. Ride pooling reduces vehicle demand, as estimated by Zwick et al. (2021) and Cristóbal et al. (2018). Accurate demand estimation, essential for station-based pooling, is explored by Asady (2023) and Pfundstein (2023). Despite limitations, optimized station arrangements and fleet sizes can enhance station-based ride-pooling services, fostering sustainable urban transportation.

Methodology

The methodology employed in this study utilizes the **SUMO** traffic simulation framework in conjunction with the **FleetPy** fleet simulation framework, integrated via **TraCI** for real-time interaction with the traffic simulation. Initially, the road network of Ingolstadt was transformed from edge-to-edge to node-to-node format to ensure compatibility with FleetPy and again to edge-to-edge for simulating. Four different scenarios were simulated, firstly the base scenario utilizing door-to-door service and subsequent scenarios using existing bus stops as boarding and alighting points while others use virtual bus stops spaced 600m or 200m apart. Different fleet sizes were tested based on two demand sets: one derived from MiD data and the other randomly converting 10% of private car trips to taxi trips. The simulation generated results on travel time, time loss due to traffic, and emissions, forming the basis for analysis and conclusions.

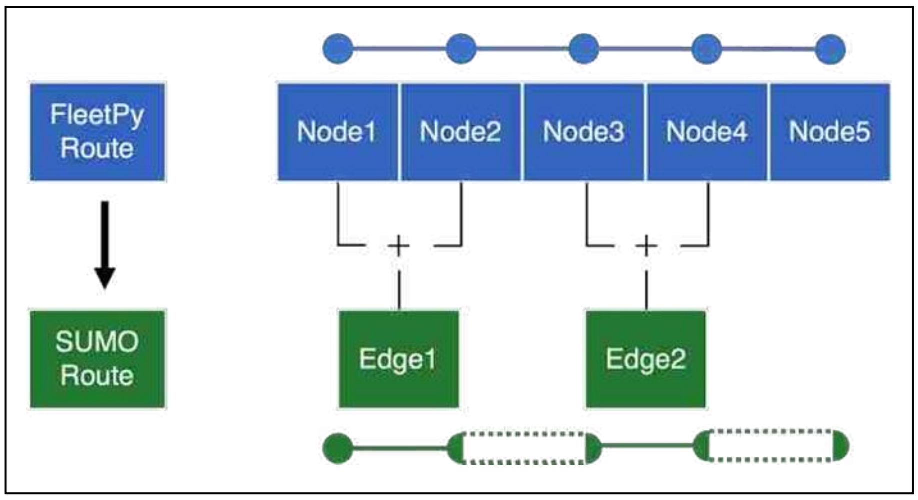

Fig. 1 FleetPy to SUMO conversion of route (Christof Pfundstein, 2023)

Results

In examining transit efficiency, numbers play a crucial role, showing us trends and the best ways to operate. Take, for example, the longest travel time of 1312.57 seconds in stop-to-stop travel when there are 450 vehicles running smoothly with a 99.8% service rate. On the other hand, the shortest travel time is 842.62 seconds for door-to-door trips, but with a lower service rate of 47.4%. Somewhere in between lies an average of 1125.62 seconds for trips with stops only 200m apart, using 450 vehicles with a service rate of 78%.

When we look at pollution, carbon dioxide (CO2) is the primary concern. We see emissions ranging from 0.99 metric tons in scenarios with stops 600m apart and 250 vehicles to 1.36 metric tons in door-to-door travel with 450 cars. However, the best scenario emits only 1.08 metric tons, happening in the stop-to-stop setup with a service rate of 99.8%.

Efficiency in time matters too. In random demand situations, we can face a wait of up to 235.02 seconds, but we can also experience as little as 191.6 seconds of waiting time when using existing stops wisely, with 450 vehicles and a 99.8% service rate. The best waiting time comes in at 225.48 seconds for stops spaced 200m apart with the same fleet size. When dealing with Mid Demand scenarios, similar trends emerge. The highest waiting time is around 303.66 seconds, but the lowest, and thus the best, is 191.6 seconds, using existing stops with 35 vehicles and a 100% service rate.

Discussion & Conclusion

It is evident that varying fleet sizes and station distributions significantly influence service rates, emissions, and time loss. The findings highlight the importance of striking a balance between these factors to achieve optimal outcomes in urban transportation. Specifically, the analysis reveals that ride-pooling services offer notable advantages over traditional taxis in terms of reduced emissions and time loss, particularly in scenarios with carefully planned station distributions and fleet sizes. Encouraging user walking and implementing strategic route planning emerge as crucial strategies for promoting a sustainable urban transportation ecosystem. Moving forward, future research should focus on refining optimization strategies tailored to different urban contexts, ultimately contributing to a more efficient and environmentally conscious future of urban mobility.

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