Murray State University uses NEVs around campus for various utility tasks. They are an economical way to haul equipment and transport people.

Electric Vehicle Noise

Are They Too Quiet?

IN BRIEF
- When operated at low speed, electric vehicles are very quiet and pedestrians may not notice their approach.
- The addition of a "motor noise" can make the vehicle much more obvious to pedestrians. Recommendations for improving the safety of these vehicles are provided as well.

By David L. Fender

Electric vehicles (EVs) are a promising automotive technology designed to reduce air pollution, decrease maintenance costs, reduce dependence on foreign oil and reduce noise emissions. Sounds good, but like any new technology, safety issues associated with that technology must be identified and controlled. For example, EVs produce little noise, a fact often touted as an advantage of such vehicles. However, this lack of noise could actually be a hazard if pedestrians cannot hear a vehicle approaching.

Although various types of internal combustion engines (ICE) have been a primary source of vehicle power, most research has focused on developing vehicles powered by electricity. In recent years, availability has been limited to hybrid vehicles, which use a combination of ICE and electric power; however, manufacturers are developing all-electric or plug-in vehicles that operate solely on electricity. EVs include vehicles intended to operate at highway speeds as well as those intended to operate at low speeds and over short distances. Those vehicles are called neighborhood electric vehicles (NEVs).

Emergence of Electric Vehicles

Efforts to reduce the noise emitted by vehicles have been ongoing. In 1997, the average sound level for passenger cars was about 90 dBA (Wiener, 1997). Currently, U.S. automobile manufacturers design cars to meet the European noise limit of 78 dBA [Federal Highway Administration (FHWA), 1995]. The U.S. Federal-Aid Highway Act of 1970 mandated FHWA to develop noise standards for mitigating highway traffic noise (FHWA, 1995).

Other efforts have focused on quieter tires and pavement. Purdue University's Institute for Safe, Quiet and Durable Highways has conducted federally funded research to design tires that make less noise (Wiebusch, 2001). Arizona is involved in a Quiet Pavement Pilot Program with a modified highway surface. In initial tests, this surface reduced moving vehicle noise by 3 to 12 dBA compared to conventional surfaces (Manuel, 2005).

Electric Vehicles & Noise

Hogan (2008) studied pedestrian injuries involving hybrid vehicles. This analysis was principally based on data from the U.S. Fatality Analysis Reporting System (FARS), which captures data on all U.S. motor-vehicle-related deaths occurring in public, from 2001 to 2006. The analysis showed that, based on reported incidents, hybrids are no more dangerous to pedestrians than other vehicles, and little variation exists in how and why blind or sighted pedestrians die in vehicular incidents.

Hogan's analysis was limited to the Toyota Prius because the database only identifies the vehicle involved in an accident by model name; the Prius is the only hybrid with a large production volume that has been produced solely as a hybrid. Other models have hybrid and ICE versions and the specific power source is not identified in FARS. In addition, the sample size for blind pedestrians is small, so it is difficult to draw definite conclusions. It will take more time, better data and a larger number of EVs before researchers can use accident data to determine actual pedestrian/vehicle collision experience with much better reliability.

The National Federation for the Blind (NFB) and the American Council of the Blind have been vocal regarding the perceived hazard of too-quiet vehicles because blind people use the sounds of traffic to determine when it is safe to cross streets (Sauerburger, 2008). These organizations have lobbied the government and vehicle manufacturers to build in some type of obvious noise when a vehicle is in quiet, low-speed operation (NFB, 2010).

A study by Wall-Emerson and Sauerburger (2008) illustrates these groups' concern. Results of this study, conducted on a quiet two-way residential street, showed that even in relatively quiet areas it was not always possible for blind individuals to hear EVs clearly enough to know when it may be safe to cross. National Highway Traffic Safety Administration (NHTSA, 2010) also has studied blind pedestrians and EVs and found that these vehicles are significantly quieter at slow speeds.

According to Bond and Easton (in press), all pedestrians, not just blind ones, use the sound of approaching vehicles. On a two-way street, subjects were asked to indicate when they felt it was safe or not to cross the street with a young child. A *risky decision* was defined as an instance when the subject felt safe to cross when the vehicle was too close (i.e., the vehicle would reach them before they crossed). Results showed that individuals made about 10% more risky decisions using vision only than when using vision and hearing.

Another study compared the relative audibility of hybrid vehicles (in their electric mode) and ICE vehicles. Binaural recordings were made of the cars approaching from either the right or left at 5 mph. Subjects were asked to listen to these recordings through headphones and indicate from which direction the car came. Experiments revealed that subjects were able to determine the approach direction of ICE cars substantially sooner than that of hybrid cars. Another experiment added natural background sounds of idling engines to the stimuli. This disproportionately hindered discernment of the hybrid cars so much that they could not be identified until they were very near. Results were the same for sighted and blind subjects (Robart & Rosenblum, 2009).

Comparing a Prius to a Ford Mustang, the Prius had to be 23 ft away (40% closer) for the pedestrian to recognize that a vehicle was approaching. When a Prius was compared with a Honda Accord, the Accord was 36 ft away when its sound was recognized compared to 11 ft (69%) closer for the Prius. At the speed the vehicle was traveling, it would take only 1.4 seconds before the Prius and the pedestrian would have collided. When normal background noise was added, the Accord was identified 22 ft (3 seconds) before arrival and the Prius 1.6 ft (0.2 seconds) *after* arrival.

David L. Fender, Ed.D., CSP, CSHM, is an associate professor in the Department of Occupational Safety and Health at Murray State University (MSU). He is a member of the National Safety Management Society, and he is a professional member of ASSE and a past president of its Wiregrass Chapter. Fender is the faculty advisor to MSU's ASSE Student Section. He holds a B.S. from Central Missouri State University, an M.S. from University of Southern California and an Ed.D. from Vanderbilt University.

A-weighted sound level readings above background noise were recorded at various speeds for a GEM vehicle and a 2007 Ford F-150 pickup, as the vehicle passed directly in front of the measuring point.

Figure 1
Vehicle Sound Level Readings

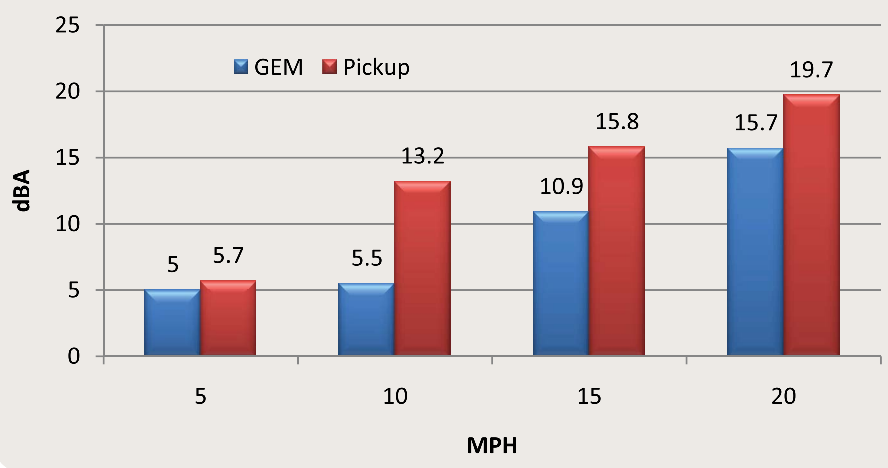
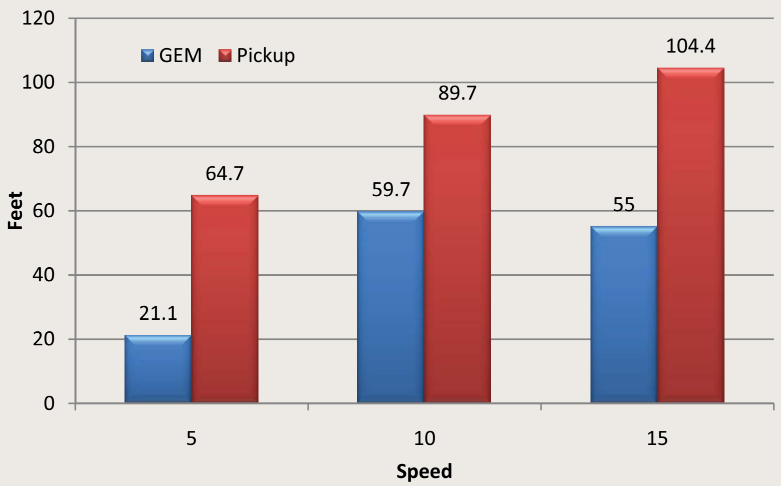


Figure 2

Vehicle Detection Distance



Average distance at which individuals recognized the vehicles approaching illustrates the concern about the lack of noise produced by EVs.

Rosenblum (personal communication, Sept. 11, 2009) has also conducted studies outside using vehicles on paved surfaces, and the results have been similar. All of this indicates that over-the-road EVs are significantly quieter than ICE vehicles, and that at low speed EVs must be significantly closer than ICE vehicles for individuals with normal hearing to detect them.

Rosenblum (personal communication, Sept. 11, 2009) has also compared Prius and Camry (ICE) vehicle noise levels and recognition of an approaching vehicle. His research showed that little noise difference existed between the vehicles at normal traffic speeds; however, below 20 mph, when the Prius may be in electric mode, it is 17 dBA quieter. Rosenblum believes that it would take only a little sound enhancing to give pedestrians enough cues, thus not increasing the overall noise level volume much.

Companies such as Lotus, General Motors and Nissan, as well as various universities have studied what would be the best sound and at what volume to make quiet vehicles sufficiently noticeable. For example, Nyeste and Wogalter (2008) report that when a variety of sounds were demonstrated, subjects preferred engine noise, white noise and hum sounds.

An NEV Study: Background

Research on the lack of noise emitted by EVs and the potential hazard to pedestrians who do not realize that a moving vehicle is nearby has been largely focused on highway-speed capable vehicles. This study focused on the same potential limited noise problem involving a much smaller and slower class of vehicles: NEVs.

NEVs have many advantages over the vehicles they typically replace such as small cars and pickups. NEVs come in many styles, are 100% battery-electric, emit zero tailpipe emissions, are low maintenance and are quieter than ICE vehicles. They have a top speed of 25 mph and a range of up to 40 miles on one charge, which makes them an economical way to haul equipment and transport people around large company sites or multiple-building campuses.

In many states, NEVs can be legally driven on slow-speed roads (35 mph or less). They are smaller and lighter than conventional vehicles and can be driven on sidewalks and narrow alleyways to reach areas where a normal vehicle cannot go, making them a convenient, efficient option for maintenance workers. NEVs made by Global Electric Motorcars (photo, p. 34), a subsidiary of Chrysler Group LLC, are an example.

The Experiment

This experiment was performed at Murray State University (MSU), which uses NEVs for utility tasks around campus. Members of the MSU ASSE Student Section, after vetting by the institutional review board, performed several experiments to assess potential noise safety issues with these vehicles.

The first experiment was designed to measure vehicle noise levels at different speeds. Measurements were taken following SAE International Surface Vehicle Standard J2889-1 Proposed Draft 2008 (Society of Automotive Engineers, 2009). As per this standard, a course was laid out in a level parking lot. The parking lot was away from street noise and weather conditions were within specified tolerances.

As per the standard, measurements were taken 2 meters from the centerline of vehicle travel at a level of 1.2 meters from the ground. Vehicles got up to speed before arriving at the measuring point so that they were cruising at that speed upon measuring. Sound measurements were made using a calibrated sound level meter.

Growing Popularity of EVs

EVs are becoming more common in vehicle fleets as companies recognize the advantages of lower operating and maintenance costs. Government organizations use both NEVs and highway-speed-capable EVs in national parks, for public functions such as water meter reading, for school campus patrol and in police departments, to name a few.

The U.S. Army intends to replace 28,000 vehicles with various types of EVs and airlines are using them on the airport tarmac. Taxi companies in Washington, DC, and Phoenix, AZ, are using hybrid vehicles in their fleets. UPS currently has 200 hybird delivery vehicles and as of mid-2010, FedEx had 264. Ford Motor Co. believes that 10% to 25% of its global fleet will be electrified by 2020. Purolator is purchasing 2,000 vehicles; Ford and Freightliner will be selling all-electric utility vehicles soon; and Navistar intends to produce EVs as well. It appears that we will be seeing an increase in all sizes and types of electric vehicles.

NEVs have many advantages over the vehicles they typically replace such as small cars and pickups. NEVs are 100% battery-electric, emit zero tailpipe emissions, are low maintenance and are quieter than ICE vehicles.

Figure 1 (p. 35) shows the A-weighted sound level readings above background noise at various speeds for the NEV and the vehicle it replaced, a 2007 Ford F-150 pickup, as each vehicle passed directly in front of the measuring point. The data show that the NEV is quieter than an ICE-powered vehicle although the difference varied at the different speeds. Additionally, at speeds of 10 mph and below, the NEV's noise level was very low.

The next experiment was designed to determine whether individuals could recognize the approach of the NEV as easily as that of the ICE vehicle. Volunteer participants were normally sighted students age 19 to 25. They were located 2 meters from the vehicle's path in a position where they would normally be if preparing to step out to cross the street. The same two vehicles were driven past the blindfolded subjects at various speeds and the subjects indicated when they recognized the vehicle approach. Figure 2 shows average distance at which the individuals recognized the vehicles approaching.

Results indicate that on average the NEV was much closer to the individual when s/he recognized it compared to the ICE vehicle. At 5 mph, a speed that would not be unusual if driving on sidewalks, some individuals recognized the NEV in as few as 2.2 seconds (16 ft) before vehicle arrival compared to 10 seconds (76 ft) for the ICE vehicle.

At 10 mph, the NEV was recognized by some subjects as few as 3.4 seconds (50 ft) before arrival compared to 5.3 seconds (77 ft) for the ICE vehicle. At 5 mph, the NEV must be 79% closer to the person to be recognized and at 10 mph 35% closer. This gives little time, even at slow speeds, for an NEV driver to react if someone steps out in front of the vehicle.

In the next part of the experiment, an electronic circuit was installed in the NEV along with a 5-in. speaker. This device simulated a gasoline engine sound and varied the volume level with vehicle speed. Noise measurements and vehicle detection data were gathered exactly as in the previous experiments.

Results show that adding the simulated sound raised the overall vehicle sound signature and increased the distance at which individuals recognized an approaching vehicle. As the vehicle passed by the measurement point at 5 mph, the sound level was increased by 8 dBA; at 10 mph, it was increased 1.6 dBA. The reason for this difference is that at 5 mph the mechanical and tire sounds coming from the vehicle are very low. At higher speeds, these mechanical sounds (e.g., motor and gear train) increased considerably and the added sound is not as obvious.

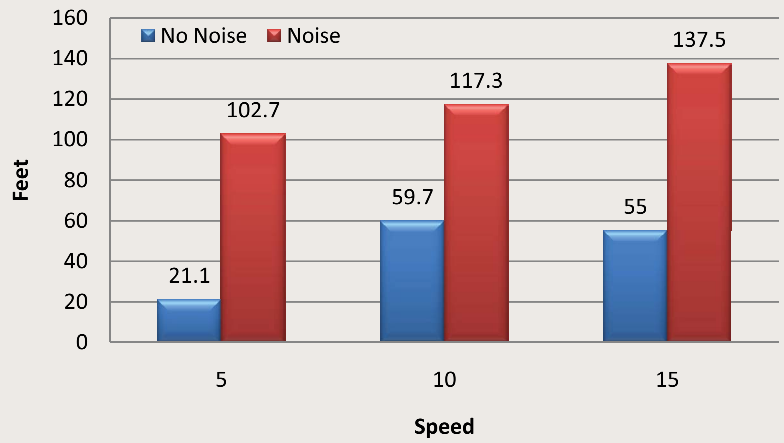
Individuals' ability to detect vehicles increased dramatically with the added sound. The vehicle was almost always detected at least 100 ft away (Figure 3, p. 38 presents average distances). This made it much easier for a pedestrian to identify that a vehicle was approaching.

Conclusion

Although this study involved one brand of NEV, it reflects the general noise issues related to EVs of all types and confirms information gathered from studies of highway-capable EVs. The lack of recog-

Figure 3

Vehicle Detection Distance: Stock vs. Added Sound



Vehicle detection by individuals increased dramatically with the added sound.

nizable sounds makes small EVs more hazardous to pedestrians, especially at speeds of 10 mph and less. Pedestrians would more likely recognize a vehicle's approach if its external sound level were increased.

More research is needed to determine the ideal type of sound, volume levels, and when to raise and lower the sound. Other considerations include installation issues, speaker type and placement, and not raising the sound levels inside the cab.

Recommendations

- Companies that purchase NEVs should consider the decreased sound signature at low speeds and the mixing of pedestrians and vehicles.
- Discuss the lack-of-noise safety issues with and encourage the manufacturer to install appropriate noise generation capability and purchase when available.
- Discuss the decreased noise signature at low speeds in driver training. Make sure operators understand that they must never assume that pedestrians know the vehicle is near and must operate the vehicle accordingly.
- To make the vehicle more visible to pedestrians, install a strobe light that operates when the vehicle is in motion. **PS**

Acknowledgments

This study was performed by the members of the MSU ASSE Student Section, including Jayme Kayne, Ashley Henderson, Ryan Rohleder and Nawal Zakari, as well as several others who served as study subjects. The section would like to thank MSU employees whose assistance was instrumental in completing the study: Dickie Turner and the mechanics at Transportation Services; Don DeMarchi and members at Central Plant; and Jeff Steen, environmental safety and health.

References

Bond, T. & Easton, R. (in press). The relative contributions of audition and vision to pedestrian street crossing judgments. *Journal of Visual Impairment and Blindness.*

National Federation for the Blind (NFB). (2010). Key stakeholders agree on measures to protect blind pedestrians from silent cars [Press release]. Baltimore, MD: Author. Retrieved June 10, 2010, from **www.nfb.org/nfb/NewsBot.asp?MODE=VIEW&ID=594.**

Department of Transportation. (2008). Quiet Cars Notice of Public Meeting and Request for Comments. (Docket No. NHTSA-2008-0108, 73 *Federal Register,* 31187). Washington, DC: Author.

Federal Highway Administration. (1995). Highway traffic noise analysis and abatement policy and guidance. Washington, DC: Author, Office of Environment and Planning, Noise and Air Quality Branch.

Hogan, C. (2008). Analysis of blind pedestrian deaths and injuries from motor vehicle crashes, 2002-2006. Vienna, VA: Direct Research LLC.

Manuel, J. (2005). Clamoring for quiet: New ways to mitigate noise. *Environmental Health Perspectives, 113*(1), A46-A49.

National Highway Transportation Safety Administration. (2010). Quieter cars and the safety of blind pedestrians: Phase 1 (DOT HS 811 304). Washington, DC: Author.

Nyeste, P. & Wogalter, M. (2008). On adding sound to quiet vehicles. *Proceedings of the Human Factors and Ergonomics Society, USA*, 1747-1750.

Robart, R. & Rosenblum, R. (2009). Are hybrid cars too quiet? *Journal of the Acoustic Society of America, 125* (4), 2744.

Sauerburger, D. (2008). Quiet cars and the safety of blind pedestrians (Docket No. NHTSA-2008-0108). Retrieved Nov. 10, 2010, from **www.sauerburger.org/dona/quiet.**

Society of Automotive Engineers (SAE). (2009). Measurement of minimum noise emitted by road vehicles J2889-1 (proposed draft). Warrendale, PA: SAE International.

Wall-Emerson, R. & Sauerburger, D. (2008). Detecting approaching vehicles at streets with no traffic control. *Journal of Visual Impairment and Blindness, 102*(12), 747-760.

Wiebusch, B. (2001). Engineers tread on quiet tires. *Design News.* Retrieved Nov. 10, 2010, from **www.designnews.com/article/11186-Engineers_tread_on_quiet_tires.php.**

Wiener, W. (1997). Audition for the bisually impaired traveler. In R. Welsh, W. Wiener and B. Blasch (Eds.), *Foundations of Orientation and Mobility* (2nd ed.). New York: AFB Press.