CARTEEH

CENTER FOR ADVANCING RESEARCH IN
Transportation Emissions, Energy, and Health
A USDOT University Transportation Center

Submission Instructions

Problem statements will be due

June 21, 2019

Completed forms must not exceed three pages, excluding cover and references, and are to be submitted electronically to the applicant's institutional CARTEEH lead or their designated representative.

Principal Investigators of projects chosen for further consideration will be notified by July 31st and invited to submit a detailed work plan and budget.

Texas A&M Transportation Institute | Georgia Tech School of Civil and Environmental Engineering | Johns Hopkins Bloomberg School of Public Health | College of Engineering | UC Riverside CE-CERT

CARTEEH Problem Statement

Proposed Project Title

Onboard Sensing, Analysis, and Reporting (OSAR): Expanded Field Demonstrations and Development of Associated Visual Aids

Problem Statement

Heavy-duty vehicles represent one of the most important contributions to the emissions inventory for both nitrogen oxides (NO_x) and particulate matter (PM) emissions. Heavy-duty engines have been subjected to increasingly more stringent standards over the years. The latest round of standards essentially requiring the use of diesel particulate filters (DPFs) and selective catalytic reduction (SCR) to meet the PM and NO_x emissions standards, respectively. While these aftertreatment systems have provided significant reductions in PM and NO_x emissions, it is important to verify that these systems are operating optimally under the full range of in-use conditions to ensure that air quality standards can be met. This is particularly true in the South Coast Air Quality Management District (SCAQMD), where it is projected that mobile source NO_x emission levels will need to be reduced significantly to meet the 2023 and 2031 ozone standards.

The heavy-duty diesel SCR equipped engine has reduced NO_x emissions, by 90%, from previous levels when tested on the certification cycle, but not during in-use operation. Compliant 2010 vehicles were found to have NO_x emissions ten times higher than the certification limit on low power test cycles, but meeting the limit on certification like cycles, (Dixit et al, 2017, Misra et al., 2013, Quiros et al., 2017, and Lee et al., 2018). The Air Resource Board is proposing a low-NO_x standard of 0.02 g/bhp-hr, a low power test cycle, and revisions to the Not-To-Exceed compliance test to try and close the gap between certification and in-use. A different solution is to measure all the trucks all the time with on board sensing and validate compliance from the in-use fleet under the conditions where they produce emissions. It is suggested, that there will always be a gap between our standards (policy) and the in-use emissions (real exposure) until we focus on in-use measurements for our compliance and certification methods.

Complying with in-use conditions will be a challenge and will require a change from laboratory or portable emissions measurement system (PEMS) testing to an on-board continuous measurement and reporting system. The system proposed here is called Onboard Sensing, Analysis, and Reporting (OSAR). OSAR utilizes sensors technology that is borrowed from the vehicles embedded control system. These control sensors have been studied and are relatively accurate, repeatable, and very durable. Tan et al., (2018) evaluated the in-use NO_x emission rates from the on-board diagnostic (OBD) sensors of 72 HDDVs. They found that high NO_x emissions were still a common problem in from in-use heavy-duty diesel fleets, primarily due to low SCR conversion efficiencies during low temperature operation and potentially from malfunctioning SCRs. Montes (2018) compared these same OBD sensors with the laboratory and found that the sensors on average were with-in 15% (with a range from -5% to +50%) of the laboratory measurement. One significant concern with OBD NO_x sensors is that they are disabled below 200 C to prevent humidity damage to the ceramic sensing element. NGK-sparkplugs, a large manufacturer of OBD NO_x sensors, developed prototypes that operate at lower conditions than the OBD sensors and also improved their accuracy. The low temperature conditions are important because this is where the highest NO_x emissions are generated for SCR equipped diesel engines. Yang et al. (2018) utilized this prototype sensor and found NO_x measurements were within approximately ±10% of those the full 1065 compliance PEMS system over a range of driving conditions and emissions sources.

Research Objectives and Plan

The overall goal of this research is to create an on-board reporting system to guide the industry into a sustainable path of emissions control for their vehicles using the real world as the design platform. UCR is already in the contracting process with the South Coast Air Quality Management District to fund Phase 1 of this work. The goal of Phase 1 of this work will be to develop and demonstrate a low cost NOx and PM sensor-based emissions measurement designed for heavy duty engines.

The OSAR system being developed under Phase 1 will include a NO_x and PM sensor, a GPS, a ECM logger, and a cellular connection for real-time data reporting. UCR has already made arrangements with a leading commercial OBD NO_x sensor manufacturer, NGK-Sparkplugs (also known as NTK Technical Ceramics), to provide 30 in-kind prototype advanced low temperature capable NO_x sensors systems. For PM, UCR has made arrangements with EmiSense, a leader in the real-time OBD PM sensors, who will provide five in-kind PM Track sensors and the project will purchase the other five in-situ PM Track sensors. EPA is also looking to provide 10 – 30 ECM cellular data loggers through their Cooperative Research and Development

Agreement (CRADA) with UCR. Also since there are many short on/off trips expected (based on our significant amount of activity data logging experience) we plan to integrate some type of ~30 minute battery buffer to delay shutdown during a key-off/on condition. This will allow the system to be warmed up and ready to capture all cold start emissions (future implementation of our design could include machine-learning to do this automatically).

The phase 1 funding, in conjunction with in-kind funding from CARB, will also be used to validate the sensor system. Bench evaluations in CE-CERT's sensor laboratory will be conducted to evaluate various aspects of the sensor/system operation prior to deploying. This will include tests to evaluate startup, data logging, sensor checks and robustness. PEMS comparisons will also be conducted for validation emissions testing at the start, middle, and end of the demonstration project. For this exercise, to be supported by CARB and the EPA, the mini-PEMS emissions measurements will be cross compared against measurements made with a 1065 PEMS. This would allow the characterization of the accuracy of the PEMS, as well as issues that might be due to aging or drift issues over a real usage cycle.

Under CARTEEH funding, the goal of the research proposed under this proposal would to expand this research to extend the time for the field demonstration for the mini-PEMS, and to develop a visual aid that would provide for provide a visual characterization of emissions on both a spatial and temporal basis. This would allow the scope of the OSAR research to be broadened considerably in terms of scope and stakeholders. This additional funding would further spur the industry into a solution that includes instrumenting all new heavy-duty trucks with ideas for retrofitting older ones depending on feedback from the Agencies. Also it is believed this proposal will be supported by the industry and fleets owners as it benefits everyone with a fair and practical solution for emissions regulations. Eventually other mobile sources will follow this pattern, including non-road and light duty passenger cars.

The overall approach for the CARTEEH program will be to expand the on-vehicle demonstration to 12 months, develop the visual aid, and analysis and reporting.

On-vehicle demonstration: The SCAQMD funded OSAR contract will provide funding to deploy the OSAR system into the field on up to eight heavy-duty trucks from up to two different vocations (4/fleet) for up to two months. Under CARTEEH funding, the sensor field demonstration for these up to eight trucks would be expanded to a full year. The CARTEEH funding would provide for student oversight of field demonstration for the additional 10 months. The student will periodically visit the site to ensure the OSAR is working correcting, and will access and analyze the additional data from the additional field demonstration. The data will be aggregated to provide average NO_x, PM, and ECM CO_2 and fuel consumption data on a g/mi, g/gfuel, and g/bhp-hr basis. It should be noted that the additional information will not only provide enhanced data from the field demonstration, it will also allow for the evaluation of the durability of the mini-PEMS system, and the associated sensors over a longer 1 year time period. The extended durability testing is of particular interest to EPA, and it is expected that this could generate additional cofunding from EPA for additional bench scale laboratory testing given the longer durability of the field study.

Development of a Visual Aid for the mini-PEMS system: The CARTEEH funding would develop a visual aid that would allow the results from the mini-PEMS system to be easily presented in terms of emissions on both a spatial and temporal scale. This would all impacts of the emissions from the vehicles on local areas to be readily monitored. This could be particularly important for characterizing emissions in environmental justice areas. This could also help to facilitate the development of geofencing algorithms that would allow emissions to be controlled to a tighter degree in environmental justice areas where higher populations of sensitive people might be exposed. Similarly, spatial emissions information as a function of time would allow the mini-PEMS data to better understand how the consequences of emissions in a regional or localized area could be mitigated by shifting traffic patterns or other mitigation measures related to vehicle operation throughout a typical day of operation.

Analysis and reporting: Emissions related ECM information will be recorded that includes up to 200 engine parameters similar to many of UCR's activity studies. From this full data set, UCR plans to investigate the activity patterns of the vehicle, the location of the routes being driven by the vehicle, cold start emissions and their impact on the region, differences between the OBD sensors and the advanced NO_x sensor results. The data will be analyzed to provide emissions profiles for specific routes and specific areas. This will provide valuable information in understanding the emissions impacts of heavy-duty vehicle emissions for specific communities, which would include environmental justice areas. The results of this study will be

summarized in a final report that will include a background section, experimental methods and a description of all sensor-based systems, a results section, and a conclusion and implications section.

Student Involvement

An important component of this project will be graduate student involvement. One graduate will be included in this study. The graduate student will be involved with monitoring the on-borad vehicle demonstration and developing the visual aid software. The data analysis and reporting will also include the graduate student. The results will be summarized in a project report, which will subsequently be converted into a journal article for a peer-review journal article. The graduate student will also present the results at two conferences, the Coordinating Research Council (CRC) Real-World Emissions Workshop and the UCR CE-CERT annual "PEMS Workshop". Both of these are international conferences with approximately 150-250 attendees from throughout the world.

Stakeholder Engagement and Technology Transfer

In terms of technology transfer, we believe the expanded development of such a sensor-based mini-PEMS system at UCR would provide benefits to not just CE-CERT, but potentially to a range of other researchers across campus. CE-CERT, in coorperation with the UCR College of Engineering is already in the process of forming of consortium, that will shortly be put in place, that will include a full range of regulatory agency, industry, and academic stakeholders. It is anticipated that with the relocation of the California Air Resources Board (CARB) southern California facility to the UCR campus in the 2021 timeframe, that this would spur additional efforts in the Riverside region that will make UCR and the Riverside area a key strategic area for emissions measurements on an international scale. Thus, technology developments obtained through this or subsequent projects would be widely disseminated through research efforts and projects, conferences, journal papers, and presentations. It should be noted that since this is a development based on an existing idea [i.e., attaching sensors to drones], the goal of this work would not be to pursue patents, but rather to utilize the developed system as a cornerstone for research projects going into the future.

Additionally, UCR will summarize the highlights of this project and will solicit heavy-duty truck manufacturers (specifically Volvo, Daimler, and Cummins) for a wide spread application of this project using industry funding (currently UCR has tentative interest in these OEMs). The ultimate goal is to leverage our success with this initial phase to create an attractive incentive for the OEM in a direction to meet ARB's growing interest for a regulatory method to control emissions from vehicles under in-use conditions.

It is anticipated that the development of data analytics utilizing this data, our archive data (200 vehicles with sub par NOx sensors), other sources of data, will be a key aspect of the next steps in this program. This data analytics effort could be tied in directly with the CARTEEH Data Hub (carteehdata.org) in a manner that would allow the data to be shared more broadly with CARTEEH researchers and other outside parties for their research and modeling.

Project Duration

The anticipated duration of this project is from approximately September 1, 2019 to December 31, 2020 for a 16 month project duration. This will include the time to gather and set up the new sensors, the time to set up and conduct the testing, and time for the analysis and reporting of the study results

Cost Estimate

The estimated cost of this project is $80,000, including the cost of the required materials, the personnel, and the other costs associated with the testing and reporting. It is expected that in-kind contributions will be obtained in the form of sensors from different sensor companies. We are also looking for and anticipate that this seed project will encourage additional cofunding from sources from as the U.S. EPA. It should be noted that the overall OSAR consortium is already securing financial commitments from the SCAQMD, EMA, CARB, and others, and this project will be operated as a project within that broader OSAR consortium structure.

Research Team Member Information

Provide the following information regarding the Principal Investigator: Dr. Kent Johnson, Research Engineer, University of California at Riverside, College of Engineering - Center for Environmental Research Technology, kjohnson@cert.ucr.edu, 951-781-5786

Other investigators: George Scora, Tom Durbin, and George Karavalakis, UCR – CE-CERT

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