POTENTIAL ENERGY AND EMISSIONS EFFECTS OF CONNECTED AND AUTONOMOUS VEHICLES IN MIXED TRAFFIC FLOWS

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1. INTRODUCTION

One of the most alarming current issues that has been debated over the years is climate change. A crucial new report by the Intergovernmental Panel on Climate Change (IPCC) says limiting global warming to 1.5°C requires “rapid and far-reaching” economic transitions (IPCC, 2018). Emission reductions from road transport have been lower than originally anticipated, partly because transport has grown more than expected and partly because, for certain pollutants (e.g. nitrogen oxides – NOx), growth in diesel vehicles has been greater than expected (European Commission, 2018). A recent study shows that almost excess emissions (above emissions standards) are associated with about 38,000 deaths globally in 2015, including about 10 % of all ozone-related premature deaths in European Union (Anenberg et al., 2017).

A significant technological advance is expected in urban mobility due to the implementation of cooperative intelligent transport systems (C-ITS) as well as due to a progressive implementation of vehicles with an increasing degree of autonomy (Correia & van Arem, 2017). This technological advance can significantly improve safety (Kamrani, Arvin, & Khattak, 2018) and traffic efficiency (Friedrich, 2016). At operational level, Connected and Autonomous Vehicle (CAV) technologies are expected to improve fuel economy and reduce emissions per unit of distance thanks to more gradual acceleration and deceleration patterns (Kockelman & Nichols, 2017) and fewer stop and go movements (Anderson et al., 2016). Eventually, these benefits can be spread to the remaining conventional vehicles (CVs). In this context, the main objective of this paper is to explore the order of magnitude of these changes for various scenarios of CAVs market penetration.

This study is based on three fundamental questions not addressed in an integrated way in previous studies:

1) What is the potential reduction of carbon dioxide (CO_2) and NO_X emissions resulting from CAVs operating in different road typologies?
2) How can network-wide emissions and fuel consumption vary according to different MPR (Market Penetration Rates) of CAVs?
3) May CAVs significantly influence the energetic and environmental performance of CVs on different road types?

This research was presented at the 22th Annual Meeting of the EURO Working Group on Transportation and selected for publication at the Transportation Letters, The International Journal of Transportation Research.

2. METHODOLOGY

Figure 1 summarizes the main steps of this research. In order to study the impact of various MPR of CAVs in the urban traffic dynamic, a properly calibrated and validated microsimulation platform (Vissim 11.0) (PTV AG, 2016) was used. The present research was conducted under some assumptions (Table 2).

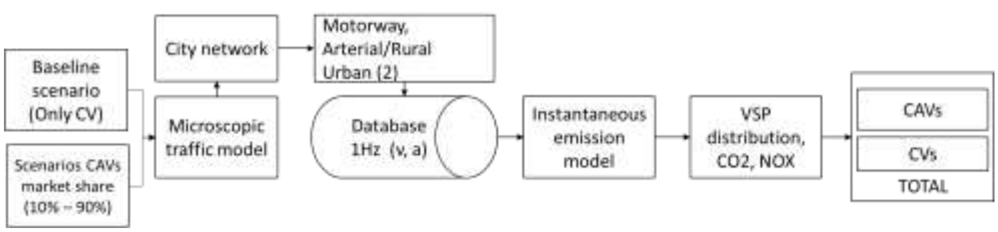

Fig. 1. Methodology overview.

2.1 Case study

The case study is the city of Aveiro, Portugal. The traffic model was validated using data collected on different road segments of the study area and 14 traffic monitoring points in the peak hour (8.15–9.15

a.m.), covering 550km. The monitoring and simulation tasks were performed in earlier research and include a wide range of road types, traffic volumes and acceleration both of traditional parameters (volume, speed, travel time) and VSP modes distribution and emissions (Bandeira et al., 2018; Dias et al., 2018). This fact suggests the ability of model in reproducing the impact of new types of vehicles with different operational parameters in the performance of CVs. Table 3 summarizes relevant information for each road segment, including type, GPS coordinates, length, number and traffic control treatment, and traffic volumes.

Table 1 Summary of study segments to analyse the operation impact of CAVs (Bandeira et al., 2018, Vicente et al., 2018, IMT, 2019)

Segment	Road Type	GPS Coordinates	Length [m]	Speed limit [kph]	# Lanes per direction	# TC	Traffic [vph]	Built Environment
A	Urban Avenue	40°38'20.1"N 8°39'01.0"W 40°38'03.7"N 8°38'38.4"W	0.75	40	2	2 Traffic Lights Roundabout	890 – 1 300	Commercial and Residential
C	National Road	40°37'25.27"N 8°39'1.39"W 40°39'19.43"N 8°37'5.41"W	4,5	70	1 – 2	8 Interchanges 1 three-lane Roundabout	1440 – 2 100	Retail Mixed land use
D	Motorway	40°38'49.43"N 8°36'46.84"W 40°38'22.87"N 8°39'51.17"W	5,1	120	2	2 Interchanges	1 560 – 3 250	Residential, Nature

 # Number; TC – Traffic Control Treatments

In this case study, five mobility scenarios representing different CAVs market share rates were simulated under the assumption CV traffic was replaced by automated vehicles. The baseline scenario (BS) represents the current traffic scenario. The testing scenarios were: S1:10%, S2: 30%, S3: 50%; S4:70% and S5:90%.

Table 2 provides an overview of the Wiedemann 99 CFAP used in previous literature and an additional sensibility in CFAP values in urban avenue was conducted to minimize NOx values during a 24-hour period. For that purpose, a Python-based code was conceived in order to allow parameters that minimized NOx emissions, for each different scenario.

Table 2 CFAP values used

CFAP	Reference	Arterial	Freeway 90 km/h	Section A adjusted
CC0 [m]	1.50	1.47	0.50	(0.50; 1.50; 2.50)
CC1 [s]	0.90	1	1	(0.50; 0.90; 1.50; 2)
CC2 [m]	4	0	0	0
CC3 [s]	-8	-13.54	-4	(-4; -8; -16)
CC4 [m/s]	-0.35	-0.13	0.1	-0.10
CC5 [m/s]	0.35	0.13	0.1	0.10
CC6	11.44			0
CC7 [m/s^2]	0.25	0.08	0.45	0.05
CC8 [m/s^2]	3.50	3.72	3.90	(3.10;3.50; 3.90)
CC9 [m/s^2]	1.50	1.60	1.90	———

(Sukennik, (2018) - CoExist project; Stogios, 2018)

3. PRELIMINARY RESULTS / DISCUSSION

Fig. 2 provides an overview of emissions per vehicle per unit of distance in different road types based on all vehicles (CAVs and CVs). These plots represent the variability of the results of the 10 run seeds according to the model stochasticity. Logically, urban sections that encompasses (traffic lights and roundabouts), have high variability of standard deviation (size of the error bars).

Fig. 2 shows the effect of relative difference in CO_2 and NOx emissions for CAVs, CVs and total fleet comparing to BS emissions. As Fig. 3 shows, there is significant effect on emission reduction and according to the growing MPR of CAVs (between 3 and 18% for CO2, and 4 and 32% for NOx).

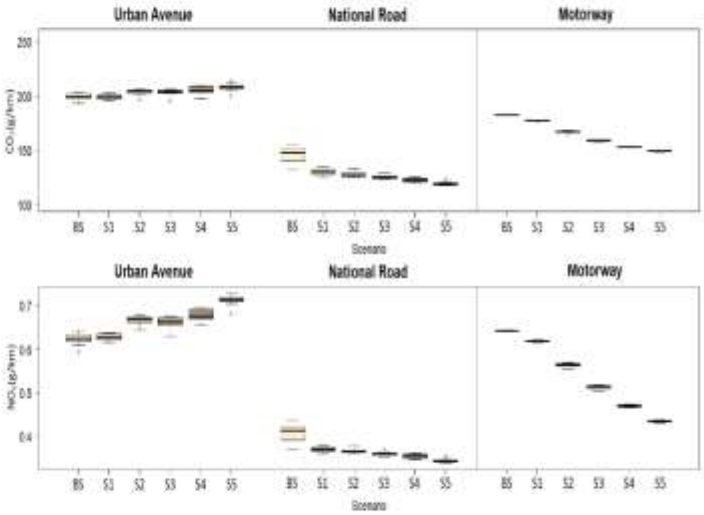

Fig. 2. Comparison of the total CO2 and NOX emissions of CAVs and CVs over multiple MPR in relation to BS.

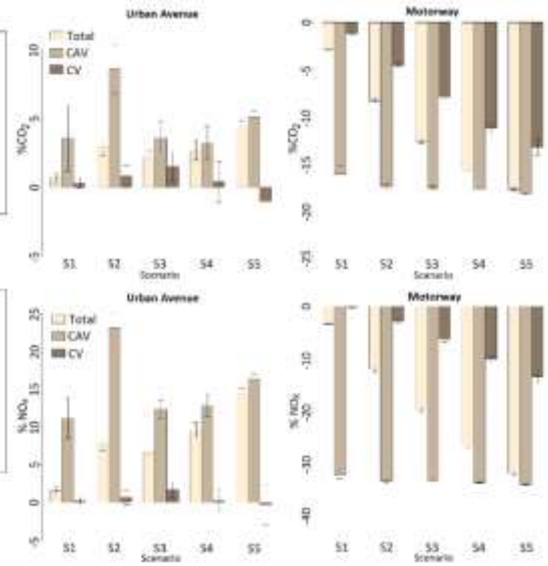

Fig. 3. Average emission factors (g/km) per vehicle for different MPR (BS – 0%, S1-10%, S2-30%, S3 50%, S4-70%, S5-90%)

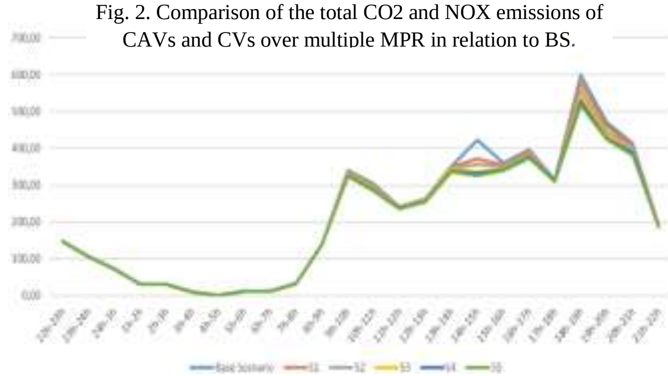

Fig. 4. Comparison of NOx in 24-hours period by scenario

Table 3 Variation of NOx emissions

CFAP	%NOx reduction (vs. previous scenario)	%NOx reduction (vs. baseline scenario)
S1	-2.10	-2.10
S2	-1.65	-3.71
S3	-1.70	-5.35
S4	-1.08	-6.37
S5	-0.92	-7.22

From the results obtained through Python, regarding CFAP in the case under study, one can conclude that CC0 and CC1 parameters are similar over throughout the 24-hour period analyzed. Simultaneously, the opposite occurs for parameters CC3 and CC8, as several changes undergo in the same period of analysis. As shown in table 3, the biggest reduction is visible in the 10% AV scenario, since NOx reduction becomes less pronounced from 70% of MPR. In the 24-hour period, a greater NOx reduction is visible from 13h to 16h, as shown in Fig. 4.

4. CONCLUSIONS

Results allow to assess the main research questions of this paper defined in introduction, namely:

1) Environment in the arterial/rural section (up to 12%); urban avenue, the impacts revealed positive: 2% NOx reduction; motorway segment, an optimization of the speed to 90 km/h => -18% of CO_2 and - 32% NOx.
2) Outside the urban context, a relationship between emissions reduction versus MPR was very good. Most negative impacts for 30% of MPR.

3) CAVs had significant influence on both energetic and environmental performance of CVs, ranging from 3 to 13%.

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