Safety impacts of autonomous shuttle bus with different operational speeds towards increasing market penetration rate of connected and automated vehicles

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Introduction

Connected and Autonomous Vehicles (CAVs) are anticipated to become more prevalent in urban road networks in the subsequent decades and to **enhance road safety** since several road collisions will be prevented, based on recent outcomes from existing literature. Concerning Connected and Automated Transport Systems (CATS), they are expected to **improve aspects such as urban mobility**, and to make transit systems more competitive to be chosen by commuters, who state that the most concerned attribute is speed. Many studies have also investigated CATS safety level by examining conflicts at a network-level, revealing their efficiency.

Objective

Since the use of surrogate safety measures provides a reliable path to assess the safety of automated systems, the current study aims at evaluating the impacts of **different operational speeds of an autonomous shuttle bus service** on road safety by increasing the Market Penetration Rate (MPR) of CAVs, while taking into account network characteristics.

Methodology

A **microscopic simulation analysis** was performed in order to quantify the impact of road safety of an automated shuttle bus service within traffic. The **study network** was the Villaverde district of the city of Madrid, Spain, in which an automated shuttle bus service was introduced, as shown in Figure 1. The simulation was conducted in the "Aimsun Next" mobility software.

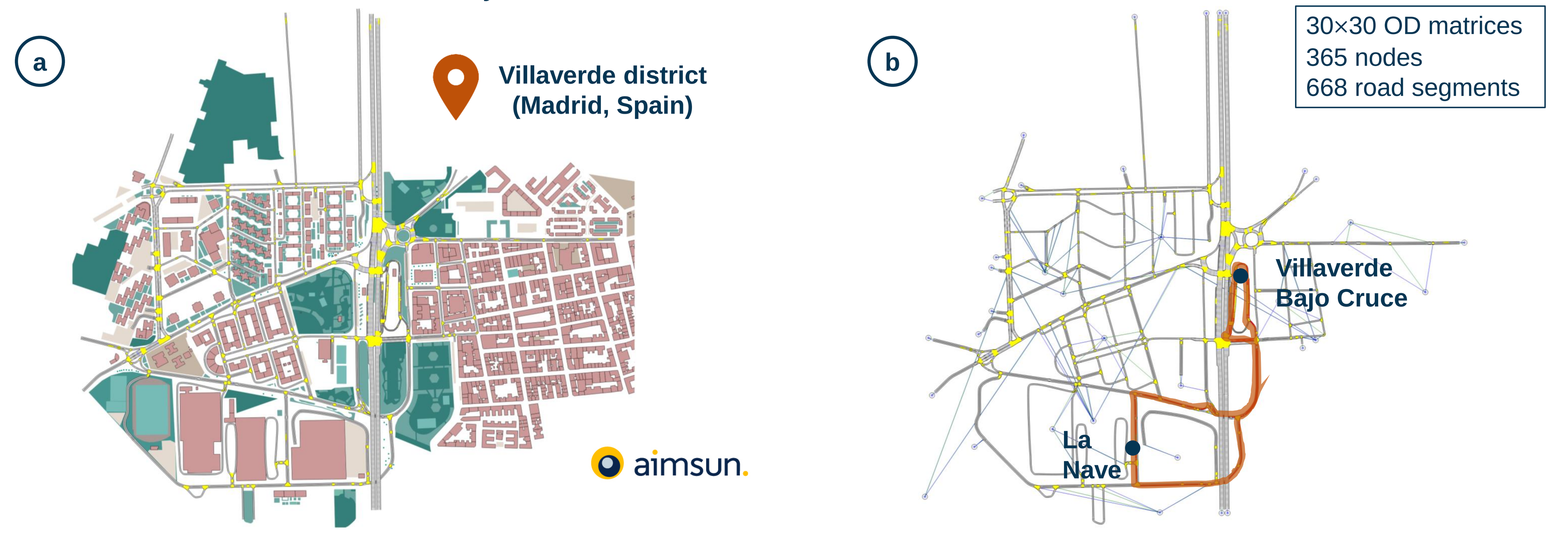

Figure 1: (a) The simulated network; (b) the automated shuttle service route and stops

Thirty-three simulation scenarios were formulated, considering:

- Eleven CAV **market penetration rates** (from 0% to 100% at 10% increments) within the current traffic demand (of the morning peak hour) applied to passenger cars and trucks.
- Three different **operational speeds** for the automated shuttle bus service i.e.,15, 30, and 45 km/h.

The **overall methodological framework** as shown in Figure 2 included the following steps:

Figure 2: Methodological framework

- Firstly, the formulated scenarios were simulated and the **vehicle trajectories** were extracted for each scenario.
- The trajectories were then analyzed using the Surrogate Safety Assessment Model (SSAM) software that **identifies conflicts** based on time-to-collision and post-encroachment time. The extracted data contained information for each conflict occurred within simulation time. In the final conflict database, only the conflicts in which the automated shuttle was involved in were included (5,500 rows in total).
- Finally, the **aggregation** of the conflict database was conducted using the most critical measurements, in order to be analyzed and consequently investigate the relationship of **conflict frequency that the shuttle bus was involved in** with regards to its speed, MPR and network characteristic (530 rows in total).

Results

The frequency of conflicts that the shuttle bus was involved in, was modeled using **negative binomial regression** and the variables that showed significant impact were the following:

- **Conflict frequency**: The recorded frequency that the shuttle bus was involved in a conflict.
- **MPR**: The Market Penetration Rate of fully autonomous vehicles within the traffic.
- **Number of lanes**: The number of lanes of the road segment where the conflict occurred.
- **Speed scenario**: The three shuttle operational speed scenarios.
- **Road type**: The road type segment where the conflict occurred.
- **Conflict type**: The type of the recorded conflict.
- **Control type**: The type of traffic control in the road segment where the conflict occurred.
- **Responsible vehicle**: The responsible vehicle of the occurred conflict.

The variables were divided into integers and categorical and **descriptive statistics** for the categorical variables are given in Figure 3.

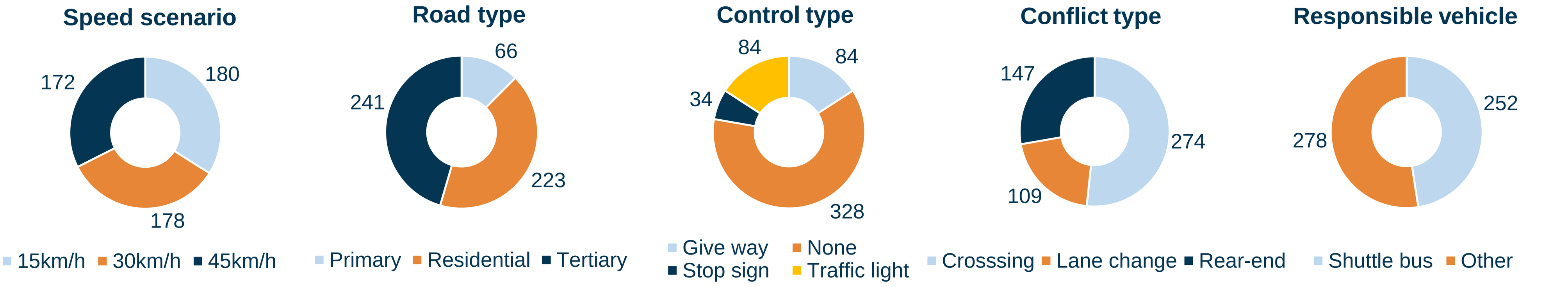

Figure 3: Number of conflicts in which the automated shuttle was involved in per categorical variable

The negative binomial model is presented in Table 1.

Table 1: Negative binomial model results (Conflict frequency as the dependent variable)

Parameters	Estimate	Std. Error	z value	Pr(>|z|)	Sig.
Intercept	-11.929	0.972	-12.271	< 0.001	***
30km/h operational speed [Ref. 15km/h]	-0.530	0.102	-5.189	< 0.001	***
45km/h operational speed [Ref. 15km/h]	-0.659	0.101	-6.487	< 0.001	***
MPR	-0.003	0.001	-2.186	0.029	*
Residential road segment [Ref. Primary]	7.649	0.631	12.115	< 0.001	***
Tertiary road segment [Ref. Primary]	8.965	0.674	13.308	< 0.001	***
Lane change conflict [Ref. Crossing]	-1.509	0.123	-12.311	< 0.001	***
Rear end conflict [Ref. Crossing]	-0.783	0.116	-6.773	< 0.001	***
No control [Ref. Give way]	0.628	0.150	4.205	< 0.001	***
Stop sign [Ref. Give way]	-1.014	0.231	-4.393	< 0.001	***
Traffic light [Ref. Give way]	-2.141	0.298	-7.187	< 0.001	***
Shuttle responsible vehicle [Ref. Other]	1.711	0.102	16.812	< 0.001	***
Number of lanes	4.728	0.321	14.707	< 0.001	***

Null deviance	1407.3 on 433 degrees of freedom
Residual deviance	422.4 on 421 degrees of freedom
2 x log-likelihood	-2403.915
Pseudo R^2 (Nagelkerke Method)	0.698

- The conflict frequency is lower when the shuttle bus operates at 45 or 30 km/h compared to 15 km/h, with the speed of **45 km/h** showing the **largest reduction**.
- **Greater CAV MPR** results in steadily **decreased conflict frequency**.
- **Crossing conflicts** occur **more frequently**, followed by rear-end and lane change conflicts.
- The frequency of conflicts is **greater** in the case of **residential or tertiary** roads, compared to primary roads.
- Road segments with **more traffic lanes** represent an **increased frequency** of conflicts.
- **Stop signs or traffic lights** on road segments presented **lower conflict frequency** than give way signs.

Conclusions

The key contribution of the current study is the establishment of a **solid relationship between the conflict frequency** that the shuttle bus was involved in and its operational speed, MPR and network characteristics. The outcomes could help stakeholders to optimize road safety of automated traffic towards the future.

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