ARE ECO-LANES A SUSTAINABLE OPTION TO REDUCING EMISSIONS IN A MEDIUM-SIZED EUROPEAN CITY?

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Abstract

Innovative traffic management measures are needed to reduce transportation-related emissions on arterials and freeways. While in Europe, road lane management has focused mainly on introduction of bus lanes, the conversion to High Occupancy Vehicles (HOV) and eco-lanes (lanes dedicated to vehicles running on alternative fuels) has not been studied comprehensively. The objectives of this research are to: 1) Develop an integrated microscale modeling platform calibrated with real world data to assess both traffic and emissions impacts of future Traffic Management Strategies (TMS) in an urban area; 2) Evaluate the introduction of eco-lanes in three different types of roads in European medium-sized cities and its effects in terms of emissions and traffic performance. The methodology consists of three distinct phases: a) Traffic and road inventory data collection, b) Traffic and emissions modeling using an integrated platform of microsimulation, and c) Evaluation of scenarios. For the baseline scenario, the statistical analysis of the integrated platform show valid results, i.e., no significant differences between simulated and Vehicle Specific Power (VSP) modal distributions. Moreover, the methodology applied shows that HOV and eco-lanes in a medium European city are feasible. The results show that on freeways a majority of passengers can reduce their travel time about 5% with a positive impact in terms of total emissions (-3% CO$_2$, -14% CO, -8% NO$_x$). On urban arterials, emissions reduction can be achieved only if the average occupancy of vehicles increases from 1.37 (current) to 1.50. The broader implications for eco-lanes are discussed.

KEYWORDS – integrated microscale modeling, eco-lanes, HOV, VSP, emissions

1. INTRODUCTION AND OBJECTIVES

The first objectives of Traffic Management Strategies (TMS) deployments were commonly focused on improving safety, relieving congestion and saving costs (1, 2). However, since the urban traffic is responsible for 70% of emissions of local pollutants and 40% of CO$_2$ emissions, there has been a growing emphasis on environmental concerns (3). In this context, the projects eCoMove (Europe) and AERIS (USA) are examples of integrated approaches to help travelers use the infrastructure more efficiently (4, 5).

One of the most common strategies to increase the efficiency in the use of infrastructures is to maximize the average vehicle occupancy rates by providing incentives to the use of the so-called High Occupancy Vehicles (HOV) (6). While HOV lanes have been widely applied in USA, currently there are few examples of HOV lanes in operation in Europe (6). One of the main reasons is that in general the European cities have fewer high capacity multi-lane urban motorways than the USA. Nevertheless, in the late 90s, cities such as Leeds, Brussels, Graz or Madrid have incorporated HOV lanes either in highways or in urban arterials. Although these case-studies have demonstrated that the introduction of HOV can be an effective way to promote car-pooling (7, 8), the environmental impact of this strategy is unclear. The majority of studies on HOV lanes impact on emissions were carried out based on American study-cases. Previous research focuses on the effect of adding new HOV lanes in the network (9), lane conversion between mixed flow and HOV, and HOV lane configuration (10).

Recently, the concept of eco-lane has become an instrument to incentivize the purchase of vehicles that would be better for the environment (5). However, with the exception of (10), previous HOV/eco-lanes impact on emissions typically uses macroscale emissions models based on average speeds and traffic volumes. Recently, the increases in
computing performance have yielded more practical use to be made of micro-simulation traffic models, which allows a more refined analysis and improve the accurateness of the total emission estimations. The output of these models can be incorporated in microscale emissions models to evaluate the consequences of different traffic management policies applied to the road network, such as traffic signal coordination, route diversion, variable speed limits, Advanced Traffic Information Systems (ATIS) and lanes management.

Table 1 summarizes the most relevant studies that linked microscale traffic models with external emissions models. In addition to the main variables analyzed and highlights of each study, the following data is provided: case study, scale, traffic model, and emissions model. The majority of the studies linked PARAMICS and VISSIM traffic models with CMEM or MOVES emissions models, but other studies integrated different traffic models such as Dracula, AIMSUN, INTEGRATION or UMTS with Mobile, EMFAC and VT-micro emission models (12-15). Song et al. found that the VISSIM model tends to produce more aggressive acceleration and deceleration than in real-world (16). However, the large majority of the studies did not assess the capability of the traffic models to capture the real-world vehicle power distributions.

The literature review shows that the large majority of studies that linked microscopic traffic simulation models with emissions models did not use real world data on vehicle dynamic to assess if the output of the model is consistent with that of real world traffic. Regarding the implementation of HOV lanes, and namely in the European, there is a lack of knowledge about the environmental impact of this measure in different types of roads, different Average Occupancy Vehicle rates (AOV) and eligible vehicles. Moreover, the available knowledge about the impact of eco-lanes on emission is very limited.

Thus, the main objectives of this research are:

1. To develop an integrated microscale modeling platform calibrated with real world data to assess the impact of future TMS in an urban area;
2. To evaluate the introduction of eco-lanes in different types of roads in a medium-sized European city and its effects in terms of emissions and traffic performance.
### TABLE 1 Relevant literature on integration of microscopic traffic and emissions models

<table>
<thead>
<tr>
<th>Ref.</th>
<th>CS</th>
<th>Scale</th>
<th>Traffic model</th>
<th>Emissions Model</th>
<th>Variables/traffic management scenarios evaluated and highlights</th>
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<tr>
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<td>Dynamic eco-driving system - Higher CO₂ reductions occur during congestion</td>
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<td>HOV lane configuration - Freeway with continuous access of HOV lane produce lower emissions</td>
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<td>Roundabouts vs. Traffic signals - CO₂ emissions depend upon turn demand and overall demand</td>
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<td>Intelligent Speed Adaptation - Net results with no significant impact on pollutant emissions</td>
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<td>Traffic Signal coordination, Types of bus stop – How to minimize emissions at traffic intersections?</td>
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<td>(16)</td>
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<td>Baseline scenario - Model calibration</td>
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<td>Driver behavior - Aggressive driving produced more emissions.</td>
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<td>Road capacity/Traffic flow - Impacts are negligible for clean vehicles</td>
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<td>Traffic signal timing - Impact on pedestrian exposure to emissions</td>
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<td>Traffic management at road maintenance - Life Cycle Assessment should be considered</td>
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<td>Signal coordination - Impact on emissions</td>
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<td>Traffic volume - Congestion yields higher emissions of CO, NOₓ and CO₂</td>
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<td>Road capacity/Traffic congestion - Indicators with the best descriptive capabilities are identified</td>
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<td>Traffic signal coordination - Reduction in emissions more correlated with stops than delay</td>
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<td>Traffic signal timing - Most of the emission savings come from a reduction in the number of stops</td>
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<td>(27)</td>
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<td>Traffic signal timing - Emissions can be reduced by about 5% to 12%</td>
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<td>Lane configuration/traffic signal coordination - Long-run emissions reductions are dubious</td>
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<td>(29)</td>
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<td>Speed, fleet, traffic volume - Reducing traffic demand by 20% led to 23% in CO₂ reduction</td>
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<td>Road capacity / Traffic flow - Link speed data provide better estimates of emissions</td>
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<td>Traffic flow - Pollutant concentrations in street canyons and backyards</td>
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<td>(32)</td>
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<td>Speed limit; traffic signal coordination - CO₂ and NOₓ reduction from 10% to 25%</td>
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<td>(33)</td>
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<td>Alternative fuels - Considerable reductions in emissions</td>
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<td>Traffic signal - Green wave allows reductions between 10% and 40%</td>
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<td>(35)</td>
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<td>Roundabout vs. Traffic signal - Emissions with roundabout are higher than simple pre-timed signal</td>
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<td>(36)</td>
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<td>Electronic toll collection - Reduces the overall network air pollution only in the short term</td>
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<td>(37)</td>
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<td>Intelligent speed adaptation - Allows CO emissions up to -48% and travel time +6%</td>
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<td>(38)</td>
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<td></td>
<td></td>
<td>Based incident-management - ITS strategies should be more weighted</td>
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<tr>
<td>(39)</td>
<td></td>
<td></td>
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<td>Green routing – Emissions reduction but with higher travel times</td>
</tr>
</tbody>
</table>

Note: CS: Case study; R: Real; T: Theoretical; I: Intersection; R: Road segment; N: Network; P: Paramics; Vi: Vissim; O: Others; C: CMEM; MOVES/VSP; V: Versit+.
2. METHODOLOGY

Figure 1 shows the main steps of the methodology developed in this study. Firstly, data on vehicle dynamics, traffic volumes, traffic signals timing and AOV were collected to evaluate the microsimulation traffic (VISSIM) and emissions model (VSP) for the baseline scenario. After that, several scenarios related with the introduction of eco-lanes will be evaluated in order to compare the use of these TMS in different types of routes. For hybrid vehicles emissions estimation, an average speed model (CORINAIR) was used.

Next the study domain (§2.1) is presented as well as the traffic (§2.2) and the emission (§2.3) tools used to estimate the road traffic emissions. Then the process of calibration and validation used to evaluate the baseline scenario is displayed (§2.4), and finally a description of several eco-lane scenarios (§2.5) are presented.

FIGURE 1 Methodological simulation framework.

2.1. Study domain

The studies conducted in medium-sized cities show that traffic problems are not just phenomena of the large metropolis (40). One typical problem is that population densities are not high enough to support efficient public transportation, further increasing the demand for individual transport. To evaluate the impact of TMS measures in a medium-
sized city, this research was conducted in Aveiro. This is a representative case of a European medium-sized city (78,500 inhabitants) with developed commercial and touristic activities. Previous empirical research was carried out in this area have addressed the impact of route choice in terms of emissions. Moreover, in Aveiro there is a high correlation between traffic and air quality levels. These studies have focused on three alternative routes that connect two points located in the city center (C) and in the suburban (S) area. In this paper, the impacts of different TMS for each one of these routes are evaluated.

Figure 2 shows the routes map. Routes A (~6.4km–4.0mi) and B (~6.1km–3.8mi) are mostly suburban. Route A is mostly a freeway (55%), and route B is mostly an arterial road (61%). Route C (~4.2km–2.6mi) is entirely in a compact urban environment. All routes have four lanes (two in each direction) in approximately 60% of their distance and two lanes in the remaining distance. In the majority of the sections the speed limits are 120, 70 and 50 km/h (75, 44 and 31 mph), for Routes A, B and C, respectively. During the morning peak hour, the highest traffic volumes in the RA and RB occur towards the city center (~2,000 vph), while in RC is in the opposite direction (~1,100 vph). Additional information on the routes are described elsewhere.

![Figure 2 Routes map and data collection points.](image-url)
2.2. Data collection

To assess the baseline scenario, field tests were conducted to collect vehicle dynamics (42-43), traffic volume and traffic signals timing:

1) Vehicles dynamics: Three different routes crossing the study domain were covered using GPS data-logger equipped vehicles to collect second-by-second vehicle dynamics. For each route, 15 trips during peak hour were performed using a passenger car. Approximately 550 km over 15 hours were collected;

2) Traffic volume monitoring: Traffic was counted in 14 strategic points of the study network (Figure 2). Based on these data, O/D matrices were defined for each intersection;

3) Traffic signals timing. The cycle length and phasing was measured six times in the traffic lights located at 2, 5, 9, 11 and 13 (Figure 2);

4) AOV: the number of passengers was collected randomly at strategic points of the network during 5 minutes periods in a total of one hour. Based on these data the AOV was estimated.

To reduce systematic errors, the data collection was done by different researchers.

The field work was conducted during the morning-peak hour (08-09:00AM) of the weekdays of March 2012 (Tuesday to Thursday).

These data were used to calibrate and validate the traffic model (see §2.3 and §2.4).

2.3. Traffic and emissions modeling

VISSIM 5.30 model was applied to simulate individual vehicle movements. This model was selected because of the possibility to define different road-user behavior parameters and sub-models for different vehicle types and traffic controls. Furthermore, it allows different vehicles performance such as desired maximum braking and acceleration per vehicle and class (45).

To estimate the emissions, the VSP categorized in 14 modes was used. This model allows to estimate the emissions second-by-second based on vehicle’s dynamics (second-by-second speed, acceleration and road grade) in accordance to the specified level of detail of the road traffic model used previously. Because of its direct physical interpretation and strong statistical correlations with vehicle emissions, VSP has become a widely recognized approach for emission micro simulation from both gasoline (46-47) and diesel (49) light passenger vehicles. More information on VSP methodology is described elsewhere (46-48).

Recent data on modal emissions rates for hybrid cars is available. However, the lack of information on engine speed which is an indicator of engine on or off operation (49) did not allow the use of this approach to estimate emissions from hybrid vehicles. Thus, the CORINAIR methodology (50) was used and adapted to consider instantaneous speed.

In this study VSP and CORINAIR methodologies were used to estimate emissions based on real data from field tests and on the data provided by traffic model. A C# console application was developed to compute second-by-second vehicle dynamics data from VISSIM output for emissions estimate. Total emissions for passenger cars were calculated considering 57.5% of gasoline and 42.5% of diesel vehicles (51). Data on vehicle dynamics from VISSIM and field tests were compared for the three routes. Due to the flat terrain, a road grade of zero was assumed. NOx, CO, HC, and CO2 total emissions by route were derived based on the time spent in each VSP mode multiplied by its respective emission factor (46-47).
2.4. Calibration and validation
In this study, traffic volumes, travel times and speed rates were selected to evaluate the model performance since these variables reflect the driving behavior parameters and the level of service (52). The model evaluation was made in three steps. While the first one is focus on driver behavior parameters, the following steps are related with observed data.

In the first step, driver behavior parameters of the traffic model were tested in order to assess their effect on travel times and also speed rates. The calibration parameters can be divided into car-following parameters, lane-change parameters and simulation resolution. By an initial sensitivity analysis, no relationship was found between lane change parameters and travel times. Regarding simulation resolution, a fixed value was assumed (10 times steps/sim.sec) due to the input of VSP model (second-by-second). After several runs, the subsequent car-following parameters were obtained: additive and multiple part of safety distance by 1.95m and 2.95m, respectively, and a value of 1.60m for the average standstill distance.

In the second step, the estimated traffic volumes, travel times and speed profiles were compared with the observed data considering a preliminary number of runs selected and using the method suggest by Hale (53). This method is based on the simulation results from the preliminary where the mean sample variance is compared to a predetermined confidence interval (CI) based on a t-distribution. The means and overall "goodness of fit" between observed and estimated traffic volumes were compared by using GEH Statistic test (52) and the percent Root Mean Square Error (RMSE) parameter (54), respectively. For this comparison 15 points of study domain were selected. Then, 10 initial random seeds runs (54) were considered in which the deviations between observed and estimated values were minimized to reduce RMSE parameters. For travel times and speed means, the "floating car runs" method suggested by Dowling et al. (52) was applied.

The final step was focused on the comparison between observed and estimated VSP modal distribution. The two-sample Kolmogorov-Sminov test (K-S test) for a 95.0% and 97.5% confidence level was then used to assess if the probability distributions of the two samples were different.

A comprehensive discussion on travel time per lane, link and network (before and after scenarios implementation) is available in the Performance measures section (§4.1).

2.5 Eco-lanes scenarios
The baseline scenario is the validated model, without HOV lanes and with an AOV of 1.37 passengers/vehicle (AOV1.37), with a distribution of 70.0%, 25.0%, 3.0%, 1.8% and 0.2% for 1, 2, 3, 4 and 5 passengers respectively. Then, six distinct scenarios of HOV and eco-lanes were simulated. The first three scenarios reflect the conversion of a General Purpose Lanes (GPL) to conventional HOV lanes, i.e. only cars with two or more passengers (HOV2+) are eligible to use these lanes. For each case, different values of AOV rates were covered. Scenario1 (S1) reflects the current AOV1.37. Scenario 2 (S2) and 3 (S3) correspond to different AOV rates after the introduction of eco-lanes (1.50 and 1.70 passenger/vehicle keeping the total number of passengers (AOV1.50 and AOV1.70)). These values were based on previous European experiences (8). For each scenario, traffic demand was recalculated as a function of AOV changes.

Scenarios 4, 5 and 6 (S4-S6) simulate the eco-lane concept. In particular, it is assumed that in addition to HOV2+, single occupant Hybrid Vehicles (HV) and Electric Vehicles
(EV) are allowed to use these lanes. In this situation, the current AOV rate is maintained assuming that increasing the number of green vehicles (with probably lower energy costs) can further encourage drivers to keep traveling alone. Thus, for scenarios S4-S6, an increased market penetration of these vehicles is simulated according the European predictions to 2020 and to 2030 (55). Summarizing, six scenarios were constructed and applied to three different road categories as follows:

- Baseline scenario: Without HOV lanes; AOV^{1.37};
- S1: HOV^{2+} and AOV^{1.37};
- S2: HOV^{2+} and AOV^{1.50};
- S3: HOV^{2+} and AOV^{1.70};
- S4: HOV^{2+} + EV (2%) + HV (2%) (AOV^{1.37});
- S5: HOV^{2+} + EV (11%) + HV (5%) (AOV^{1.37});
- S6: HOV^{2+} + EV (30%) + HV (20%) (AOV^{1.37}).

For all routes, the left lane was converted to an HOV/eco-lane: 3.8km (2.4mi) in the freeway, 1.5km (0.9mi) in the urban road and 3.0km (1.9mi) in the arterial road. In 33% of the arterial road distance an extra lane was added on segments with only one lane in each direction. The violation of HOV was no considered, since no detailed data on violation rates in the European context were found.

4. RESULTS
4.1. Model evaluation

The statistical indicators of the integrated platform show valid results. Next, the model performance is evaluated based on traffic volumes, travel time, average speed and VSP modal distribution.

Performance measures

For traffic volumes on each counter, the GEH values range from 0.0 to 0.9 (52) while RSME did not reach the 6% (54). These results indicated good accuracy of the simulation. Table 2 shows the comparison between observed and estimated means for travel times and speed. In this case, the GEH statistics test lower than 0.50 was yielded for both parameters on each route evaluated. The highest travel times differences were recorded on routes A (S→C) and C (C→S and S→C). The results indicated that 10 runs per simulation were adequate.
TABLE 2 Observed and estimated values for travel times and speed means and number of floating car runs

<table>
<thead>
<tr>
<th>Route</th>
<th>N (NMIN)</th>
<th>Travel times (s)</th>
<th>Speed (km/h)</th>
<th>GEH</th>
<th>Observed (95% CI)</th>
<th>Estimated (95% CI)</th>
<th>GEH</th>
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<tr>
<td></td>
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<td>Observed</td>
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<td>(95% CI)</td>
<td>(95% CI)</td>
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<tr>
<td>A (C→S)</td>
<td>22 (3)</td>
<td>477.33 (±16.79)</td>
<td>480.64 (±10.82)</td>
<td>0.15</td>
<td>52.00 (32.30mph)</td>
<td>51.35 (31.89mph)</td>
<td>0.09</td>
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<td></td>
<td></td>
<td>(95% CI)</td>
<td>(95% CI)</td>
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<tr>
<td>B (C→S)</td>
<td>16 (6)</td>
<td>597.59 (±32.81)</td>
<td>590.50 (±23.57)</td>
<td>0.29</td>
<td>38.50 (23.91mph)</td>
<td>38.58 (23.86mph)</td>
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<tr>
<td>C (C→S)</td>
<td>22 (5)</td>
<td>613.36 (±30.51)</td>
<td>604.18 (±19.06)</td>
<td>0.37</td>
<td>25.77 (16.01mph)</td>
<td>27.33 (16.98mph)</td>
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<td>(95% CI)</td>
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<tr>
<td>A (S→C)</td>
<td>16 (4)</td>
<td>515.33 (±16.74)</td>
<td>528.38 (±16.74)</td>
<td>0.57</td>
<td>42.23 (26.23mph)</td>
<td>40.50 (25.16mph)</td>
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<tr>
<td>B (S→C)</td>
<td>18 (7)</td>
<td>565.88 (±20.50)</td>
<td>568.44 (±22.81)</td>
<td>0.11</td>
<td>38.65 (24.01mph)</td>
<td>37.69 (23.41mph)</td>
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<tr>
<td>C (S→C)</td>
<td>18 (3)</td>
<td>543.77 (±39.52)</td>
<td>551.67 (±11.99)</td>
<td>0.34</td>
<td>26.96 (16.75mph)</td>
<td>26.59 (16.52mph)</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Notes: NMIN: Minimum number of required floating car runs, 95%CI: Confidence Interval at 95%. GEH: Geoffrey E. Havers Statistics test.

VSP modes
The columns charts of Figure 3 display the observed and estimated VSP modal distribution, with the respective standard deviation. VSP distributions followed the same trend in both approaches. The highest absolute differences were found for modes 2 and 4 (modes with small speeds and decelerations or low accelerations) on routes A and B (C→S and S→C). This can be explained due to higher deceleration rates simulated in the traffic model confirming the findings of (16). Concerning mode 4, this difference arises from the fact that when the simulated vehicles reach the cruising speed they maintain a constant speed, while in reality there are more fluctuations in speed which enhance the occurrence of different VSP modes.

The two-sample K-S test (D-value) to a 95.0% confidence level indicated that routes C(C→S) and C(S→C) have similar distributions. In these cases, D-values for these routes were 0.068 (D-critical = 0.078) and 0.078 (D-critical = 0.082), respectively. For a 97.5% confidence level, the observed and estimated VSP distributions of all routes did not show significant differences. Regarding CO₂ emissions, the relative differences range from 0.5% to 5.4%.
FIGURE 3 Observed and estimated VSP modes distribution (with standard deviation intervals) for: (a) Route A (C→S); (b) Route B (C→S); (c) Route C (C→S); (d) Route A (S→C); (e) Route B (S→C); (f) Route C (S→C).

4.2. Eco-lanes scenarios
The analysis focuses on the network segments that were transformed by converting the left lane to an eco-lane. Table 3 presents travel times for the baseline scenario for each lane and direction. Then the relative difference to the baseline scenario and the comparative time savings by choosing the left lane are presented.
Regarding the freeway segments, in the direction center to suburbs, no significant changes in travel times are observed since a low ratio volume/capacity is maintained. In this case, no significant time savings incentives for car-poolers would be observed. However, in the opposite direction, single morning commuters would be expected to suffer some additional delays caused by presence of more vehicles in the right lane. HOV\(^{2+}\) vehicles could save up to 27% in travel time with AOV\(^{1.70}\) (S3). Regarding the introduction of HV and EV in eco-lanes (S4-S6), no significant differences in relation to the previous scenarios are observed. However, as the percentage of these vehicles increases the benefit of choosing the eco-lane is slightly diminished. The overall corridor performance is not affected in terms of total travel time.

For the urban roads (C→S direction) the travel time in the right lane would increase considerably due to an unbalanced distribution of traffic among HOV (left) and right lane. Single travelers could experience a considerable increase in travel time after the introduction of the eco-lane. If there was no change in the AOV, S1 shows that traveling on the eco-lane could save up to 34% in travel time. This route was found to be particularly sensitive to slight changes in traffic volumes, since the travel time savings by choosing the eco-lane decreases considerably for the remaining scenarios. The overall corridor performance (in terms of travel time) is only slightly affected in S1 with 7.3% increase in total travel time. However, 49% (S1), 57% (S2) and, 63% (S3) respectively of the passengers traveling on this corridor could benefit from a reduction in travel time by choosing the eco-lane (Table 3).

Finally, in the arterial road, the addition of an extra eco-lane would allow a reduction in travel time for all scenarios and both lanes. It should be mentioned that in this case for all scenarios there is an increase in road capacity. Although significant travel time savings are likely to be achieved, the eco-lane would not provide any competitive advantage over the remaining lanes, since travel time savings by choosing the left lane would not exceed significantly the current situation. Previous research has shown that significant time-savings for car-poolers should be possible and at least 20% of initial proportions of HOVs should benefit from the use of the eco-lane (8). While the latter criterion is reached in all scenarios (31%), the relative time savings are only more significant in the case of the urban arterial road (C→S) and freeway (S→C).
TABLE 3 Travel times for road type for the baseline and relative difference for the remain scenarios

<table>
<thead>
<tr>
<th>Road type</th>
<th>Scenario</th>
<th>Centre – Suburbs direction</th>
<th>Suburbs – Centre direction</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left lane</td>
<td>Right lane</td>
<td>Left/right savings</td>
</tr>
<tr>
<td>Freeway</td>
<td>Baseline</td>
<td>123 s</td>
<td>130 s</td>
<td>-5.2%</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>-4.1%</td>
<td>2.8%</td>
<td>-11.6%</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>-10.3%</td>
<td>2.5%</td>
<td>-17.1%</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>-8.0%</td>
<td>1.5%</td>
<td>-14.1%</td>
</tr>
<tr>
<td></td>
<td>S4</td>
<td>-6.8%</td>
<td>2.7%</td>
<td>-14.0%</td>
</tr>
<tr>
<td></td>
<td>S5</td>
<td>-4.9%</td>
<td>3.0%</td>
<td>-12.5%</td>
</tr>
<tr>
<td></td>
<td>S6</td>
<td>-0.3%</td>
<td>3.5%</td>
<td>-8.7%</td>
</tr>
<tr>
<td>Urban road</td>
<td>Baseline</td>
<td>141 s</td>
<td>154 s</td>
<td>-8.3%</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>-4.5%</td>
<td>32.5%</td>
<td>-33.9%</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>-3.1%</td>
<td>5.6%</td>
<td>-15.9%</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>-2.4%</td>
<td>-3.1%</td>
<td>-7.7%</td>
</tr>
<tr>
<td></td>
<td>S4</td>
<td>-3.9%</td>
<td>7.9%</td>
<td>-18.4%</td>
</tr>
<tr>
<td></td>
<td>S5</td>
<td>-3.3%</td>
<td>7.6%</td>
<td>-17.6%</td>
</tr>
<tr>
<td></td>
<td>S6</td>
<td>-2.6%</td>
<td>5.5%</td>
<td>-15.4%</td>
</tr>
<tr>
<td>Arterial</td>
<td>Baseline</td>
<td>236 s</td>
<td>250 s</td>
<td>-5.8%</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>-3.6%</td>
<td>-6.7%</td>
<td>-2.7%</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>-7.9%</td>
<td>-9.8%</td>
<td>-3.8%</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>-9.9%</td>
<td>-11.1%</td>
<td>-4.5%</td>
</tr>
<tr>
<td></td>
<td>S4</td>
<td>-4.9%</td>
<td>-7.5%</td>
<td>-3.1%</td>
</tr>
<tr>
<td></td>
<td>S5</td>
<td>-5.4%</td>
<td>-7.9%</td>
<td>-3.2%</td>
</tr>
<tr>
<td></td>
<td>S6</td>
<td>-6.3%</td>
<td>-8.6%</td>
<td>-3.5%</td>
</tr>
</tbody>
</table>

Figure 4 compares the relative differences in pollutants emissions over the baseline scenario to the three study-cases. Generally, scenario S6 performs the best, primarily because of the high portion of EV that have zero emissions (in the city). The second best scenario is S3 due to the considerable traffic reduction motivated by the increase of AOV rate. In a short-term, the most important scenarios to evaluate are the S1 and S4 (current AOV rate and realistic market share of HV and EV). Namely, it needs to be ensured that total emissions will not increase considerably immediately after the introduction of HOV/eco-lanes. This fact occurs for all routes with the exception of the urban road (S1) where an increase of 5%, 7% and 27% is observed for NOx, CO2 and HC respectively. While emissions in the left lane are consistently lower after the introduction of an HOV lane, in the right lane, emissions increase considerably. This increase was higher on the urban road, where CO2 could climb up 88%.

Both on the motorway and on the urban road the reduction of emissions can be mainly attributed to the reduction in traffic (S2 and S3) or a higher share of cleaner vehicles. In the arterial road, the reduction of emissions results primarily from the increased capacity and consequent improvements in traffic conditions.

Overall and considering both results in terms of travel times and emissions, in short term, the only defensible strategy to reduce emissions would be the conversion of the freeway left lane to an eco-lane. In this case a substantial proportion of commuters could benefit from slightly lower travel times with a positive environmental impact (-3% CO2, -8% NOx, and -14% CO). Although in the arterial road all scenarios showed positive results, it is not guaranteed that an additional demand for this route (caused by lower travel times) would have future negative impacts. Moreover, the main objective of the increase of
AOV could not be achieved (no significant advantages in travel time). In the urban corridor the results can be positive in medium term, i.e. after rise to AOV1.50 or the green vehicles penetrate the market sufficiently to have a measurable impact on total fleet fuel consumption and emissions.

**FIGURE 4** Comparison of total pollutant emissions (NOₓ, HC, CO and CO₂) for HOV/eco-lanes scenarios with the baseline scenario.
5. CONCLUSIONS

An integrated platform for modeling traffic and emissions using the VISSIM model and methodology VSP and CORINAIR has been developed. After a rigorous calibration process the model was validated in terms of speeds, volumes, travel time and VSP modal distribution. This platform was then used to simulate the inclusion of HOV and eco-lanes in an urban area.

The methodology applied shows that HOV and eco-lanes in a medium European urban city are feasible. When the existing traffic demand is still less than the corridor capacity, the conversion of a GPL to an eco-lane was shown to have no significant impacts on network performance. It has been found that in the freeway the majority of passengers can reduce their travel time about 5% with a positive impact in terms of total emissions impact (-3% CO₂, -14% CO, -8% NOₓ). In the urban corridor, the reduction of emissions could be achieved only if the AOV is increased to 1.50 passenger/vehicle. In this situation, the total emissions of the corridor can be reduced up to 20%. In the arterial road the increase in the capacity (with an extra eco-lane) has shown to be a positive impact on travel time and emissions if the current traffic volumes remain similar. Nevertheless, the choice of the eco-lane would not bring significant time savings when compared with the current situation. The incorporation of green vehicles in the HOV lanes did not show a significant impact on the corridors performance in terms of travel time. Thus, it seems to be a valid option allowing the incorporation of these vehicles into HOV lanes as a way to promote their market penetration.

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