ASSESSING THE IMPACT OF V2V / V2I COMMUNICATION SYSTEMS ON TRAFFIC CONGESTION AND EMISSIONS

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ABSTRACT: The fundamental goal of this research is to assess the value of intelligent transportation systems to test the hypothesis that the use of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication technologies and protocols can significantly alleviate traffic congestion, and reduce fuel consumption and emissions from mobile sources. Microscopic traffic simulation modeling using the VISSIM model is being used for operational assessment, while emissions are being estimated from real-world vehicle activity data, using a methodology based on the "Vehicle Specific Power" concept. The global methodology will be applied to a simulated case study of these innovative methodologies in a Portuguese city.

1 INTRODUCTION AND LITERATURE REVIEW

Linkages between new transport technologies and analysis methods grow more strongly all the time [1]. The development of a communications network on the roadway infrastructure and in the vehicles has the potential to improve transportation and quality of life in ways not imagined a generation ago. In the near future, vehicles will communicate with one another in a cooperative way in order to control speeds, obtain traffic information and to improve safety (eSafety). It is predicted that the urban infrastructure will have sensors that can communicate and interact with the vehicles, using traffic signals, traffic cameras, ramp meters, bus priority systems, etc. V2V (vehicle-to-vehicle) is a technology designed to allow vehicles to serve as data sensors and anonymously transmit traffic and road condition information from every major road within the transportation network. V2I (vehicle-to-infrastructure) is the direct wireless exchange of information between vehicles and the fixed infrastructure.

From the literature review, it appears that V2V and V2I communication systems research has mostly focused on crash prevention, safety and traffic control [2-6]. V2V is currently in active development by General Motors [3], which demonstrated the system in 2006. Other automakers working on V2V include BMW, Daimler, Honda, Mercedes and Volvo. In another development, the Portuguese Government intends to launch an identification chip in vehicles with information related to insurance and vehicle inspection status. It could be also used to pay tolls (green lane or virtual tolling). Portugal is the first country to create and test such an electronic identification system for vehicles. Nevertheless, there is no apparent application of the proposed technology in terms of communicating with other vehicles or receiving signals from the infrastructure or, moreover, give real-time information to the user about the vehicle performance / fuel use / emissions.

More specifically, Santa et al. [7] state that V2V communications are the main object of research nowadays, because V2I approximations are already being developed as commercial solutions. In [8] the reliability of inter-vehicle communication in a traffic stream was discussed and the information propagation in a traffic stream via inter-vehicle communication was analyzed. According to [9], V2V is assumed to have a beneficial impact on traffic efficiency and road safety. Furthermore, [10] and [11] studied the impacts on traffic flow and safety of V2X communication using a simulation approach. Kang et al. [12] reported on the direction of a ubiquitous transportation system (u-Transportation, based on the concept of ubiquitous computing technology, which is the latest emerging technology which enables human-computer interaction in everyday objects and activities) and were more focused on the description of traffic operation and management under u-Transportation. More recently, Rouphail and Hu [13] have assessed the impact and benefits of u-Transportation network using mesoscopic modeling, and plan to evaluate both operational and safety benefits of such a system for many types of road facilities, where the additional information could improve the human-based traffic performance. Mei et al. [14]

The authors were unable to locate any published research on the potential impact of vehicle communication technologies on energy use and pollutant emissions. The closest contribution was the work of Ericsson et al. [15] but that is not specifically focused on V2X technologies. The assessment of the impacts of short range communication technologies requires a micro or mesoscale approach; the macroscale approach may be too crude for this purpose. In particular, Vehicle Specific Power (VSP) is a methodology based in on-board emission measurements [16] and is a function of vehicle speed, road grade, and acceleration, all of which can be determined from simulated vehicle trajectories in a microscopic simulation model.

2 OBJECTIVES

The fundamental goal of this research is to assess the value of new intelligent transportation system technologies in terms of their transportation impacts (such as traffic congestion and emissions) in order to test the hypothesis that the appropriate use of V2V and V2I communication technologies can positively influence the quality of urban travel, the quantity of fuel use and emissions from mobile sources.

Changes in personal travel may change the total quantity of emissions, as well as their spatial and temporal patterns. This research will help identify the contribution of these new technologies as fundamental determinants of travel behavior, vehicle activity and on-road emissions. Traffic modeling will be developed, in order to characterize the effect of V2V and V2I information on driving pattern and route change. The modeling system will forecast energy and emissions under each scenario and quantify the uncertainty in the emissions estimates. The last step will be to compare scenarios and determine the statistical significance of the different levels of emissions.

3 METHODOLOGY

In order to achieve a successful implementation of V2V and V2I technologies, the analyses of the potentials impacts are very important. Since these represent new technologies that are yet to be implemented on a wide scale, their effects cannot be observed from empirical observations. Thus, the research approach will be developed through numerical modeling of traffic and communications networks. The steps of this research are shown on Figure 1.

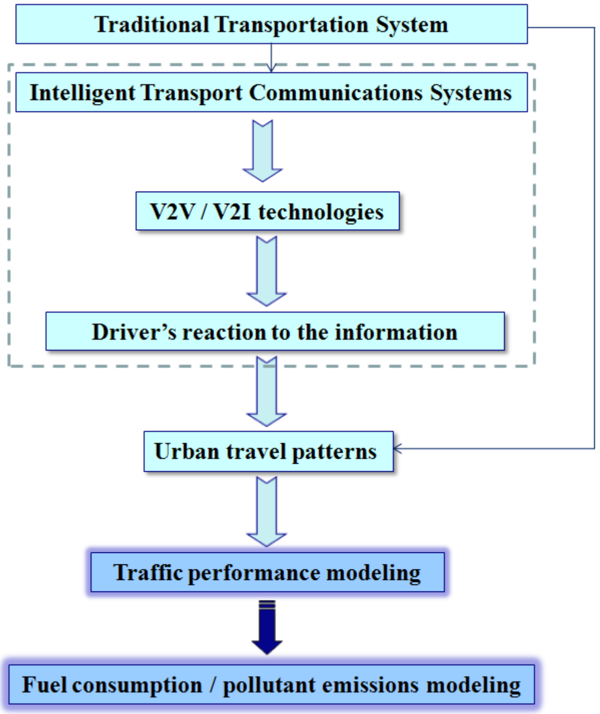

Fig.1. Flowchart of the research

The authors are in the process of developing a modeling framework comprising the following four modules: 1) simulation of V2V or V2I communication protocols; 2) drivers' response to the presence of V2V or V2I technology; 3) influence of the drivers' response on the individual vehicle motion; 4) traffic modeling and modal approach to estimating emissions based upon models derived from portable emissions monitoring systems (PEMS). Since there is not much experimental data, the main work will be done by computational modeling using API ("Application Programming Interface") together with VISSIM model in order to analyse modules 1 and 2. The third module can be experimentally validated with traffic flow data when applied to a specific case-study (in the regions of Aveiro and Porto). Finally, the fourth module will be supported by on-board measurements of vehicle dynamics (namely, speed, acceleration and terrain grade) and the emissions will be calculated using VSP methodology.

The modeling platform will be supported by the VISSIM model [17] for traffic simulation, and Vehicle Specific Power (VSP) methodology (for fuel use and emissions estimation, using speed profiles). VISSIM is a microscopic multi-modal traffic flow model. “Microscopic simulation” means that each entity (for example, a vehicle) is simulated individually, which means that it is represented by a corresponding entity in the simulation, thereby considering all its relevant properties. The same holds for the interactions between the entities. VISSIM has the ability to simulate multiple vehicle classes (light duty vehicles, public transport, cyclists, pedestrians) and all these types can interact mutually. In addition, external programming can be performed through an external controller DLL and a specific GUI DLL (in C or C++ programming language), which are required to be accessed by VISSIM. The “Application Programming Interface” (API) functions are powerful tools that will be used to interact with VISSIM environment and implement V2I and V2V protocols [17].

Traffic modelling results are, then, integrated with fuel consumption / emissions modeling. Several modeling approaches to calculate fuel consumption / emissions are based only on average speed, and do not account the various levels of accelerations (namely to take into account the mode where the highest emission rates occur) or the roadway infrastructure effects on power demand. To overcome these limitations, the methodology is based on a vehicle-specific power term (VSP). This parameter is highly correlated with emissions. Second-by-second VSP values for a generic light duty vehicle is expressed as follows:

$$VSP = v \times [1.1a + 9.81\times(\sin(\operatorname{atan}(\phi))) + 0.132] + 0.000302v3$$

where: VSP = vehicle specific power (kW/ton); v = instantaneous vehicle speed (m/s); instantaneous acceleration / deceleration rate; ϕ = road grade (dimensionless fraction) [16, 18-20]. This method already takes into account parameters related with the kinetic energy, road grade, drag force and rolling resistance.

It has been shown elsewhere [16, 18, 19] that it is possible to discretize the VSP bins computed in the previous equation in a limited number of “bins”, each one of them having an average emission factor (for a vehicle with a certain age, range of engine sizes), which is different from all other bins. The emission factors obtained for different types of vehicles can be found elsewhere [16, 18-21].

After completing the review of technical literature, the specification of the integrated methodology was developed. The modeling algorithm of the communications system is under development, in order to be implemented and tested in the later phases of the research. In terms of simulation methodology, the traffic model VISSIM [17] is being interfaced with a communications simulation module, in order to simulate several scenarios analyzing the impacts on traffic congestion relief, fuel use and emissions. Subsequently a calibration of the traffic performance should be performed, using real-world data for the baseline (i.e. no communications) case, and taking into account scenarios on market penetration. Then, the different models can be integrated and tested.

In VISSIM modeling interface, the objective is to alert the drivers to take divert from their current (fixed) route and onto an alternate (also fixed route) in response to a certain incident. The authors will use "dynamic route assignement", in which the current and alternate routes, different classes of vehicles, and a condition that tells some or all drivers to change routing assignment are given.

Finally, the estimation of mobile source emissions will be carried out on the basis of two principal inputs. The first set of inputs is represented by the outputs from the multimodal travel demand models, which will produce aggregate estimates of modal link trips and their corresponding modal speeds on the transportation network. The second set of inputs is an activity knowledge base that will integrate the facility-specific driving cycles, vehicle technology and congestion levels. These set of inputs will be based on PEMS previously collected and on VSP methodology [16]. By integrating data from travel demand model forecasts, along with the emissions activity knowledge base, a series of time profiles of driving modes can be developed. The time-weighting assigned to each driving mode will be multiplied by modal emission factors to arrive at an estimate of total emissions for a given vehicle operating on a particular facility. Then, scenario-specific emission estimates will be generated. In addition, uncertainty in emissions data and estimates will be quantified using statistical methods. After the emissions module has been run for each scenario, emissions forecasts and their uncertainty will be produced.

4 CONCLUSIONS

This paper summarizes on-going research, included in a R&D Project between the Centre for Mechanical technology of the University of Aveiro, in Portugal, and the Institute for Transportation Research and Education, in USA. There are two specific innovations in this research: first, the calculations of fuel consumption and emissions savings due to the existence of V2V and V2I. The authors found that previous research is much more focused on safety and traffic congestion only. Finally, another innovation will be the application of this research to urban buses, since the authors did not find any V2V and V2I application and impacts modeling.

With this integrated modelling platform, multiple scenarios can be explored in order to assess the effectiveness of V2V and V2I technology use as a means for improving traffic congestion relief, reducing emissions from on-road mobile sources, and targeting investments in transportation infrastructure to areas that might influence changes in the fuel consumption and amount of pollutant emissions. Many different entities, such as transit agencies, the Portuguese Transportation and Mobility Institute or Public Municipalities will have interest in using this type of methodology to address some of their problems, in terms of traffic congestion relief and, consequently, lower fuel consumption.

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