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INFLOWENCE PROJECT: AUTONOMOUS VEHICLES OPPORTUNITIES FOR AIR QUALITY

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Abstract: Currently, for various reasons environmental concerns are not usually a priority associated with the task of driving. However, this situation can be changed as vehicles becoming increasingly connected and autonomous and road infrastructures will progressively incorporate cooperative intelligent transport systems, contributing to the positive-sum game of both efficiency and environmental sustainability. The main vision of InFLOWence is to take advantage of the predictable market penetration of connected and autonomous vehicles (CAVs) in short-medium term to influence, in a positive way, the performance of the road transport system in terms of congestion, energy consumption and atmospheric pollutant emissions. With respect to tactical decisions, the main project outcome will be to provide a sustainable traffic assignment and navigation tool for CAVs encompassing their own impacts, but also the marginal impacts on the other vehicles in the network, evaluated through an environmental (air quality) and economic evaluation. This work aims to present the first InFLOWence results related to the opportunities of this technology to improve cities air quality, focused on NO_2 air pollutant. For that, a modelling system composed by a road traffic, road transport emission and a Computational Fluid Dynamics air quality models was applied to an urban area and two set of scenarios were developed: i) baseline scenario; and ii) autonomous scenario, assuming different rates of CAVs penetration. Considering a CAVs market penetration rate of 30% the results revealed that autonomous vehicles promoted both increases and decreases of NO_2 concentrations. InFLOWence will support policy makers to prioritize cooperative Intelligent Transport Systems, whose impact is most beneficial from the environmental point of view.

Key words: *Connected and Autonomous vehicles (CAVs), air quality management, road traffic flow, road transport emissions*

INTRODUCTION

Despite the increasingly stringent emissions standards, emission reductions from road transport have been lower than originally anticipated over the last two decades. Despite of that, the more recent European Air Quality report highlights that the air quality levels remain above the (European) air quality standards in many European cities. Estimates of the health impacts attributable to exposure to air pollution indicate that nitrogen dioxide (NO_2) concentrations in 2018 were responsible for about 54 000 premature deaths originating from long-term exposure in Europe (EU-28) (EEA, 2020). However, new opportunities under the domain of Cooperative Intelligent Transport Systems are arising. The European Strategy for Low-Emission Mobility (2016) highlights the potential of cooperative, connected and automated vehicles to reduce energy consumption and atmospheric emissions from road transport (EC, 2016a). In fact, Connected Automated Vehicles (CAVs) are becoming a reality with several pilot projects demonstrating that the technology will be available soon (Correia and van Arem, 2017) and CAVs will be part of a mixed road traffic flow composition over the next decades (Wagner, 2016). The report SAE2014 (SAE, 2016) provides six levels of driving automation span from no automation to full automation. The greater technological gap occurs between levels 2-3, where the automated driving system starts to perform the entire dynamic driving task.

In this context, researchers have focused in examining how CAVs may affect road traffic management applications and showed that CAV have the potential to generate substantial time gains at traffic signals (Wagner, 2016). Friderich (2016) demonstrated that a significant increase in road capacity could be expected from using CAVs. Empirically researchers find out that 5% of vehicles being automated and carefully controlled allow to eliminate ”stop-and-go” waves caused by human driving behaviour (Lee et al., 2019). While there is a consensus that CAVs may play a decisive role in improving road safety (Liu and Khattak, 2016) and road capacity, some doubts remain about the impact on environment. Some studies highlight that this technology could lead to an increase in demand resulting in negative environmental impacts (Correia and van Arem, 2017; EC, 2016b). Wadud et al. (2017) state that at relatively low levels of automation, many of the energy intensity saving applications could be done which would probably outweigh the potential increases due to the increase in travel demand by new user groups. Therefore, significant uncertainties remain about the net effects of CAVs impacts on CO_2 emissions and energy use, and further research is warranted (EC, 2016b). The studies addressing the environmental impacts of the CAVs have focused separately on strategic level (Wadud et al. 2017; Levin and Boyles, 2015), operational level and connection with infrastructure (Wu et al., 2014) and connection between vehicles (Jia and Ngoduy, 2017). Lee et al (2019) pointed out the greatest savings may be achieved by implementing advanced tactical road traffic management solutions such as streamlining traffic flow or eco-routing. At operational level, CAV technologies are expected to improve fuel economy and reduce atmospheric emissions per unit of distance thanks to more gradual acceleration and deceleration patterns (Wu et al., 2014) and fewer stop-and-go movements (Greenwald and Kornhauser, 2019). Wu et al. (2014) showed the environmental benefits of vehicle automation at signalized intersections can go up to 7% in greenhouse gases (GHG) and 22% in criteria pollutants.

In this context, the ongoing InFLOWence research project aims to contribute to help policymakers to make wise policy decisions in this rapidly evolving field. InFLOWence will also contribute for improving regulations in order to encourage manufacturers to provide efficiency-optimizing features like automated eco-driving, eco-routing, platooning or on board energy saving algorithms. The goal of this work is to describe the InFLOWence approach and its first results related to the opportunities of the CAV technology to improve cities air quality.

INFLOWENCE APPROACH

To accomplish the proposed goal, a brief description of the InFLOWence approach is performed in this section, including an overview of the concept and the numerical modelling tools applied and a description of one of the project case studies.

Concept and numerical modelling tools

The InFLOWence project is a step forward compared with the state-of-the-art in different domains: from the concepts behind the impact assessment models (focusing in the whole fleet system impacts and considering effective impacts on air quality) to the process of bi-level and multi criteria optimization. The InFLOWence approach have being developed in five main steps, as follows:

1. Development of scenarios representing different levels of connectivity, fleet composition evolution, and scenarios of integrated shared mobility, and mixed traffic flows of autonomous vehicles and conventional vehicles. A comprehensive range of realistic scenarios were established to be further studied.
2. Development, calibration and validation of traffic-related models (for the baseline scenario – current technology).
3. Test different behaviours of CAVs (e.g. speed, acceleration regime and connectivity with Intelligent Transport System) to evaluate the consequences in terms of environmental and traffic performance. For that, traffic flow (PTV VISSIM) and emissions (VSP) models were applied. The output of this phase includes atmospheric emissions and road safety.
4. Explore the impact of the different CAVs scenarios on air quality, by applying the Computational Fluid Dynamics (CFD) VADIS model, providing a detailed characterization of pollutant concentrations within the urban areas and to identify hotspot areas.
5. Developed a multilayer platform, built in Geographic Information System (GIS) software, to serve as an interface platform among the various outputs.

Case study description

The InFLOWence approach was firstly applied to a main avenue called *Avenida 25 de Abril* of a medium-size city in the Northwest of Portugal, Aveiro (Figure 1a). This avenue is located in the city centre, surrounded by residential buildings and two high schools, contributing to high road traffic volume levels at peak hours. Furthermore, this avenue is one of the city's traffic getaways as it connects the city centre to higher flow and interregional roads, and highways. Connections with other roads are scattered throughout the avenue, allowing for a stop-and-go situation during demanding road traffic flow periods. All these features make this avenue a perfect worst-case scenario for CAVs, with plenty parameterization to be made.

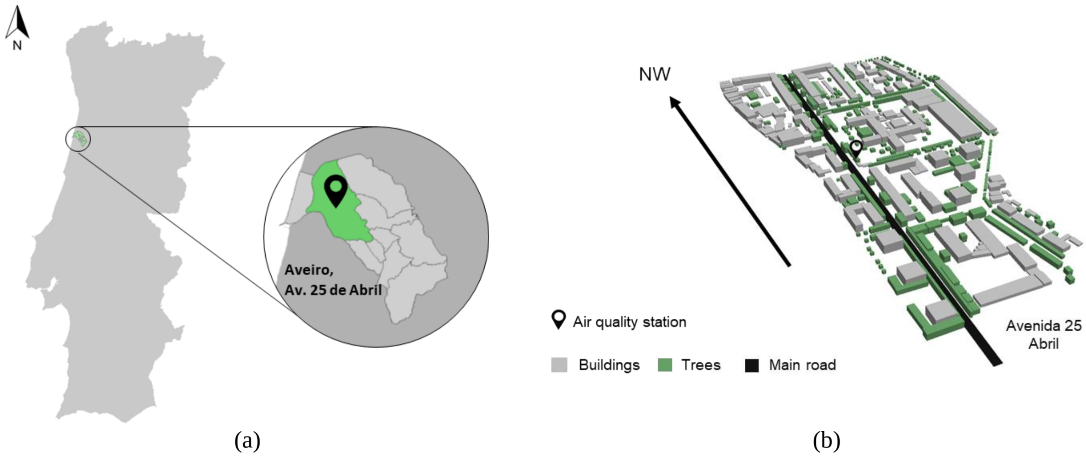

Figure 1. (a) Geographical location of Avenida 25 de Abril. This street is located in the centre region of mainland Portugal, in the municipality of Aveiro at 40°38'14.9"N 8°38'54.5"W. (b) Computational domain considered for the CFD VADIS simulations – Avenida 25 de Abril in Aveiro, Portugal.

The baseline atmospheric emissions (which characterize the current scenario) were calculated on the transport emissions model using as inputs the road traffic flow characterization, made during an experimental campaign (on 7th February 2017). During this campaign, several factors were studied, including road traffic flow speed, time, distance and vehicle counting in an hourly basis. The meteorological conditions (hourly wind velocity and wind direction) during the experimental campaign day were characterized by using measured data recorded in a meteorological station located next to the study area. To assess the influence of CAVs on road transport emissions and air pollutants dispersion, six autonomous vehicles scenarios have been established, considering different rates of CAVs penetration – 10%, 30%, 50%, 70%, 90% and 100% - and assuming an engine technology in line with the remaining vehicle fleet. It should be noted that the penetration rate of each scenario was applied to the baseline conditions. This means that the inclusion of 30% of AV to the network implies that 30% of conventional vehicles were removed from the total amount of vehicles. In this way, it was assumed that the penetration of CAVs has no impact on road traffic demand.

For this assessment, the modelling setup composed by the PT VISSIM (to estimate the impact of CAVs on traffic network), VSP - Vehicle Specific Power (to estimate the impact of CAVs on atmospheric emissions) and CFD VADIS (to estimate the CAVs impact on air quality) were applied to both baseline and CAVs scenarios. The computational domain used is displayed in Figure 1b. A more detailed description of this application can be found on Rafael et al. (2020).

OUTCOMES – FIRST RESULTS ON AIR QUALITY

Given the described methodology, the influence of CAVs penetration on the urban vehicle fleet on air quality is presented in this section. The analysis is focused, as an example, on the scenario considering the 30% CAVs penetration rate and on nitrogen dioxide (NO_2) pollutant.

The effects of CAV penetration on the NO_2 concentrations were investigated considering as reference the baseline case. The analysis consisted in mapping the hourly differences of NO_2 concentrations to understand the spatial variability of the differences according to the configuration of the built-up area; for this analysis two different periods (peak periods) were selected (8-9 a.m. and 6-7 p.m.) based on different rates of road transport emission reductions and on different wind conditions.

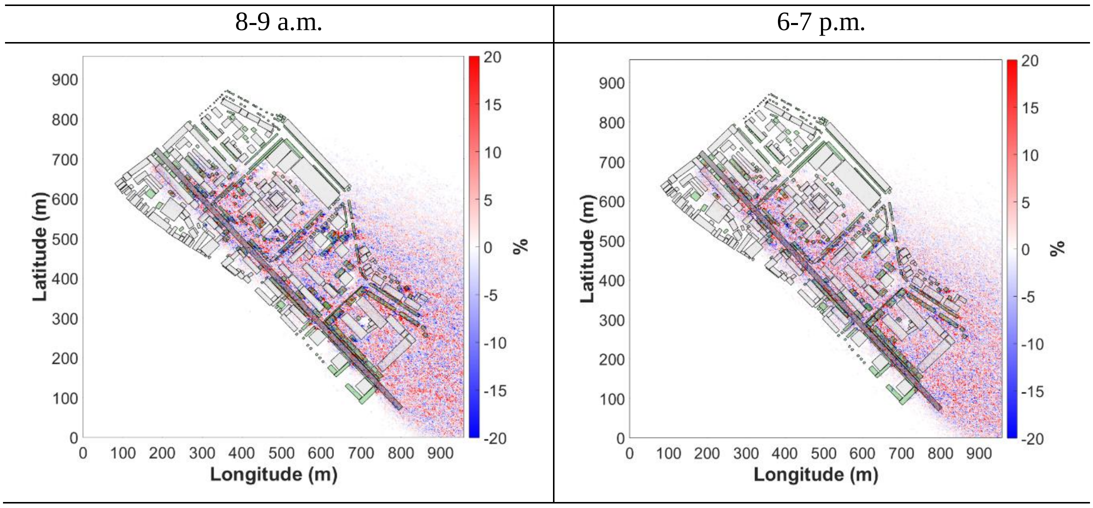

Figure 2. Spatial distribution of the relative difference (in percentage) between the CAV scenario and baseline case across the computational domain, for 1.5 m high horizontal streamlines. Contours refer to the period of 8-9 a.m. (with a wind velocity of 1.9 $m \cdot s^{-1}$ and a wind direction of 289º), and 6-7 p.m. (with a wind velocity of 3.7 $m \cdot s^{-1}$ and a wind direction of 293º).

The analysis of the results revealed that the implementation of 30% of AV to the network, promotes both increases (illustrated by the red colour in Figure 1) and decreases (illustrated by the blue colour in Figure 1) of NO_2 concentrations.

At 8-9 a.m., 49.5% of the domain (50.5% at 6-7 p.m.) shows an increase of NO_2 levels, 45% (42.0% at 6-7 p.m.) recorded a decrease of NO_2 concentrations and 5.5% (7.5% at 6-7 p.m.) registered no changes. At the morning peak period (8-9 a.m.), the increases of NO_2 concentrations reach +68 $\mu g.m^{-3}$ (an increase of +38%), while the NO_2 reductions ranged between -44 $\mu g.m^{-3}$ (-34.5%) and 1.0 $\mu g.m^{-3}$, when compared to the baseline scenario. At the afternoon peak (6-7 p.m.), increases varying between 1 $\mu g.m^{-3}$ and +53 $\mu g.m^{-3}$ (+63.5%) and reductions that can reach up to -68 $\mu g.m^{-3}$ (around -27%) were obtained. In the morning (8-9 a.m.) around 42.8% of the domain shows NO_2 levels above 5 $\mu g.m^{-3}$ (this value was obtained in 30% at 6-7 p.m. and 1.5% at off-peak period); 2.7% of the domain shows NO_2 concentrations above 50 $\mu g.m^{-3}$ and only 0.5% displays concentrations above the hourly limit value (200 $\mu g.m^{-3}$). At the afternoon peak, no changes were found. Analysing the area where maximum NO_2 concentrations occur (in the baseline scenario) – a hot-spot area –, changes varying in a range of -21% (at 5 p.m.) and +31.6% (at 5 a.m.) were recorded. At the peak periods, an increase of +11% (at 8-9 a.m., corresponding to an absolute difference of 24 $\mu g.m^{-3}$) and +10.8% (at 6-7 p.m., with an absolute difference of 15 $\mu g.m^{-3}$) were registered. In a daily average, for this area, this autonomous scenario promotes an increase of +1.7% of NO_2 concentrations, similar to the rate of increase in NOx atmospheric emissions.

More details about the model setup and the obtained results can be found in Rafael et al. (2020).

CONCLUSIONS

The first results of InFLOWence project revealed that the autonomous vehicles promoted an overall increase of NOx (+1.8%, considering a 30% CAVs penetration rate) atmospheric emissions due to the slight increase of the traffic demand, traffic flow and more aggressive acceleration after a stop to the cruising vehicle speed. This impact on atmospheric emissions implies that both increases and decreases on NO_2 concentrations were found.

In general, the InFLOWence project highlights the potential of CAVs technology to improve urban air quality. Due to the novelty of this issue, more evidence are needed to improve the evaluation reliability. Further research is required, focused on optimizing the Wiedemann 99 car following adjustment parameters (CFAP) for different links with different saturation levels, road transport emission standards scenarios as well as air quality impacts from urban to local scales.

In the end of the InFLOWence project, it is expected that the main research contributions will be: 1) the assessment of scenarios related to the penetration of autonomous and connected systems in the Portuguese transport system; 2) the assessment of the potential impact of CAVs both at operational and strategic levels; and 3) a bi-level optimization tool taking into account multiple levels of connectivity and autonomy.

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REFERENCES
Correia, GH de A, B. van Arem, 2017: Estimating Urban Mobility Patterns Under a Scenario of Automated Driving: Results from a Model Application to Delft, the Netherlands. In: Compendium of the Transportation Research Board 96th Annual Meeting. Washington D.C.

EC - European Commission, 2016a: A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility. Vol. 30, COM. Brussels.

EC - European Commission, 2016b: A European Strategy for Low-Emission Mobility. COM/2016/0501. Brussels.

EEA - European Environment Agency, 2020: Air quality in Europe - 2020 report.

Friedrich, B., 2016: Autonomous DrivingThe Effect of Autonomous Vehicles on Traffic. In: Maurer M, Gerdes JC, Lenz B, Winner H, editors. Autonomous Driving. Berlin, Heidelberg: Springer Berlin Heidelberg. pp 317-334.

Greenwald, J., A. Kornhauser, 2019: It's up to us: Policies to improve climate outcomes from automated vehicles. *Energ. Policy*, **127**, 445-451.

Jia, D., D. Ngoduy, 2016: Platoon based cooperative driving model with consideration of realistic inter-vehicle communication. *Transp Res Part C Emerg Technol.*, **68**, 245-264.

Lee, S., E. Jeong, M. Oh, C. Oh, 2019: Driving aggressiveness management policy to enhance the performance of mixed traffic conditions in automated driving environments. *Transp. Res. A Policy Pract.*, **121**, 136–146.

Levin, M.W., S.D. Boyles, 2015: Effects of Autonomous Vehicle Ownership on Trip, Mode, and Route Choice. *Transp Res Rec J Transp Res Board*., **2493**, 29-38.

Liu, J., A.J. Khattak, 2016: Delivering improved alerts, warnings, and control assistance using basic safety messages transmitted between connected vehicles. *Transp Res Part C Emerg Technol.*, **68**, 83-100.

Rafael, S., L.P. Correia, D. Lopes, J. Bandeira, M.C. Coelho, M. Andrade, C. Borrego, A.I. Miranda, 2020: Autonomous vehicles opportunities for cities air quality. *Sci Total Environ*, **712** .

SAE International, 2016: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.

Wadud, Z., D. MacKenzie, P. Leiby, 2016: Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. *Transp Res Part A Policy Pract.*, **86**, 1-18.

Wagner, P., 2016: Traffic Control and Traffic Management in a Transportation System with Autonomous Vehicles. In: Maurer M, Gerdes JC, Lenz B, Winner H, editors. Autonomous Driving Technical, Legal and Social Aspects. Berlin, Heidelberg: Springer Berlin Heidelberg. pp 301-316.

Wu, G., K. Boriboonsomsin, H. Xia, M. Barth, 2014: Supplementary Benefits from Partial Vehicle Automation in an Ecoapproach and Departure Application at Signalized Intersections. *Transp Res Rec J Transp Res Board.*, **2424**, 66-75.