Technical paper 1

INFORMATION MANAGEMENT FOR SMART AND SUSTAINABLE MOBILITY

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ABSTRACT

The main objective of this work is to present a modular platform to manage traffic information for smart mobility. The management and collection of dynamic data is a challenging process especially in the context of low penetration of floating car data (FCD) and limited availability of traffic monitoring stations. In this work, three different road segments of a European medium-sized city were selected to collect vehicle dynamic data over multiple scenarios of traffic demand. Simultaneously, traffic volumes were recorded in real time. The main objective of this pilot experiment was to assess how it would be possible to read and predict traffic congestion and emissions levels with limited information and how data from multiple sources should be managed in order to correlate and deal with this information in real time. It was possible to correlate simultaneously multiple data set such as congestion values, specific vehicle power (VSP) mode distribution, Google traffic data and emission. Preliminary findings suggest that in urban arterials travel time and congestion levels can be reliable indicators for estimating emissions in real time. In sections of rural arterials, the estimation of real-time traffic performance is more complex. Key issues towards the implementation of a prototyping platform in an urban context are also discussed.

Keywords: ATMS, Traffic congestion, ITS, Database, FCD

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1. INTRODUCTION AND OBJECTIVES

Road transport will remain a key sector regarding impacts on climate change, air pollution and noise. Efficient use of existing infrastructures has been identified by the European Union as a key strategy to reduce transport externalities (1-4). A big challenge to traffic management systems is the coordination of the data collected and the implementation of effective solutions *(5)*.

To improve operations, Intelligent Transportations systems (ITS), vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications have to be set and optimized while considering the coexistence and cooperation between them *(6)*.

The main objective of this work is to assess key issues regarding interoperability between traffic models and new sources of data, including FCD and traffic monitoring sensors. The ultimate objective is to develop a dynamic structure based on geographic information systems containing information related to real-time traffic performance and associated environmental externalities. Therefore, the main research questions addressed in this paper are:

- Could we predict accurately dioxide carbon (CO_2) emissions and local pollutant emissions with limited FCD?
- How can traffic data obtained from different sources be used in different links?
- Can we trust in Google traffic data as a primary qualitative indicator to predict the environmental performance in a given link?

2. LITERATURE REVIEW

ITS are faced with difficulties in data sharing and cooperation among them. It is also referenced the importance of creating a modular platform in order to assess different impacts related to transport *(7-8)*.

The implementation of advanced traffic management systems (ATMS) must consider different topic including the human factor as well as institutional and legal problems which are considered the most difficult areas to overcome *(9-10)*.

Researchers have tested the integration of V2V and V2I communications, demonstrating improvements in the performance of road networks operation (10-14). A communication architecture integrating V2V and V2I communications based on mobile networks was evaluated being the innovative part of this project the implementation of the communication architecture on the developed system Juxtapose (JXTA) for P2P communication, which allows the propagation of messages between vehicles and between vehicles and infrastructures (JXTA allows communication between devices regardless of their physical location and network technology in which they are installed) (15).

Regarding traffic flows monitoring, vision systems are one of the various ITS proposals, offering advantages such as easy maintenance and great flexibility *(16)*. Some author's explored data mining methods and mathematical functions to estimate traffic volumes and networks' performance based on a limited subpopulation of FCD. This new knowledge opens new research challenges to also ascertain the environmental performance of road network in real-time (17-19). *FCD*, appears as a complementary method of large-scale data collection to define the traffic flow speed, managing to assimilate information (location, speed, direction and time). However, given the variability in the dimensions of the database itself, and the complexity of traffic dynamics, there are considerable challenges to characterize traffic flows. To overcome this issue, researchers have presented a multidimensional analysis method based on the 'data cube' in which the processing of data occurs through aggregations of different levels/dimensions *(20)*.

Although there are several technologies in transmitting data (as Bluetooth, Wifi, Zigbee, usb etc), there are some limitations that need to be overcome as distance, slow transfer rates, high power consumption, scalability as accuracy (being, specially accuracy very difficult and costly to produce and compile). There are also issues related to synchronization among different types of computing elements, due to the large adoption of many-cores accelerators (21-25).

A network of any kind with processing capacity can establish communication between multiple devices, enabling exchange of data between programs and systems. Over the years, there has been developed a variety of protocols to optimize the requirements of each network. The WiFi protocol has been used in location scenarios and simultaneous mappings, as well as for the interconnection of robotic vehicles, in which the signal strength received by a router is used to estimate the vehicle position (26-32).

What has arisen from literature review is that although there has been a strong technological development, institutional and legal problems may delay the full implementation of these applications. Some studies demonstrated optimal ways of how to collect data or suggest the application of mathematical models for describing traffic conflicts, usually at intersections. However, there is a lack of research regarding the implementation of modular systems, namely with the possibility of imposition of rules, allowing reading massive amounts of processed data. There is also a lack of flexible systems to support this dynamic information and mathematical models able to set as close as possible what is happening on a route with or without traffic volume information and with the final goal of determining traffic environmental performance (CO_2 and local pollutants) in real time.*(33)*

3.METHODOLOGY

3.1 Overall methodology

Figure 1 presents the overall methodology of the work. The objective of the second task was to obtain a preliminary set of results and correlations to include into a database that will feed in turn the prototyping platform. To assess whether information provided by Google Traffic can be used as a complement and reliable indicator for predicting traffic performance and carbon dioxide (CO_2) emissions, a print screen of Google maps traffic information has been recorded with a periodicity of 1 minute during field work.

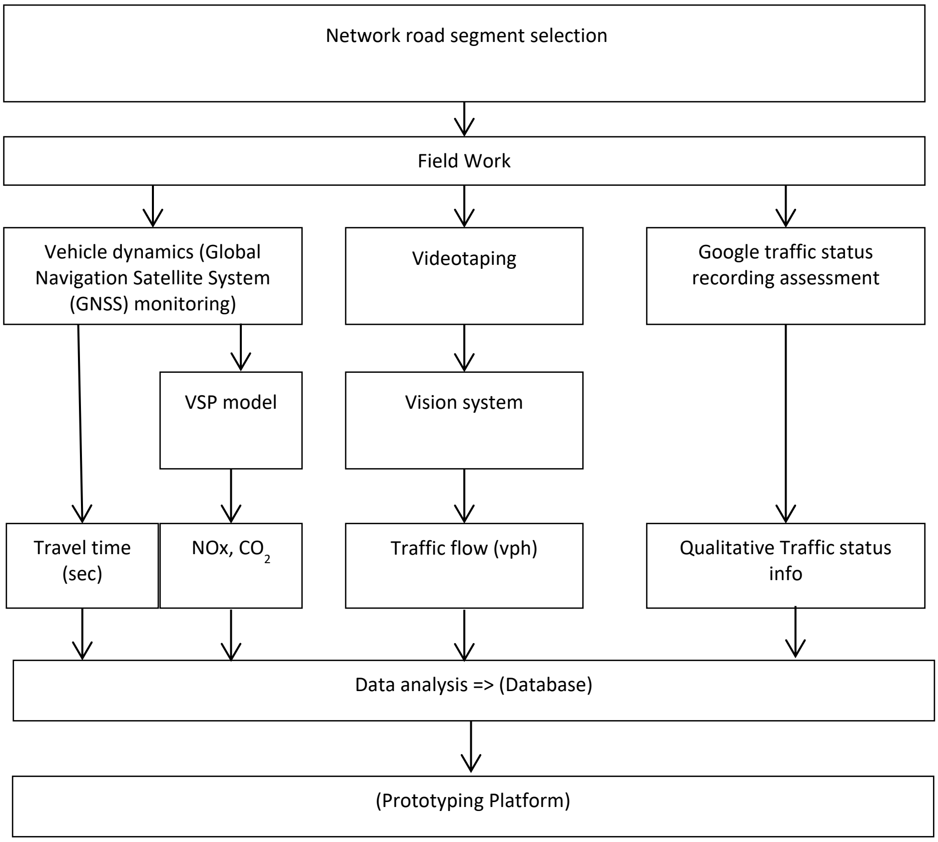

FIGURE 1 Methodology Overview.

3.2 Selection of Road segments

To conduct this pilot test, three road segments with distinct features located in a European medium-sized city (Aveiro, Portugal) were chosen.

TABLE 1 Routes characteristics (Q – traffic volume per hour) and number of trips performed

Route name/type	Route code	Length (m) - *yd*	Lanes	Intersections	Qmax (vph)	Av Q (vph)	Google traffic data	N° trips	Built environment
Av. 25 Abril, Aveiro (Urban Street)	R1	850 m *930 yd*	2	1 roundabout, 2 intersections, 2 traffic lights,	1582	1068	No	70	2 high schools, 2 traffic lights,4 bus stops, 6 crosswalks
N109, Aveiro (arterial ring road)	R2	900 m 985 yd	4	2 roundabout 3 intersections	2880	1218	Yes	45	2 gas stations
Av. Universidade Aveiro Urban Avenue)	R3	1400m *1531 yd*	4	1 roundabout, 3 intersections	779	577	Yes	34	1 University, 1 Hospital, 2 gas stations, 1 traffic light

One videocameras was installed in key points of each route to get traffic data information. In R1, the location of the camera was near a traffic light intersection, in R2 the location of the camera was near the main roundabout and on R3 was near the traffic lights. Qmax represents the max volume obtained in each Route in all tests, and Average Q represents the average volume of all tests.

3.3.Pilot study – Empirical Work

For vehicle dynamic monitoring different light duty vehicles were equipped with GNSS data loggers to collect second-by-second trajectory data required for microscopic analysis. For traffic flow monitoring, a static video camera was used. In order to obtain higher diversity and heterogeneity of driving patterns, two vehicles and three drivers were used. The probe vehicle moved according to the driver's perception of the average speed of the traffic stream *(34)*. Wherever possible, GNSS measurements were recorded by two vehicles at the same time.

3.4.Data processing

3.4.1.Calculation of emissions

The VSP model reflects the comparison of driving behavioral effects in fuel consumption and vehicle emissions (CO_2, carbon (CO), nitrogen oxide ($NO_{x)}$ and hydrocarbon (HC)). It is a model that has proven to be very effective in estimating emissions from petrol cars and diesel cars. The VSP (typically ranging from -2 to over 39 kW/ton) represents the power required to the engine based on the road gradient, aerodynamics, kinetic energy and friction to the movement *(35)(36)*.

$$VSP = v[1.1a + 9.81 \times \sin(\arctan(grade)) + 0.132] + 0.000302v^3 \qquad (1)$$

VSP = specific vehicle power (kW/ton);

v = instantaneous speed (m/s);

a = instantaneous acceleration (m/s^2);

grade = instantaneous road gradient (± %);

In a second step, VSP values were categorized in 14 modes with a specific emission factor for CO_2, CO, NO_X and Hydrocarbon (HC) emissions. Then, the number of seconds spent in each VSP mode (was multiplied by the respective modal emission rate and summed over all modes, to obtain total emissions of each run (eq. 2). Emissions rates (LDGV and LDGV) for each VSP mode can be found in Coelho et al., (2009).

$$REi = \sum_{1}^{14} EFij \times tij \qquad (2)$$

RE_i = Total emissions of the pollutant *i* generated on each run (g);
EF_{ij} = Emission factor for the source of pollutant *i* (NO_X, CO_2, CO, HC) for the VSP mode *j* (1, 2, 3…14) (g/s);
t_{ij} = Time spent on VSP mode *j* in each run (s).

It should be noted that negative VSP values (Mode 1 and 2) are typical related to decelerations or paths downhill. Mode 3 includes emissions during idling or constant speed, while modes 4 to 14 show linearly increasing VSP values. The VSP methodology fits the values recorded in 14 modes. To apply VSP, it is needed to record each second, the slope of the road and the speed profile. In the case of CO_2, NOx and HC, the VSP1 and VSP2 modes present together values higher than VSP3 mode. Generally values for VSP4 and higher modes tend to indicate linearly increasing values VSP (35-38).

Taking into account some performed analyzes, for VSP modes, and observations made during the tests, it was decided to group the VSP modes into 3 types: VSP1-VSP3; VSP4-VSP6; VSP7-VSP14.

- VSP1-VSP3 represent slowdown situations, accelerations and STOP&GO situations in traffic singularities, such as intersections, roundabouts, traffic jams etc;
- VSP4-VSP6 represent driving situations which the vehicle takes to reach cruising speed, including smooth accelerations or soft decelerations (such as dropping the accelerator instead of breaking);
- VSP7-VSP14 may correspond to larger and stronger accelerations usually at speeds above 7 m/s.

There are two main reasons for the aggregation of VSP modes, these being the reduction of data to be processed without jeopardizing the information obtained after processing it, and through this methodology.

3.4.2. Congestion equation

In this pilot experiment, an equation to define the existing traffic flow conditions was explored (Eq. 2). The purpose of this equation is to allow a comparison to the results presented by Google traffic and also to serve as an additional object to explore possible relationships to VSP distributions (gathered from FCD) with emissions under multiple congestion levels.

$$X = \ln\left(\frac{\Delta T}{\Delta Tr}\right) \times \left(\frac{V\max - V\min}{Vav}\right) \qquad (3)$$

- X: is dimensionless and quantifies the traffic conditions level. In case of values between 0 and -0.7, the flow is not much slower than expected. For values equal to -1.5 the travel time can be 2 times the travel under free flow conditions. Positive values ideally will be disregarded, because they represent speeding;
- $\ln\left(\frac{\Delta T}{\Delta Tr}\right)$: This part of the function gives the positive or negative sign to it. ΔT is the time a vehicle takes to cover a particular section in free flow conditions ΔTr is the actual time that the vehicle takes to cover the road segment. In case the latter is higher than the first (the vehicle takes longer), a negative value for the function result will be assigned. This log also serves to limit the function values between 0 and 1.5 (positive or negative) and to determine values higher than 1.5 - extreme cases of traffic congestion;

- $\left(\frac{V\max - V\min}{Vav}\right)$: This relates the maximum speed (Vmax) reached in a route with the minimum speed (Vmin) and average speed (Vav). This relationship serves to set a range of values, to set the traffic conditions. In this case, the values range typically from 0 to 12, hence the need to have to limit the range to assign meaning to values. Minimum and maximum speed refers to the maximum and minimum speed recorded in the road segment or to a defined time interval. Vav is the average speed on that time period/route. The ratio between 0 and 12 (mathematically speaking, the max ratio is infinite, but in the typical case scenario, 12 is a really big ratio, like (40 (m/s) – 0(m/s))/4(m/s), which is 10. It is possible to give results above 12, but they will be extraordinary situations, and the ln will always reduce this time interval) is obtained by (vmax-vmin)/(vavg). 0 is only obtained by vmax=vmin. Because this algorithm is being applied to data from each test (alongside the route) this never happens, vmax always different from vmin. The equation was planned also to consider the cases where it is not data alongside the route but data from time intervals in the segmentations of some route that are being studied. The case where data from time intervals is being studied was not addressed in this paper, however the equation is prepared if needed to conduct this type of analysis.

3.5.Ongoing work – Database and prototype platform integration

The database under development is based on the 'data cube' concept (15). The database must contain a set of statistical data and link based performance based to enable an easy integration with optimization algorithms and decision support tools connected to the prototyping platform. The system under development is modular, meaning that if one part goes down or needs an update, all the system still works, being just one node down.

Accurate and scalable simulation has been an enabling factor for systems research. There is a lack of systems whose architecture is as modular as possible and to allow to deal with different limitations. Reasons to the lack of accuracy, especially on Geographic Information Systems, may result from mistakes of many sort (such as lack of signal, bad weather, etc). To prevent this kind of situations, a modular system should be developed containing functions that should be activated when the informatic system fails (as the congestion equation), or should be created and studied in a way that they could be implemented and also predict traffic performance parameters based on historic data or other kind of scenarios/information.

In figure 2a a scheme of the database operations is shown. Essentially, the database must be prepared and configurated to be used by researchers and transport infrastructure managers. In figure 2b, the circles referenced by the numbers are traffic signals locations that will be monitored in real time (based on FCD and/or video data) - links with a continuous line. Where the platform is not available, the link performance evaluation will be based on historic/statistical information and intelligent algorithms (links with dash lines). The objective is that the system could still operate if some element (eg. 2 or 5) is not operational. Figure 2c shows a scheme of how the relation between platform and database should work. In 1 satellite sends GNSS position to the platform instaled in a vehicle. The platform located inside the vehicle sends the data to the static platform (2) whenever is in range. This platform sends the data to the servers (3). If a video camera is installed, this platform may send video live transmission to the server, where the vision system will be used to estimate traffic flow in real time. The final platform will be also able to interact to road infrastructure and drivers.

The system will be integrated in an electronic prototyping system denominated by "*Dech*" which stands for "decomplicate hardware". The main advantage is that every module is an element in a flexible network. The protocol will be an open source meaning that modules can be developed by anyone with access to the platform.

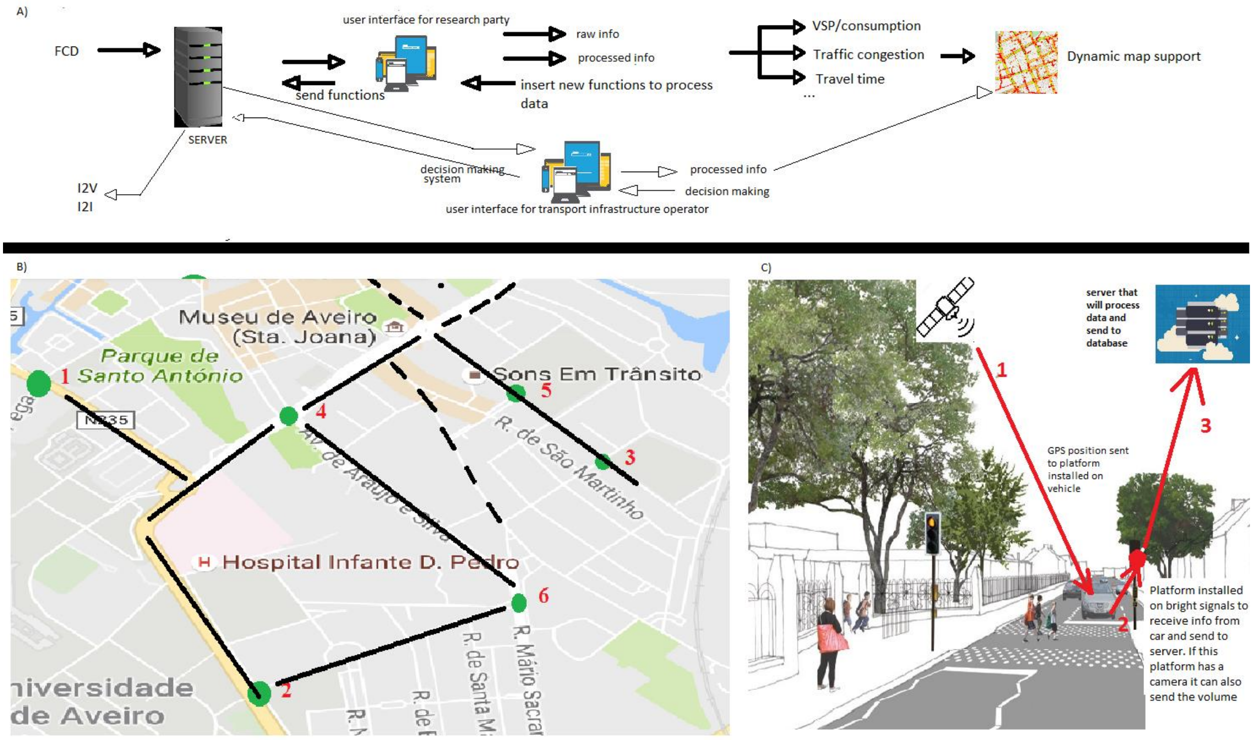

FIGURE 2 Decision Making Support Information A) Database functioning B) geographic data collected with platform C) platform functioning *(39)*.

4.RESULTS

The main objective of this pilot experiment is to identify key variables towards the development of advanced link based performance functions for characterizing the environmental and traffic performance of the road network.

4.1. Emission and VSP Mode Distribution

The graphic presented in Figure 3 relates CO_2 emissions for diesel and gasoline vehicles with VSP Mode Distribution. The values presented represent the mean of each variable for each test.

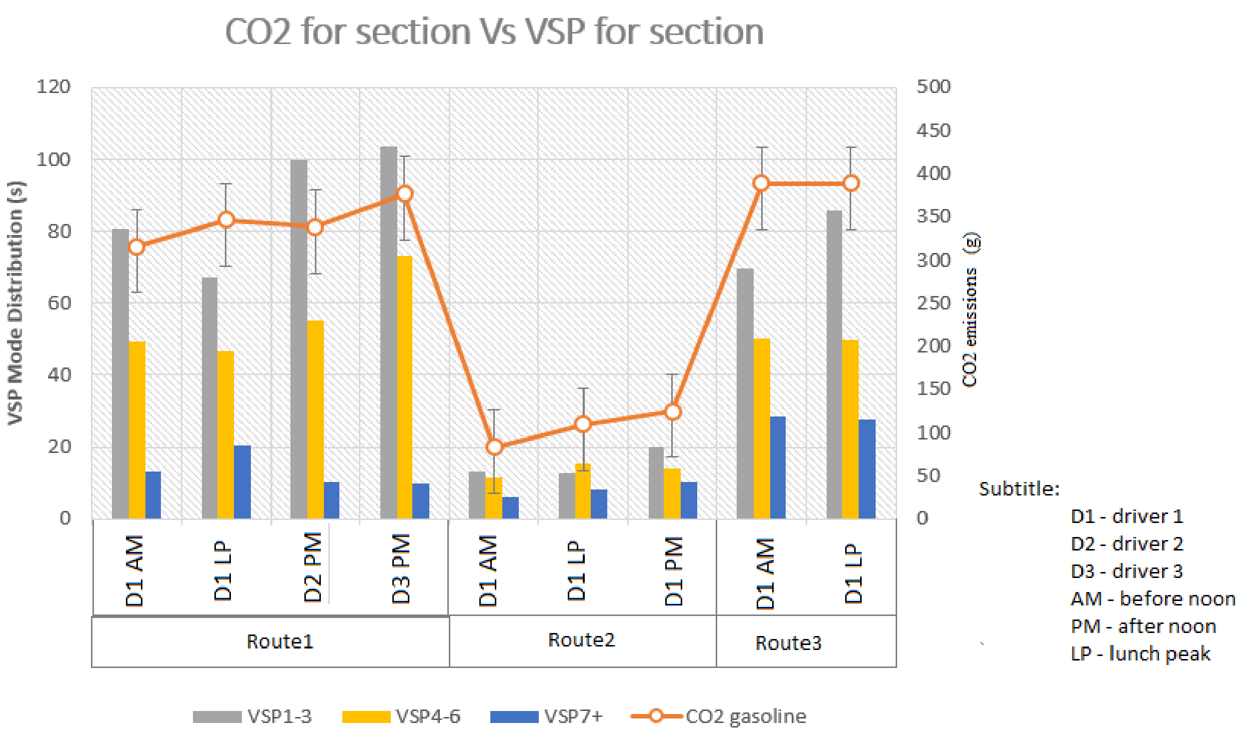

FIGURE 3 Comparison between total CO_2 emissions in each route and time spent on VSP intervals

CO_2 emissions are the mean of all CO_2 emissions (g/s) in all tests made in each part of the day for each route.

As expected higher time spent VSP1-VSP3 will lead to higher CO_2 emissions, as a result of more time spent on stop and go situations (leading to an increase of VSP 3). However in route 1 D1LP had higher CO_2 emissions than D1AM. Although the slower traffic flow in D1AM, during the morning period, the driver showed a smoother driving behaviour, when compared with D1LP which presented a more aggressive driving style (higher VSP7+). Comparing D2PM and D3PM, which drove at the same period, there is no significant statistic difference. Outside the urban road environment, CO_2 emissions tend to be lower as a result of less congestion and inexistence of traffic lights. It must be emphasized that in route 3 the number of tests was lower because of the occurrence road works.

4.2.Estimation of traffic and emissions performance through alternative traffic data services

The qualitative information on traffic levels offered by Google traffic has been compared with empirical data on travel time and estimated emissions (Figure 4).

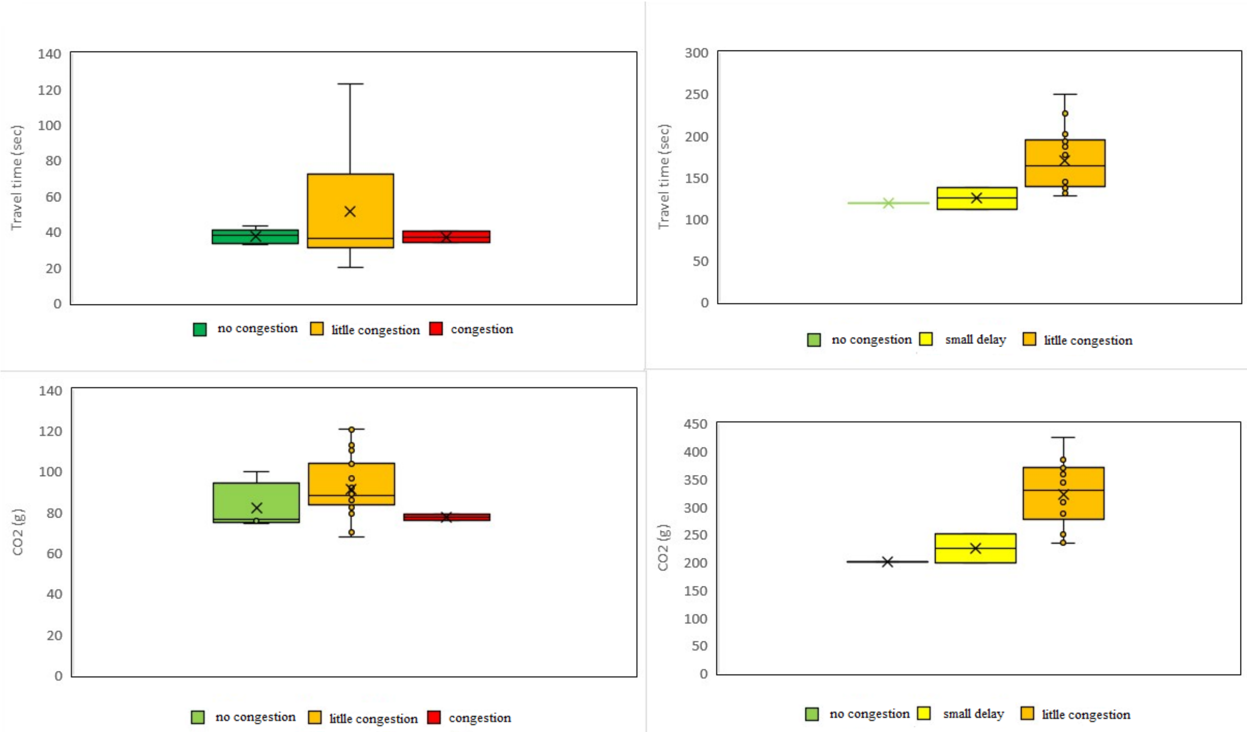

FIGURE 4. Comparison of observed travel time (top) travel CO_2 emissions (bottom) according to different levels of online traffic information (Google traffic) for Route 2 (left) and Route 3 (right)

While for R2 (rural arterial) is not possible to establish an evident relationship between the qualitative Google data (given for a 4 colour code green – yellow – orange red) and the actual travel time, in the case of Route 3 it can be seen that the tests performed during the occurrence of traffic showed as orange colour in Google maps, the travel time is considerably higher than the tests performed when traffic information in this link was showed as yellow and green. The same pattern is also true for emissions. It can be seen that CO_2 emissions are also considerably higher during traffic information with an orange colour. However, in R2 it is not possible to establish a clear pattern between emissions and Google traffic info.

4.2. Comparison between two drivers

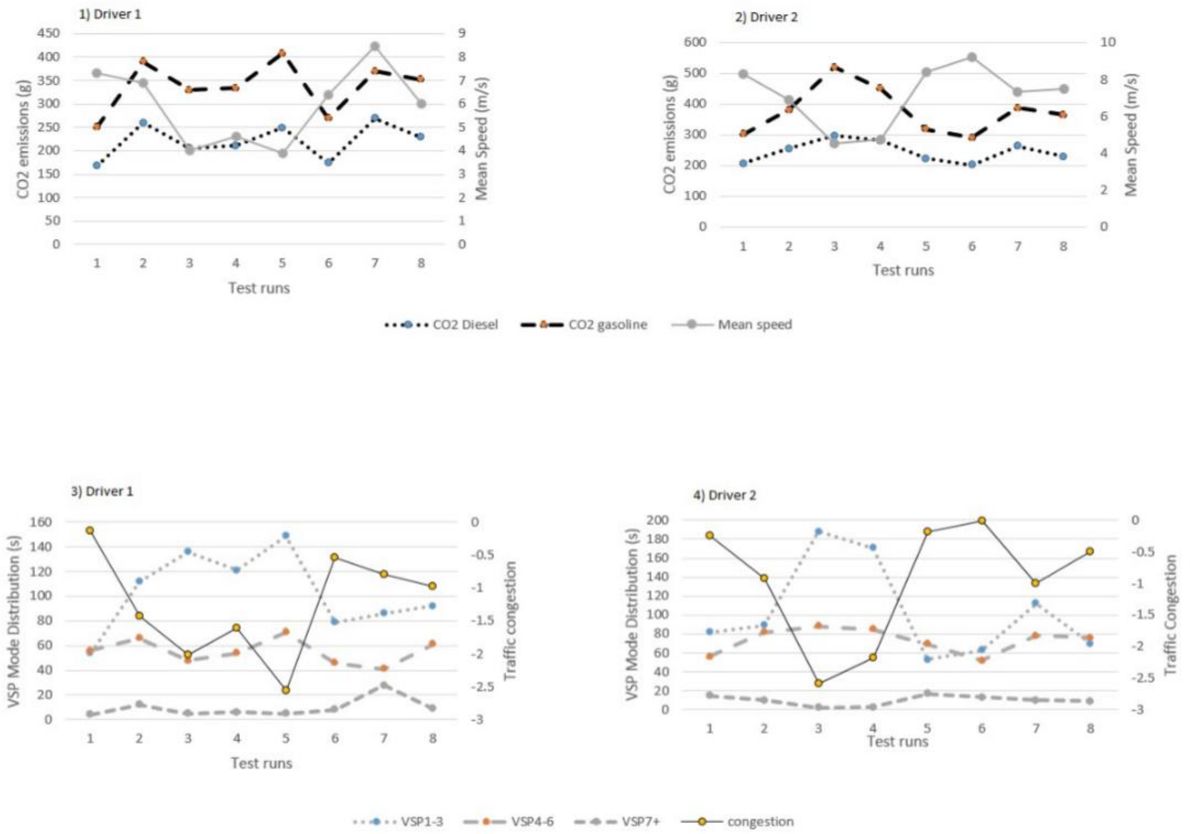

FIGURE 5 Comparison between two drivers (R1)

Regarding the relationship between VSP mode distribution Vs traffic congestion level it is noticed that runs where more time is spent in VSP1-VSP3, the traffic congestion levels are higher (higher, meaning the negative values more distant to zero). Driver 2 had cases where he spent less time between VSP1-VSP3, and more on VSP4-VSP6 generating higher CO_2 emissions, as in test run 6. Some runs present almost the same time spent in VSP1-VSP3 as VSP4-VSP6 but with this information, it is only possible to observe that the driver spent more time having strong decelerations and smooth accelerations or decelerations. However, if congestion value is above 1.5 (as in test run 3 of driver 1) it means that the traffic flow was slower and the driver was forced to follow the traffic stream. Another interesting case is if in similar conditions, the driver spends more time on VSP7-VSP14, having decreased or not his time on VSP4-VSP6 (as in driver 1 test run 2, 7 or driver 2 test run 5). In these situations, it is possible to predict the occurrence of congestion in a restricted zone and free flow situation in the remaining part of the route.

4.3 Exploring descriptive variables to estimate vehicle emissions

Figure 6 and 7 explores linear relationships between traffic congestion, travel time, traffic flow and CO_2 and NOx emissions respectively.

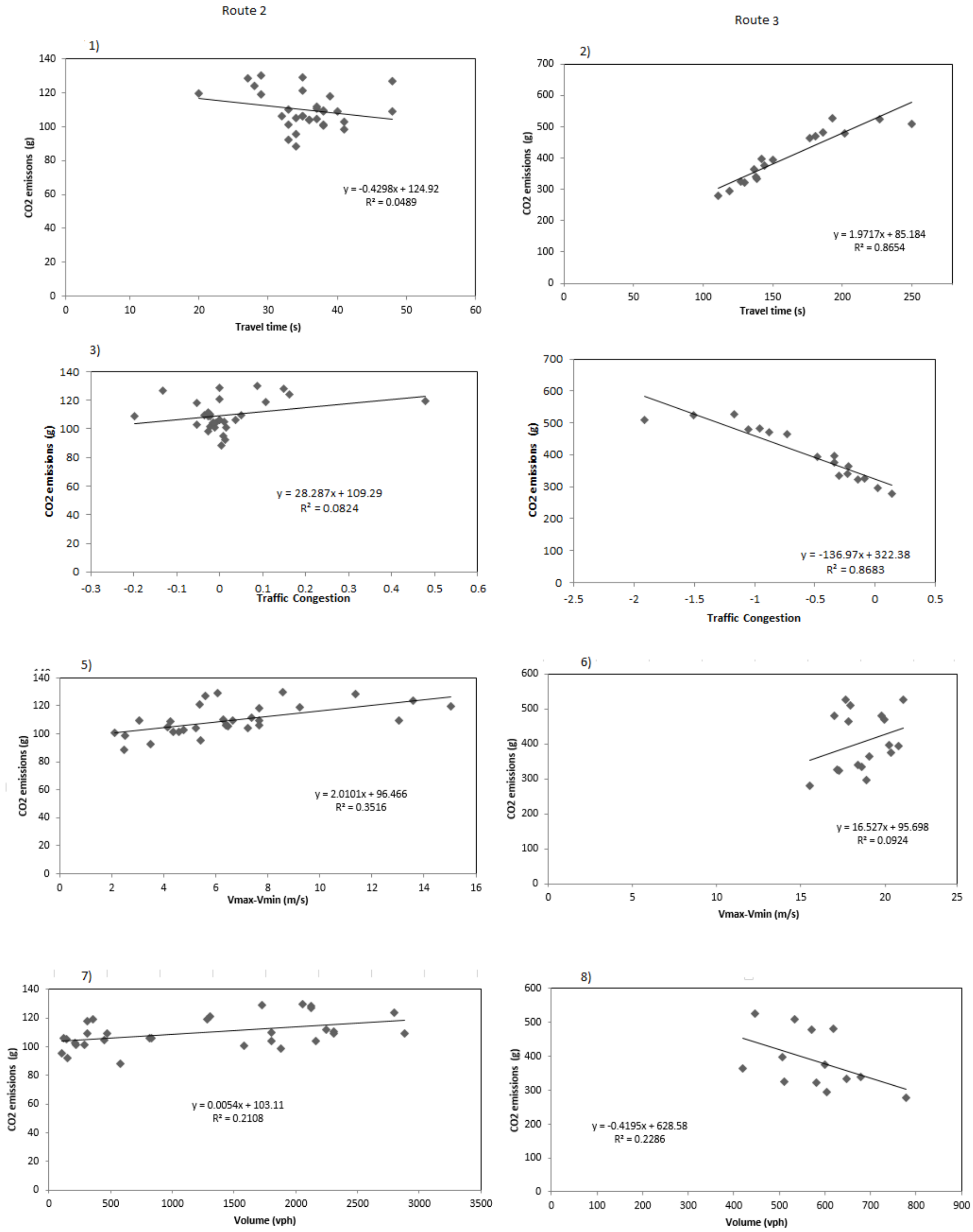

FIGURE 6 Linear correlations between emissions and Travel time/Volume/congestion/Difference between Max velocity and Min velocity in route 2 and 3

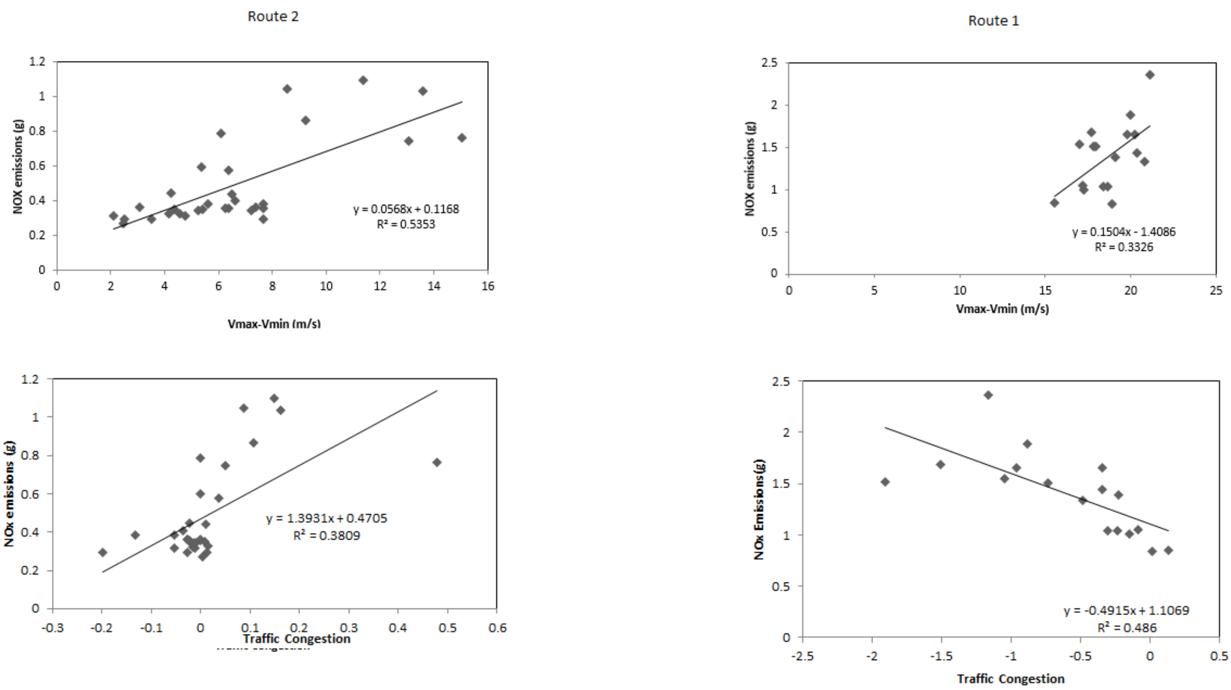

FIGURE 7 Linear correlations between Traffic congestion/Difference between Max velocity and Min velocity in route 2 and 3

Comparing directly R2 and R3 it is noticed that in R2 the travel time is the most important factor and can explain more than 88% of the variability in CO_2 emissions. However, in R3 this factor can just explain less than 43 % in CO_2, meaning that in R3 the driving behaviour assumes a higher relevance (see graph 1 and 2 in figure 6).

CO_2 emissions are higher when the time spent from VSP1-VSP3 is higher. If the difference between the maximum speed and the minimum speed in each test is lower, and the minimum speed of that test is higher than 1m/s CO_2 emissions will decrease. The traffic congestion equation gives a reasonable perception of what happens to CO_2 (on urban road), but it fails when it comes to CO_2 emissions on arterial roads (figure 6, 3, 4). However, based on this relationships and associating VSP Mode Distribution with traffic congestion level algorithm, it is expected to reach a better understanding about higher CO_2 emissions behaviour, namely anticipating if emissions are mainly generated during Stop&Go situations or mainly caused by aggressive driving behaviour during non congested situations.

Traffic volume seems to present a different behaviour on the rural arterial and urban road (figure 7 and 8). Intuitively, higher traffic volumes should lead to an increase of emissions, but this may not be the case if a more compact flow implies a more stable speed profile or the green time of traffic lights is adapted to meet an increased demand. It was found that this variable cannot explain properly the variability in emissions. However, the knowledge of the volume is still important to extrapolate the impacts of the whole fleet circulating in the link.

Regarding local pollutants, it has been found a higher variability in emission output when compared to CO_2 emission which is associated with a higher dependence of the driving style. The Difference between Max and Min speed was shown to be the best analysed variable to explain the variability in NO_X emissions.

As shown in figure 6, link based performance functions, specially in the rural context may should not be based in simple linear correlations. In fact, for each network segment will be needed to establish ad hoc functions having into consideration the most relevant factors and the available information.

5. FINAL REMARKS

The main goal of this work was to assess how it would be possible to read and predict traffic congestion and environmental performance with limited FCD and taking advantage of traffic data from multiple sources. In the urban links, the knowledge on travel time has shown to help in anticipating vehicle' emissions levels. However, in other links this information has to be supplemented with other parameters related the individual driver behaviour. Regarding the use of Google traffic as complementary indicator to predict traffic performance, it has been found that in the urban link the qualitative data tend to be a reliable indicator regarding the observed travel time and also the estimation of emissions. However, in the rural artery there is a great variability in emissions which hinders the use of this source of information. In future, more tests must be done especially on links with a greater variability of demand and additional data sources.

The correct correlation of VSP, with congestion algorithms and with CO_2 emissions can be obtained, enabling a better understanding of the driving style and its impacts on emissions. Moreover it is expected that after a longer period of data acquisition it will be possible to develop ad-hoc functions for each link in addition to apply automatic learning machine algorithms to relate traffic volumes/FCD and associated environmental impacts.

Given that commercial solutions do not respond to the growing needs in the medium/long term, a prototyping platform is being designed and developed as an alternative solution; this solution has nothing to do with the data collected so far but will have everything to do with the future data collected in real time.

A next step will be the development of the database and the respective incorporation into the modular platform, and test it in real time. The development of a GNSS platform that works directly with the created platform will be required. Another key issue to address is related to data privacy. Namely, if the FCD to be used in the platform must be associated to the vehicle or to an individual/independent device (e.g., smartphone) and to assess the impacts of this choice in terms of data encryption requirements.

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