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UTC Project Information	
Project Title	**A data driven approach to the development and evaluation of acoustic electric vehicle alerting systems for vision impaired pedestrians**
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Total Project Cost	$550,215
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Start and End Dates	11/01/2020 – 06/30/2022
Brief Description of Research Project	The steady increase of electric vehicles (EVs) has led to safety concerns for vulnerable populations. EVs produce considerably less noise compared to the internal combustion engine (ICE) vehicles, especially at low speeds. Although pedestrians across all demographics are at risk, visually impaired pedestrians face significantly greater disadvantages in environments where ambient noise levels are high in relation to EV noise output. A major reason for this is because these pedestrians depend on auditory cues when making life-threatening decisions, such as crossing complex intersections or walking through city streets. In response to this safety concern, the National Highway Traffic Safety Administration (NHTSA) has developed regulations (FMVSS-141) that require EVs to emit sounds that meet specific frequency content and overall sound pressure levels. Previous work by the PIs has shown research gaps in the current implementations of EV warning sounds that may compromise safety for pedestrians, particularly the vision impaired. These gaps include a lack of uniform sound radiation around the vehicle, creating “dead” zones where little sound may reach pedestrians. Additionally, there is a lack of understanding of signal characteristics have the most significant effect on vehicle detectability by vision impaired and/or potentially distracted pedestrians. Based on previously collected data and new

	experiments, this project continues development of EV acoustics-based safety measures for vision-impaired pedestrians. The project will establish data-driven safety performance measures, such as probability of vehicle detection with respect to scientifically-oriented additive sounds that meet existing standards, as well as techniques for uniform sound transmission around the vehicle.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	1. Deliverables of the final report and the data 2. Planned Learning Modules • Results from this project will be used in an existing course, ME 4764, Audio Engineering Technology, to produce a new project in 3D audio. The undergraduate project will use 3D audio recordings of EV drive-bys using a soundfield microphone to generate 3D ambisonics soundfields in a VT ASPIRE lab. Students will then compare real-world recorded sounds to those generated in a virtual environment. • Data sets from this project will be shared online with researchers worldwide. Since the project will generate a large set of high-quality data, these data will be made available to the international research community through sharing sites, such as GitHub and Safe-D's own data repository. These datasets will be of great interest to other researchers in higher education, researchers in government regulatory agencies, and particularly the automotive industry, which must satisfy existing requirements for additive sounds. • The project will include 1 Virginia Tech Mechanical Engineering graduate student. The student will produce an MS thesis based on the results of the proposed work at the end of the project period. Additionally, 2 undergraduate researchers will work on the project. These students will each receive 3 research credits for their contributions to the work. Each undergraduate researcher will produce a short written report at the end of each semester of participation. The proposed work will provide exposure for the students to real-world engineering problems and practice. Due to industry sponsor participation of past projects and continued interest in this project, it is expected that students will have exposure to industry sponsors and industrial needs, procedures, and engineering practice. 3. Technology Transfer Plan • Planned Stakeholder Involvement The project champion is Mr. Douglas Moore, who currently serves as the Vehicle Performance Owner for Passby/Legal in GM's Global Noise and Vibration Center. Mr. Moore will participate in most aspects of the project and will serve as the main subject matter expert from the automotive industry. • This project will deliver guidelines for the development of additive warning sounds for electric vehicles. Complimentary

	to the guidelines, the project will deliver data-driven models that predict the human detection performance of newly developed warning sounds. This project will also develop and illustrate the efficacy of using 3D, immersive-audio techniques for human subject listener testing for determination of additive warning sound effectiveness with significant cost and time savings while providing increased test repeatability. • The results of the project will appear in several publications, including a MS thesis in mechanical engineering as well as at least two journal papers submitted to *IEEE Transactions on Vehicular Technology* and /or the *Journal of the Acoustical Society of America* (or similar). Additionally, at least two conference presentations are expected at the SAE Noise and Vibration Conference (or similar). The content of these publications will include findings on the detection performance of human listeners who were given alert sounds designed to meet the regulatory requirements, but also designed for optimal human detection. Students will appear as authors on all publications. For graduate students, authoring scientific publications is a critical requirement for their research career development. For undergraduate researchers, their involvement in this research will provide a boost for admissions to graduate programs. Students will also be expected to present research results at academic conferences. This will provide avenues for the further development of their public speaking as well as presentation skills and will also present them with opportunities to interact with other experts in the field in a professional capacity. • Raw data used in all experiments will be published and made publicly available via GitHub, the Safe-D data repository, or similar open-source sharing resources. • Beyond GM, who will be involved in this project, we plan to present our findings to other potentially interested parties either in person or via webinars (Safe-D webinar, etc.), providing exposure to a wide audience. This will likely include specific groups and committees with similar topic areas (SAE, ISO, etc.), as well as organizations interested in this work (NFB, etc.). By presenting our research we hope to help industry leaders assess their own strategies for reducing vehicle-pedestrian conflicts, thus ultimately elevating the general understanding of the issues surrounding the topic and working collectively towards the goal of improving safety for all road users. • It is expected that at least two patent applications will be submitted as a result of work from this project. First is a patent on the adaptive system for uniform warning sound transmission, and second is the model and method for predicting the detection performance of additive EV warning

	sounds.
Impacts/Benefits of Implementation (actual, not anticipated)	The market for this project's outcomes includes OEMs engaged in production of EVs as well as regulatory bodies that oversee traffic safety. Detection guidelines currently exist but prescribe mean detection distance based on specific sound-based requirements. The results from this project will show that probability of detection presents a much clearer picture of the performance of EV additive warning sounds. The application of advanced 3D immersive-audio techniques will show that these techniques give significant time and cost savings. It is anticipated that future EV auditory alert systems will adapt to their environments and will optimize their warning sounds based on pedestrian data, local noise conditions, road surface roughness, and weather. This project provides the foundations for that adaptability. The results of this project will complement future research projects and will uniquely position the PIs to target future research funding, particularly in the area of connected vehicles and their relation to vulnerable users
Web Links • Reports • Project website	https://safed.vtti.vt.edu/projects/a-data-driven-approach-to-the-development-and-evaluation-of-acoustic-electric-vehicle-alerting-systems-for-vision-impaired-pedestrians/