Volume 5 No.1, January 2015 ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

Will Vehicle and Roadside Communications Reduce Emitted Air Pollution?

Qing Li[1], Fengxiang Qiao[2], Lei Yu[1]

[1]Innovative Transportation Research Institute, Texas Southern University, Houston, Texas, USA

[2]Innovative Transportation Research Institute, Texas Southern University, Houston, Texas, USA, Corresponding Author

ABSTRACT

Transportation has been one of the largest sources of air pollution produced by human activity in the United States; this calls for the development of innovative technologies, such as renewable energy, ecological driving, and connected vehicles. Based on the United States Environmental Protection Agency's (EPA) newly released emission model, MOVES, an unstable speed profile and excessive acceleration may greatly affect Vehicle Specific Power (VSP) and the Operation Mode Identification (OMID) distributions, which will yield higher emission estimations. The Vehicle to Infrastructure (roadside) (V2I) communication technology is capable of improving driving performance, in terms of smooth speeds and acceleration rates. In this paper, the impacts of the V2I system on vehicle emissions were explored. The V2I technology was employed to provide audio messages to drivers who are approaching intersections in the situations of sun glare and work zones. Impacts on speed and acceleration rates, as well as VSP, OMID distributions and resulted air pollution emitted from vehicles with and without the V2I system, were analyzed through simulated driving tests. The results illustrate that the V2I system can not only improve safety, but also mitigate emitted air pollution.

Keywords: *Vehicle to infrastructure communication, vehicle emissions, pollution, connected vehicle, sun glare, work zone*

I. INTRODUCTION

Since 1880 till 2013, the earliest year that comprehensive worldwide temperature records were available, nine of the ten warmest years in the 134-year period of record have occurred in the 21st century, with the only exception in 1998 [1]. The consequences of global warming include increased atmospheric moisture, leading to severe precipitation and floods, as well as high heat stress to land-crops and plants. Even worse, the land is no longer able to hold in water and eventually desertification and drought are formed. What's more, the warming has been accompanied by significant and harmful effects to human health, the environment, and communities, such as disruptions in the food supply, less fresh water being available, plants and animals becoming endangered or extinct, and more frequent and intense heat waves.

It is a scientific consensus that human activities are the primary driver of global warming, which is attributed to greenhouse gases. Human activities are responsible for almost all of the increase in greenhouse gases in the atmosphere over the last 150 years [2]. According to the Environmental Protection Agency (EPA) [3], transportation has been one of the largest sources (approximately 28%) of greenhouse gases emissions produced by human activity in the United States (U.S.). Over 90% of the fuel used for transportation is petroleum based, which includes gasoline and diesel [4]. The automobiles in the U.S. account for 30% of the world's automobiles and contribute to 45% of the world's automotive CO_2 emissions [5]. Moreover, with annual increased vehicle mileages and lower fuel efficiency, as compared with the international level, U.S. driving is playing a crucial role in the contribution of CO_2 emissions.

With regards to this, many affordable and clean vehicle technologies have been proposed and applied in the improvement of fuel economy in vehicles, such as hybrid-electric vehicles, electric cars, and advanced biofuels. To maximize the fuel economy and correspondingly reduce vehicle emissions, eco-driving is newly proposed, which refers to driving in a smart, smooth and safer pattern, instead of aggressive driving maneuvers. This has been considered as the most cost-effective method of improving road safety, reducing vehicle emissions, as well as minimizing fuel consumption.

Volume 5 No.1, January 2015 ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

In 1995, a National Research Council report noted that aggressive driving with excessive accelerations is responsible for 15 times higher CO emissions and 14 times higher hydrocarbon (HC) emissions than the normal driver on the same trip [6]. Ten years later, El-Shawarby *et al.* further proved that as the aggressiveness of acceleration maneuvers increased, fuel consumption and emissions rates increased significantly [7]. Later on, Ahn and Rakha specifically demonstrated that 25% of the total CO_2 emissions and 28% of the fuel consumption levels are caused by 10% of the most aggressive driving maneuvers on a typical trip [8]. Furthermore, McKinsey (2009) estimated that teaching drivers to eco-drive can improve actual fuel efficiency by an average of 17% [9].

On the other hand, vehicle-to-infrastructure (V2I) communication provides real-time traffic information between vehicles (drivers) and roadside facilities. This is a kind of vehicle to roadside communication with smart advice provided by the Intelligent Transportation System (ITS). With such a system, drivers are able to plan ahead for better driving maneuvers, in terms of dynamic driving speeds and acceleration rates. While the V2I system is mainly dedicated to safety purposes, it is possible that the system may enable significant environmental benefits, especially in the reduction of vehicle pollution.

The amount of emission changes can be estimated based on the EPA's newly released model, MOVES [3]. The change in speed and acceleration rates could greatly affect the Vehicle Specific Power (VSP) distribution and the corresponding Operation Mode Identification Number (OMID) distribution. Such a change will yield different estimations of vehicle emissions. In this paper, the impacts of V2I technology based "vehicle and roadside communications" on vehicle emissions are explored in cases when vehicles are approaching a work zone and a signalized intersection with sun glare.

II. IMPACTS OF VEHICLE EMISSIONS ON THE ENVIRONMENT AND HUMAN HEALTH

Vehicle emissions are the byproducts of the engine fuel combustion process and the evaporation of fuel. The resulting pollutants include unburned HC, nitrogen oxides (NO_x), carbon monoxide (CO), sulfur oxide (SO_x), volatile organic compounds (VOCs), and particulate matter (PM). A number of studies have shown that exposure to these pollutants may lead to adverse environmental and health effects.

Effects on Health

Probably no one would argue that the automobile is one of the major contributors to urban air pollution, especially in the U.S., where most people rely on their own private vehicles for daily activities. In the meanwhile, vehicle emissions have been considered toxic and carcinogenic air pollution, which raises public health concerns.

In practice, vehicle emissions may impair human health directly or indirectly. For instance, the HC reacts with nitrogen oxides and sunlight to form ground-level ozone, namely smog. The smog irritates the eyes, damages the lungs, and aggravates respiratory problems. Children and the elderly are especially vulnerable to smog.

Even worse, a number of exhaust HCs are toxic and may cause cancer. Carbon monoxide (CO_2) reduces the flow of oxygen in the bloodstream and is particularly dangerous to people with heart disease. Moreover, fine particulate matter (*e.g.*, $PM_{2.5}$) can be especially damaging, because of its small particles that are easily inhaled and its toxic components, such as polycyclic aromatic hydrocarbons (PAH) and heavy metals. Some of the VOCs, such as such as benzene and 1, 3-butadiene, are cancer causing agents. Though its current levels in the environment are small, they are precursors to ozone and secondary particulate matter formation.

Effects on the Environment

Many studies have demonstrated that vehicle emissions are responsible for a number of adverse environmental effects, such as photochemical smog, acid rain, and global warming. Smog can inhibit plant growth and cause widespread damage to crops and forests. Acid rain may change the pH value of waterways and soils, thereby harming the organisms that rely on these resources. Global warming may result in the increase of average temperatures around the world, extreme weather events, and a shift in climate patterns worldwide. Though carbon dioxide does not impair human health directly, it may make contributions to global warming when its amount emitted by human activities is greater than the natural absorption system.

III. COUNTERMEASURES TO MITIGATE POLLUTION FROM VEHICLES

Utilizing Less Fossil Fuels

Many countermeasures have been applied to reduce pollution from motor vehicles. Currently, the most effective way to utilize less fossil fuel is either by expanding the use of renewable energy or encouraging alternative transportation modes.

Renewable energy refers to energy that is cleaner and less dependent on coal and other fossil fuels, such wind power, solar energy, geothermal energy, hydrokinetic energy, and corn-based ethanol biofuels. However, the application of renewable energy is often associated with costly innovative technologies, such as hybrid-electric vehicles, electric cars, and mobile electricity auto chargers. On the other hand, alternative transportation modes, such as a bus, train, or bike, can be considered a feasible solution. That being said, this requires associated transportation facilities and a system that provides an accessible public transportation network, as well as dedicated pedestrians and cycle paths. This is more suitable to dense cities, such as Washington DC and New York.

For areas where the population density is rather low (*e.g.* most urban areas in the U.S.), the choice of other modes of transportation is quite limited, and hence, motor vehicles are still the major transportation mode.

Increasing Vehicle Fuel Efficiency

From another standpoint, maximizing mileage for each gallon of fuel consumption can also mitigate vehicle emissions. This can simply be achieved by regular maintenance, properly inflated tires, and fuel-efficient driving habits. Compared with other methods, the cultivation of fuel-efficient driving habits is the most complicated. Fuel-efficient driving habits are similar to the concept of eco-driving, driving moderately with limited idling and keeping moving with less acceleration.

Based on previously mentioned studies, the eco-driving pattern is able to increase mileage for each gallon of fuel consumption [10; 11; 12]. However, peoples driving patterns are diverse and quite subject to individual performance, which depends on many factors, such as personality, driving experience, and driving skills.

With the application of a V2I system, driving patterns can be guided towards desired forms, such as the eco-driving profile. This is because the V2I system enhances the communication between vehicles and roadside infrastructure (*e.g*. traffic signal, signs, and control devices), especially in areas with safety threats, such as work zones or signalized intersections with a visual disturbance. Drivers can become aware of changing or fuzzy situations earlier and be able to prepare to stop or change lanes at the right time and space locations. In this way, excessive acceleration or sudden braking can possibly be avoided, and eventually, travel speeds can be regulated within a desired range. Such a driving pattern is likely to be beneficial to fuel efficiency as well.

Controlling Driving Speeds and VSP

To estimate emissions from mobile sources, EPA's Office of Transportation and Air Quality (OTAQ) developed a modeling system called MOtor Vehicle Emission Simulator (MOVES) [3, 13]. MOVES defines the classification of the operation mode identification (opMode ID, or OMID) with the binning standard of a VSP, acceleration rates (a), and speeds (v). VSP itself can be calculated by Equation 1.

$$\text{VSP} = v * (1.1 * a + 9.81 * \text{grade\%} + 0.132) + 0.000302 * v^3 \quad (1)$$

The distribution of OMID is essential for the estimation of vehicle emissions in MOVES. Therefore, vehicle emissions can be mitigated by updating the distribution of OMID through controlling driving speeds and acceleration rates.

IV. ADVANCED V2I TECHNOLOGY TO REDUCE EMISSIONS

The vehicle-to-infrastructure (V2I) communication between vehicle and roadside provides the wireless exchange of critical dynamic traffic situations and operational data between vehicles and roadside infrastructures. More specifically, the data

ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

exchanged between vehicles and infrastructures will be calculated for the identification of special situations to safety and emissions in advance. Drivers will receive the identified critical situations before entering. A typical example is to deliver the signal phase and timing information to drivers with active safety advisories and warning, with which they are able to react to the situation early and smoothly.

Smooth driving is a feature of eco-driving. Based on the OMID distribution, the vehicle emission rates are significantly lower at a certain range of speeds and VSPs. In this respect, the V2I system can guide drivers to target eco-driving.

The concept of eco-driving has been applied in one of the Applications for the Environment: Real-Time Information Synthesis (AERIS) program, Eco-Signal Operations by the U.S. Department of Transportation. Concretely, connected vehicle technologies are used to decrease greenhouse gases and criteria air pollutant emissions on arterials by reducing idling, reducing the number of stops, reducing unnecessary accelerations and decelerations, and improving traffic flow at signalized intersections.

V. SCENARIO DESIGN AND TESTING

Considering the fact that participants may undertake a high risk of collisions with other vehicles or pedestrians during on-road tests, a driving simulator is used in the experiment to verify the impacts of V2I system on vehicle emissions. Designed scenarios include vehicle driving approaching signalized intersections and work zones.

Approaching Signalized Intersections

A track of approximately 1,000 meters in an industrial area with three intersections was generated in the scenarios (Figure 1). The distance between intersections is about 300 meters, while the posted speed limit is 72 km/h (20 m/s). Each subject was the only driver on the track. Subjects were required to drive through the three intersections in three different situations: no sun glare and no V2I, with sun glare and no V2I, and with sun glare and V2I.

With the V2I system, drivers received audio messages about the real-time signal while approaching a signalized intersection under the visual disturbance of sun glare. The location in which they received audio messages depends on the play time of the message (one second), driving speeds, perception-reaction time, and minimum sight distance for signal visibility. 2.5 seconds was chosen as the perception-reaction time [14]. The minimum sight distance was 140 meters for the posted speed limit of 72 km/h (20 m/s) [15]. Therefore, drivers received the audio message at 210 meters away from the third intersection ((1.0+2.5)×20 m/s+140 m=210 m).

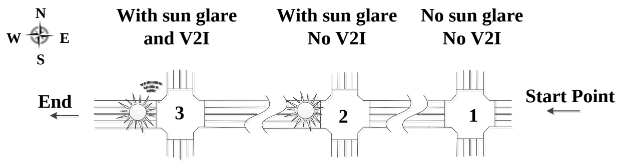


Figure 1: Layout of the test route with and without the V2I and sun glare.

Approaching Work Zones

In this set of tests, subjects drove twice through a short work zone with two lanes in one direction for different scenarios: only with a traditional sign control and with both traffic signs and the V2I guidance (Figure 2). The posted speed limit was changed from 72 km/h (45mph) to 48 km/h (30 mph or 13.33 m/s) when approaching the work zone. With the V2I system, drivers were instructed by audio messages relevant control information. This is in addition to the traditional traffic signs. They received audio messages at the distance of 70 meters and 107 meters for traffic sign and risk warning, respectively. These distances considered the stopping distance instructed by the 2009 MUTCD [15] and the reaction-time of 2.5 seconds [14].

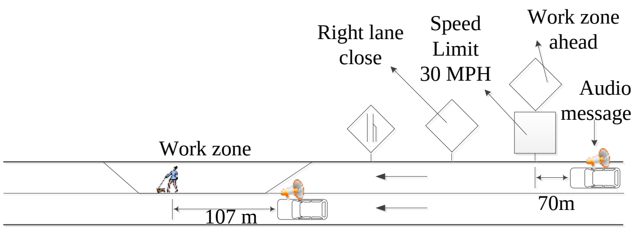


Figure 2: Layouts of Two Scenarios at a Work Zone (With and Without Audio Messages).

Participants

In total, thirty subjects were recruited for the driving simulator tests. The recruitment was based on Houston's demographics from the 2010 census. The proportion of subjects regarding gender, age, and education background was adjusted for the legal

Volume 5 No.1, January 2015 ISSN 2224-3577
International Journal of Science and Technology

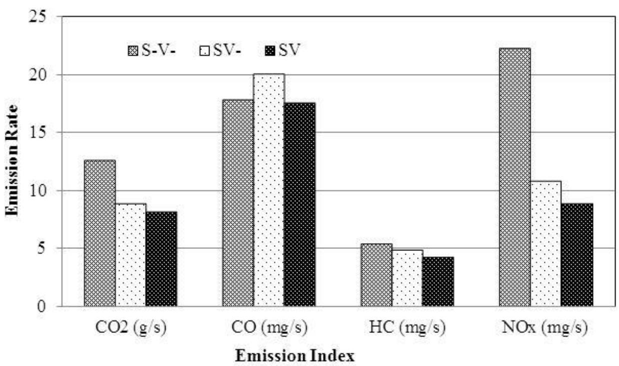
http://www.ejournalofsciences.org

driving age in the U.S. Fifteen male and fifteen female subjects aged above eighteen years old with valid C class drive licenses participated in the test. More specifically, twenty-six subjects were between the ages of eighteen and sixty-four, while four subjects were seniors aged sixty-five plus. Twenty-one subjects had obtained high school or associated degrees, while nine obtained a bachelor's degree or higher. All subjects have self-reported normal, or corrected-to-normal, vision and do not have any problem with hearing.

VI. IMPACTS OF THE V2I ON VEHICLE POLLUTION

Emissions at the Signalized Intersections with Sun Glare

The VSP is calculated using Equation (1) with dynamic driving speeds, acceleration rates and grades recorded. The vehicle emission rates occurring at the simulator tests were estimated by a Nissan Altima car manufactured in 1999 with mileage of 80,000 miles. The emissions estimation results are illustrated in Figure 3. Within each emission index (CO_2, CO, HC, and NO_x), there are three columns representing the emission rates for the three different scenarios.



Note: S-V-: No sun glare, no V2I
SV-: With sun glare, no V2I
SV: With sun glare, with V2I

Figure 3: Vehicle Emission Rates Related to Driving Directions at Intersections.

In Figure 3 except for CO, the emission rates at a normal situation (no sun glare and no V2I system, purple columns) are 20% to 80% higher than the others. This implies that normal driving behaviors are not beneficial to the air quality at intersections.

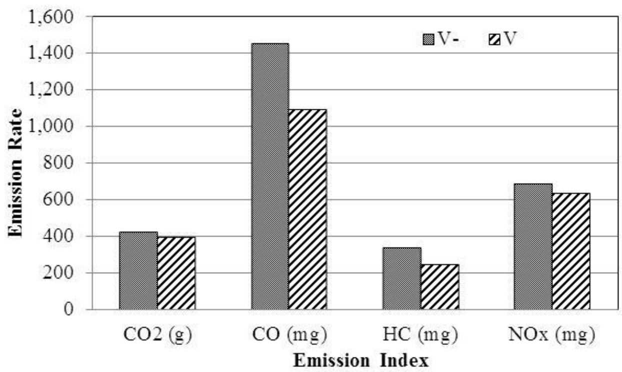
On the contrary, the emission rates under sun glare without V2I (red columns) are lower. However, seven of the thirty (23%) subjects ran red-lights unconsciously, as some of them were either too late to stop or weren't aware of the upcoming signalized intersection, due to the visual impairment of sun glare. As such, the emissions rates could be lower, with a result of less idling, braking or excessive acceleration.

Not surprisingly, with the V2I system, the emissions rates (green columns) were significantly lower than the other situations. This phenomenon is reasonable, since the V2I system provides audio instructions for safer and smoother driving.

For the CO emissions, the emissions rate under a sun glare effect without the V2I system (the red column) was the highest, while there was not much difference between the situations of no glare (the purple column) and glare with the V2I system (the green column). This implies that the V2I system can well compensate the negative impacts of sun glare on CO emissions.

Emissions at Work Zone

Figure 4 illustrates the comparison of vehicle emissions with and without the aid of the V2I system while driving through a work zone with a sudden pedestrian's crossing. At first glance, the green columns with the V2I system are obviously shorter than the blue columns without the V2I. More specifically, the total emissions for the four main emission indexes (CO_2, CO, NO_x and HC) were apparently reduced, particularly for CO with 361 grams per vehicle reduced. This is 24.9% less CO emitted from a vehicle compared with no V2I system. In other words, the application of the V2I can reduce vehicle emissions.



Note: V-: No V2I; V: With V2I

Figure 4: Vehicle Emissions With and Without the V2I Warning System.

VII. CONCLUSIONS

In this investigation, the impacts of a V2I system on vehicle pollution were tested using a driving simulator. The results illustrate that the sun glare may impair a subject's vision and, in turn, they may drive erratically and even commit red-light offenses unconsciously. The sun glare effect brings out 23% of the subjects to run a red-light. The V2I system can assistant subjects to drive steadily, thereby producing lower vehicle emissions. Moreover, the V2I system is able to guide subjects to drive through a work zone in a safer and smoother manner, particularly in high-risk situations (*e.g.*, worker's crossing in this test). In the meanwhile, the audio instruction and/or warning messages favor the reduction of vehicle emissions. Thus, the V2I system is not only able to secure safer driving, but also make an important contribution to the improvement of air quality.

ACKNOWLEDGMENTS

Supports for this research in part by the U.S. National Tier 1 University Transportation Center (UTC) TranLIVE #DTRT12GUTC17/KLK900-SB-003, and the U.S. National Science Foundation (NSF) CREST #1137732 are gratefully acknowledged.

REFERENCES

[1] Global Analysis - Annual 2013, NOAA National Climatic Data Center, State of the Climate: Global Analysis for Annual 2013, published online December 2013, retrieved on December 5, 2014 from http://www.ncdc.noaa.gov/sotc/global/2013/13.

[2] Intergovernmental Panel on Climate Change (IPCC). 2007. Summary for Policymaker. 4th Assessment Report, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[3] Environmental Protection Agency (EPA). 2009. EPA Releases MOVES 2010 Mobile Source Emissions Model: Questions and Answers. Guides EPA-420-F-09-073, Washington, D.C.

[4] Kahn Ribeiro, S., S. Kobayashi, M. Beuthe, J. Gasca, D. Greene, D. S. Lee, Y. Muromachi, P. J. Newton, S. Plotkin, D. Sperling, R. Wit, and P. J. Zhou (2007). Transport and its infrastructure. In Climate Change 2007: Mitigation.

[5] DeCicco, J.and F. Fung. 2006. Global Warming on the Road the Climate Impact of America's Automobiles. Environmental Defense, New York, NY.

[6] National Research Council (NRC). 1995. Expanding Metropolitan Highways: Implications for Air Quality and Energy Use, Transportation Research Board, Special Reports 245, 387.

[7] El-Shawarby, I., K. Ahn, and H. Rakha. 2005. "Comparative Field Evaluation of Vehicle Cruise Speed and Acceleration Level Impacts on Hot Stabilized Emissions." Transportation Research, Part D: Transport & Environment, 10(1): 13-30.

[8] Ahn, K. and H. Rakha. 2008. "The Effects of Route Choice Decisions on Vehicle Energy Consumption and Emissions." Transportation research Part D, Transport and environment. 13(3): p. 17.

[9] McKinsey & Company. 2009. Roads toward a Low-Carbon Future: Reducing CO_2 Emissions from Passenger Vehicles in the Global Road Transportation System. New York City, NY.

[10] Kurani, K.S., T. Stillwater, and M. Jones, 2013, Ecodrive I-80: A Large Sample Fuel Economy Feedback Field Test Final Report, Report: ITS-RR-13-15, Davis, CA.

[11] Wu, C., G. Zhao, and B. Ou. 2011. "Fuel Economy Optimization System with Applications in Vehicles with Human Drivers and Autonomous Vehicles." Transportation Research Part D: Transportation and Environment. 16(7): 515-524

[12] Stillwater, T. and K.S. Kurani. 2012, "Goal Setting, Framing, and Anchoring Responses to Ecodriving Feedback." Transportation Research Part F: Traffic Psychology and Behaviour, 19: 85–96.

[13] Frey, H.C. and B. Liu. 2013. "Development and Evaluation of a Simplified Version of MOVES for Coupling with a Traffic Simulation Model." The Journal of Transportation Research Board. Paper 13-1201, Washington, D.C.

[14] Chang, M.S., C. J., Messer, and A. J. Santiago. 1985. "Timing Traffic Signal Change Intervals Based on Driver Behavior." The Journal of Transportation Research Board, 1027: 20-30.

[15] U.S. Department of Transportation (USDOT). 2009 Manual of Uniform Traffic Control Device (MUTCD) with Revisions 1 and 2, May 2012.