Lecture Notes in Mobility

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Transport Transitions: Advancing Sustainable and Inclusive Mobility

Proceedings of the 10th TRA Conference, 2024 Dublin, Ireland - Volume 6: Connected Mobility Ecosystems

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Lecture Notes in Mobility

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Fleet and Traffic Management Systems for Conducting Future Cooperative Mobility

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Abstract. As urbanization continues to increase worldwide, cities face the challenge of accommodating growing populations while maintaining efficient and sustainable transportation systems. The advent of connected and autonomous vehicles promises transformative changes in urban mobility. This paper addresses developments and innovations aimed at seamlessly integrating CAVs into the complex urban mobility ecosystem. It presents assumptions related to a fleet of fully connected and autonomous vehicles coordinated by traffic management centers and focuses on optimizing route assignments based on various performance metrics, including travel time, energy consumption, congestion, and emissions. We are also exploring the integration of people and goods mobility by leveraging the cost efficiency and versatility of on-demand autonomous services.

Keywords: traffic management · fleet management · CCAM · load-balancing; demand-responsive transportation · multimodality · traffic simulation

1 Introduction

In the coming decades, the massive irruption of connected autonomous vehicles will lead to a profound transformation of the transportation sector and the mobility ecosystem. Cooperative connected autonomous mobility (CCAM) is one of the keys to achieving higher levels of road safety and greater environmental efficiency. However, transportation managers and service operators should be prepared to manage the demand and impact of these mobility services on the network to realize their full potential.

This paper describes how the Horizon Europe project CONDUCTOR [4] will improve traffic management and prepare for the entry of CCAM through the development and integration of advanced traffic and fleet management tools. These tools are based on machine learning, data fusion techniques, and traffic simulations. They will

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enhance the capabilities of authorities and operators, making them true conductors of future mobility networks. The solution portfolio will be demonstrated in complementary environments in different regions of Europe. Specifically, this paper describes the solutions developed for the management of traffic disruptive events and the integration of urban parcel distribution with on-demand passenger transport in the presence of CCAM services.

2 Introducing Connected Autonomous Vehicles into the Mobility Ecosystem

Various components are developed to demonstrate integration of Connected Autonomous Vehicles (CAVs) into urban transportation.

2.1 Traffic Management and Fleet Management Optimization Developments

In the context of the CONDUCTOR project, a relevant part of the developments relates to the use of the connectivity and automation possibilities offered by the entry of CCAM to improve traffic management and the integration of the movement of goods and people. Therefore, two components are being developed. The first one focuses on improving traffic management by leveraging the automatic rerouting capabilities of CAVs to balance the load on the traffic network during disruptive events in mixed traffic scenarios. In module development we made the following assumptions: There is a fleet of full-fledged CAVs connected to different traffic management sub-centers (TMC), which in turn are coordinated by the traffic management center (hierarchical control). The component also assumes that the origin and destination of each CAV are known to the TMC and that there are one or more predefined routes between each origin and destination. The component optimizes the route assignment for the entire CAV fleet (e.g., for each OD pair and route, the proportion of CAVs that take that route) and the traffic routing plan on specific arteries of the network under consideration given the following performance metrics: (i) travel time difference between CAVs and conventional vehicles, (ii) energy consumption of CAVs, (iii) total congestion levels in the system, and (iv) total emissions in the system.

The second component focuses on integrating the mobility of people and goods by leveraging the lower operating costs and greater versatility of autonomous on-demand services to provide sharing-a-ride services. On the one hand, autonomous on-demand services will be used to increase the use of public transportation in cities and solve the first/last mile problem, especially in areas that are not densely populated and/or where public transportation services are infrequent. On the other hand, these autonomous on-demand services are also used for parcel delivery. The objective of this component is to estimate the required CAV fleet and operating routes of autonomous on-demand services to serve both passenger requests and package deliveries. To this end, the component assumes that passengers specify in advance the origin and destination of their trips, with the preferred departure and arrival time windows. Similarly, it is assumed that the pickup and delivery locations of the packages are known, as well as their respective time windows, if requested by the customer. The performance indicators to be optimized by the component are the following: (i) percentage of passenger trips requests served, (ii) percentage of packages picked up/delivered, (iii) operating cost of the autonomous on-demand fleet, (iv) total energy consumption of the autonomous on-demand fleet, and (v) average travel time of the passenger trip request served.

2.2 Demand Prediction and Classification

Planning and management of transport infrastructure and services require accurate, reliable, and up-to-date information about transportation demand. This applies to the characterization of general mobility and mobility by modes. The factors leading to the adoption of CCAM services and the substituted mode will depend on the characteristics of the services and different attributes of the passengers. Attitudes toward conventional public transport services may not change if they are served by CAV, but other services may affect demand for other modes of transportation. In particular, demand-responsive transportation (DRT) and car-sharing services are expected to be among the services boosted by the arrival of CAV [1]. The demand forecasting component aims to characterize and estimate travel demand from the fusion of anonymized mobile network data (MND) and other data sources. The goal is to create an origin-destination (OD) matrix segmented by mode, that distinguishes between professional trips related with delivery, and personal mobility performed by conventional public transportation, DRT with CCAM (DRT-CCAM), and private and non-motorized trips.

This component includes the integration of existing solutions and the development of new ones. Public transport trips are characterized using Nommon's Transit Insights [6], a solution that generates OD matrices for public transportation trips from anonymized intelligent fare collection systems. Private and non-motorized trips are identified using Nommon's Mobility Insights [7] solution, which generates 'activity travel diaries' [3] from MND.

New developments focus on achieving full characterization of demand. These developments are: Identification of delivery trips and DRT- CCAM estimation. Delivery trips are identified through longitudinal analysis of mobility patterns obtained from the fusion of MND, e-commerce surveys, land use information, and the location of points of interest (i.e., logistics and delivery centers).

Since there are currently no CCAM services in cities, the demand for DRT-CCAM trips is approximated by the demand for carsharing services, since these services are the best candidates to become DRT-CCAM when they become a reality [1]. Carsharing trips are estimated using Nommon's WiseRide solution [8]. WiseRide applies machine learning to analyze and predict the distribution of share mobility (SM) trips based on SM services, public transportation, general mobility matrices (from MND), weather and land use data. Based on the predicted carsharing demand, different DRT-CCAM penetration scenarios are created. These are created considering the travel and user characteristics observed in the predicted carsharing demand. The demand estimate is complemented by a mode substitution analysis that estimates what mode of transportation would have been used if the DRT-CCAM service had not been available. This information allows for the analysis and characterization of the impact of different CCAM penetration levels on each mode based on the socio-demographic characteristics of users.

To improve this characterization of demand, user profiles are further enriched with sociodemographic information about CCAM use that is not included in the MND. This is done by data fusion of MND and survey data based on machine learning techniques. The relevant identified features are household structure and car ownership.

2.3 Integration with Simulation Environment

The proposed demand traffic and fleet management models will be integrated into a state-of-the-art multi-resolution traffic simulation model Aimsun Next [2] to evaluate the network-wide impacts of the implemented strategies.

The integration will be done using the Aimsun Application Programming Interface (API) functions to transfer data from the simulated network to the external application. The external model then applies its own algorithm to evaluate the simulation results and responds dynamically with appropriate actions (e.g., changing the signal cycle) that are implemented in the next simulation step.

In addition, the Aimsun Ride simulation platform, which is a plug-in within Aimsun Next, simulates various on-demand service operations. The simulation results are then used to calculate actual operating costs and various fleet- and user-related KPIs. This tool is used in the UC to model and evaluate fleet operations for urban logistics with on-demand passenger transportation services in the simulation environment. Figure 1 summarizes the integration framework for modeling advanced functionalities for traffic management solutions in the presence of CAVs and shared mobility services.

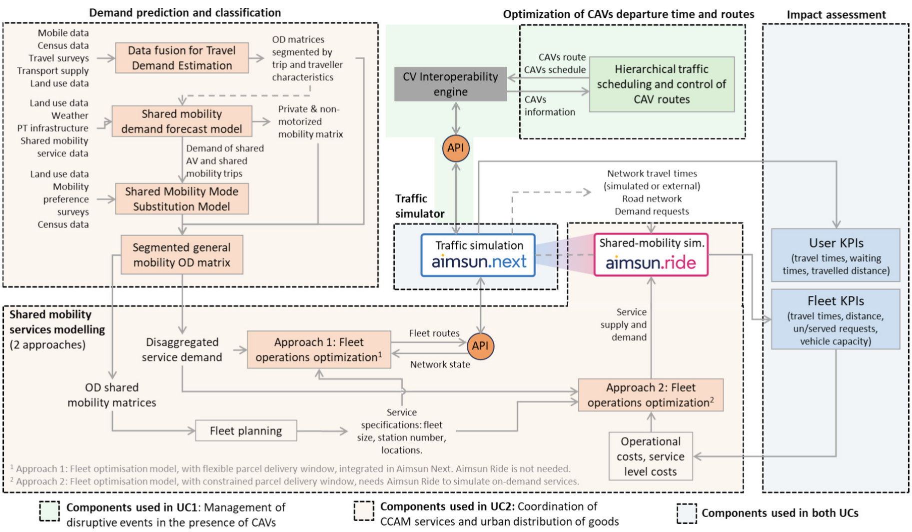

Fig. 1. Integration framework, outlining the workflow within both use cases

3 Application to the City of Madrid

The developed components and tools will be tested in the city of Madrid in two use cases (UCs) described below. More details on the UCs can be found in [5].

3.1 Management of Disruptive Events in the Presence of CAVs

This UC focuses on improving traffic management by using the automatic rerouting capabilities of CAVs to balance the load on the traffic network during disruptive events in mixed traffic scenarios. The study area is the Madrid M-30 ring road, a 32 km urban highway that surrounds the central neighborhoods of Madrid. The adjacent urban road network is also considered to account for possible detour options on these secondary roads. The UC is based on a simulated environment using the Aimsun traffic simulation software. The M-30 ring network is available with a microscopic resolution of traffic flow, so that vehicle behavior and interactions can be simulated in detail. However, to simulate rerouting decisions following disruptions on M-30, the surrounding urban network is modeled at a mesoscopic level to assess the impact on the broader network.

Planned events (e.g., roadworks) and unplanned events (e.g., accidents) are considered in different scenarios with varying penetration levels of CAVs. The vehicles in the simulation will communicate with the environment and receive personalized information, such as optimal departure times and routes, lane selection, and speed adaptation. An integrated optimization module will adjust the schedule and develop new CAV routes that will be transmitted to the simulator.

The expected benefits of this UC are the reduction in: (i) recovery time, (ii) average travel time and travel distance per connected vehicle, (iii) economic losses due to travel delays, and (iv) total vehicle emissions of CO2 and NOx.

3.2 Coordination of CCAM Services and Urban Distribution of Goods

Demand for urban delivery has increased over the past decade and is expected to further increase. The introduction of e-commerce, exacerbated by the COVID-19 crisis, is responsible for this shift and especially for traffic due to last mile delivery. To address the problem, this UC involves the combination of the components discussed in Sect. 2. It aims to develop and test coordination strategies for last mile delivery of parcels and DRT-CCAM services. The goal is to leverage the excess capacity of DRT-CCAM vehicles during periods of lower demand. In this way, we can effectively reduce the presence of delivery vehicles on the road, increase the occupancy of passenger cars and minimize the number of empty trips made by CAVs after their arrival. This addresses a common criticism of CAVs as an environmentally sustainable option that ultimately leads to less congestion and lower emissions.

The first step in implementation is to identify low-demand time windows for a particular DRT-CCAM service and predict delivery demand using the demand component described in Sect. 2. Based on this information, strategies are applied to coordinate and balance supply and demand. Although the goal is to prioritize passenger mobility, the potential negative impacts on delivery service must also be minimized. For this purpose, two levels of prioritization are considered: (i) optimization of the passenger route with flexible time window for package delivery and (ii) optimization of the passenger route with preference-based categorization (high and low priority) of the time window for package delivery. Moreover, in this second scenario, passenger demand still remains the priority. Finally, the simulation tools Aimsun Next and Ride are used to simulate the new traffic scenarios and evaluate the impact of the proposed solutions.

The expected benefits of this UC are the reduction in: (i) average travel time for all vehicles, (ii) total distance traveled by delivery vehicles, (iii) the number of vehicles used to deliver goods, and (iv) overall transportation emissions.

4 Conclusions

This paper outlines the developments and innovations that are driving the integration of CAVs into urban mobility systems. Insights are provided, through two use cases, on managing disruptive events in the presence of CAVs and coordinating CCAM services with urban freight distribution. Ultimately, our research aims to illuminate the path towards a better connected, automated, and efficient urban mobility ecosystem.

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