

NSTSCCE

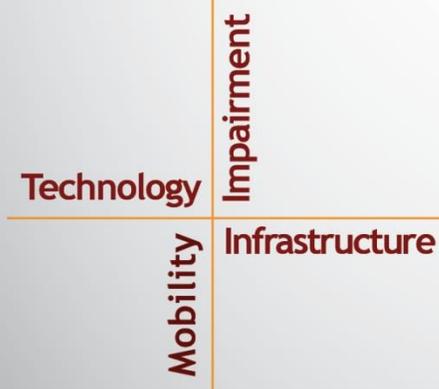
National Surface Transportation
Safety Center for Excellence

An Assessment of Quiet Vehicles and Pedestrian and Bicyclist Safety

Issue Status and Research Opportunities

Andrew S. Alden

Submitted: June 13, 2014



Housed at the Virginia Tech Transportation Institute
3500 Transportation Research Plaza • Blacksburg, Virginia 24061

ACKNOWLEDGMENTS

The authors of this report would like to acknowledge the support of the stakeholders of the National Surface Transportation Safety Center for Excellence (NSTSCE): Tom Dingus from the Virginia Tech Transportation Institute, John Capp from General Motors Corporation, Lincoln Cobb from the Federal Highway Administration, Chris Hayes from Travelers Insurance, Martin Walker from the Federal Motor Carrier Safety Administration, and Cathy McGhee from the Virginia Department of Transportation and the Virginia Center for Transportation Innovation and Research.

The NSTSCE stakeholders have jointly funded this research for the purpose of developing and disseminating advanced transportation safety techniques and innovations.

TABLE OF CONTENTS

| | |
|---|-----|
| LIST OF TABLES..... | v |
| LIST OF ABBREVIATIONS AND SYMBOLS | vii |
| CHAPTER 1. INTRODUCTION..... | 1 |
| CHAPTER 2. BACKGROUND..... | 3 |
| CALL TO ACTION | 3 |
| NOTABLE RELATED RESEARCH | 3 |
| <i>Incidence of Pedestrian and Bicyclist Crashes by Hybrid Passenger Vehicles, Hanna et al., September 2009</i> | 3 |
| <i>Quieter Cars and the Safety of Blind Pedestrians: Phase 1, Garay-Vega et al., April 2010</i> | 4 |
| <i>Assessing whether Quiet Electric and Hybrid Vehicles Pose a Safety Risk To the Vision Impaired, Morgan et al., Jan. 2011</i> | 6 |
| <i>Incidence Rates of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles: An Update, Wu et al., October 2011</i> | 7 |
| <i>Quieter Cars and the Safety of Blind Pedestrians, Phase 2: Development of Potential Specifications for Vehicle Countermeasure Sounds, Hastings, October 2011</i> | 8 |
| CHAPTER 3. CONTRIBUTING TRENDS | 11 |
| <i>Increased Numbers of EPVs</i> | 11 |
| CHAPTER 4. REGULATIONS AND STANDARDS | 13 |
| UNITED STATES..... | 13 |
| JAPAN | 14 |
| WORLD | 14 |
| NON-GOVERNMENTAL ORGANIZATION (NGO) SUPPORT | 14 |
| NOISE MEASUREMENT STANDARDS | 15 |
| CHAPTER 5. PROPOSED COUNTERMEASURES | 17 |
| VEHICLE-BASED COUNTERMEASURE SYSTEMS | 17 |
| <i>OEM Systems</i> | 17 |
| <i>Aftermarket Systems</i> | 19 |
| CHAPTER 6. ADDITIONAL CONSIDERATIONS..... | 21 |
| TRANSPORTATION TRENDS | 21 |
| <i>Quieter Vehicles</i> | 21 |
| <i>Increasing Prevalence of QVs in Urban Areas</i> | 21 |
| <i>Technology Advances</i> | 21 |
| UNINTENDED CONSEQUENCES..... | 22 |
| CHAPTER 7. OPPORTUNITIES FOR ADDITIONAL RELATED RESEARCH | 23 |
| SHRP 2 NATURALISTIC DRIVING STUDY..... | 23 |
| <i>NDS-Related Potential Research Topics</i> | 24 |
| OTHER QVS..... | 25 |
| ASSISTANCE ANIMALS | 26 |
| TIRE TECHNOLOGY | 26 |
| EXCEEDING COUNTERMEASURE CROSSOVER SPEED..... | 26 |
| REFERENCES | 27 |
| BIBLIOGRAPHY..... | 33 |

LIST OF TABLES

Table 1. Comparison of SDS States and Reporting Years Used in Hanna, 2009 and Wu, 2011. 7

LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|-------|---|
| ABS | anti-lock braking system |
| BEV | battery-electric vehicle |
| BEVx | battery-electric vehicle – extended range |
| CAFE | Corporate Average Fuel Economy |
| CARB | California Air Resources Board |
| CNG | compressed natural gas |
| dB | decibel |
| DOT | U.S. Department of Transportation |
| EIA | Energy Information Administration |
| EPV | electrically propelled vehicle |
| EV | electric vehicle |
| FHWA | Federal Highway Administration |
| FMVSS | Federal Motor Vehicle Safety Standards |
| GHG | greenhouse gas |
| GM | General Motors |
| GPS | Global Positioning System |
| HE | hybrid electric |
| HEV | hybrid electric vehicle |
| ICE | internal combustion engine |
| ISO | International Organization for Standardization |
| JASIC | Japan Automotive Standards Internationalization Center |
| LEV | low emission vehicle |
| LNG | liquefied natural gas |
| LPG | liquid petroleum gas |
| MLIT | Ministry of Land, Infrastructure, Transport and Tourism |
| MUARC | Monash University Accident Research Centre |
| NDS | Naturalistic Driving Study |
| NEPA | National Environmental Policy Act |
| NGO | non-governmental organization |
| NHTSA | National Highway Traffic Safety Administration |
| NOx | oxides of nitrogen |

| | |
|---------|---|
| OEM | original equipment manufacturer |
| OR | odds ratio |
| PEDSAFE | Pedestrian Safety Guide and Countermeasure Selection System |
| PHEV | plug-in hybrid electric vehicle |
| PSEA | Pedestrian Safety Enhancement Act of 2010 |
| QV | quiet vehicle |
| RITA | Research and Innovative Technology Administration |
| SAE | Society of Automotive Engineers |
| SDS | State Data System |
| SHRP2 | Second Strategic Highway Research Program |
| SUV | sport utility vehicle |
| UNECE | United Nations Economic Commission for Europe |
| USDOT | U.S. Department of Transportation |
| VIN | Vehicle Identification Number |
| V2P | vehicle to person (or pedestrian) |
| VPNS | Vehicle Proximity Notification System |
| VSP | Vehicle Sound for Pedestrians |
| ZEV | Zero Emission Vehicle |

CHAPTER 1. INTRODUCTION

In 1998 the California Air Resources Board (CARB) mandated requirements for auto manufacturers to produce limited numbers of “zero emission vehicles” (ZEVs) for public use. Manufacturers responded and soon created cars such as the General Motors (GM) EV1 to meet those demands. Manufacturers produced a variety of ZEVs using numerous technologies to meet the goal of zero tailpipe emissions. Whether batteries or fuel cells were used for energy storage, all of these vehicles used electric motors for propulsion, arguably ushering in the age of the modern electric vehicle (EV). The reasons for the demise of these vehicles are manifold and controversial, but most would agree that the technology to build these types of vehicles had not yet advanced to the point of economic viability. Of course, this same argument was used by some to predict the downfall of the Toyota Prius when it was introduced to the American market in 2001. The Prius, now in its third generation of production, is still successful despite increased competition in the hybrid market from almost all major automotive manufacturers. As of December 2011, 37 different models of hybrid electric vehicles (HEVs) or EVs were being sold in the United States with 2.73% of the light-vehicles market share for December 2011.⁽¹⁾

The demands on our modern transportation systems are changing in response to numerous factors, including population growth, income gains, cultural pressures, and sprawl. Increased petroleum fuel costs, greater commuting distances, a lack of public transportation, and personal efforts to live sustainably have led many to seek out vehicles that can be operated economically and efficiently. Many vehicles, including those powered by conventional internal combustion engines (ICEs), may meet these requirements. However, the success of HEVs and EVs can, in large part, be attributed to the perception that they are either inexpensive to operate, environmentally friendly, or both.

Hybrid vehicles, by definition, use multiple types of propulsion systems that provide enhanced performance when paired. HEVs use one or more electric motors in combination with another prime mover, typically an ICE fueled by hydrocarbon sources such as gasoline, diesel, compressed natural gas (CNG), liquefied natural gas (LNG), or liquid petroleum gas (LPG). HEVs generally use the electric motors for all low-speed operation, some high-speed operation, and acceleration. A new class of HEV has recently been classified as BEVx, denoting a battery-electric vehicle with an ICE range extender to enable short travel to the nearest charging station. EVs are propelled solely by electric motors, typically powered by batteries or fuel cells. Those vehicles that can operate in a purely electrically propelled mode include HEVs, BEVxs, and EVs and are referred to in this report as electrically propelled vehicles (EPVs).

Vehicles in motion generate a wide variety of sounds. These emanate primarily from the following major sources during normal operation:

- Prime movers, whether an ICE or electric motor, and ancillary equipment
- (for ICEs) Pumps, belts, cooling fans, and exhaust systems
- (for EPVs) Motors, electronic controllers, regenerative systems, pumps, and cooling fans
- Vehicle contact with pavement (tires)
- Vehicle interface with the atmosphere (wind, precipitation)

At lower speeds, the engine or motor and related systems generate most of the sound. At higher road speeds, generally above approximately 20 mph, tire and wind noises predominate. The speed at which tire noise becomes predominant is called the “crossover point.”⁽²⁾

When in their dedicated electric mode, EPVs typically operate more quietly than their conventional ICE-propelled counterparts. Their description as “quiet vehicles” is, in some sense, a misnomer because there are quiet vehicles other than EPVs on roadways, such as bicycles, street cars, trolleys, scooters, Segways[®], buses, and even certain ICE-powered cars. Regardless, EPVs’ low noise operation at low speeds, coupled with their increased numbers on roadways and the lower traffic speed and increased presence of pedestrians and pedalcyclists in urban areas, has led to concerns for the safety of those who depend on sound for the detection, identification, and location of moving vehicles. Previous work with at-risk pedestrians has shown that audible detection of EPVs operating at higher speeds (30 mph) is not problematic. Numerous advocates for the visually impaired, including the American Council for the Blind and the National Federation of the Blind, which represent 1.3 million visually impaired people in the United States, contend that visually impaired pedestrians are at increased risk of conflict with these quiet vehicles during low-speed operation and have called for action on the part of auto makers and the regulatory community.⁽³⁾

In response to these concerns and the results of related research, President Obama signed the Pedestrian Safety Enhancement Act of 2010 (PSEA) into law on January 4, 2011. This law directs the U.S. Department of Transportation (DOT) to address the issue of increased risk to pedestrians posed by quiet vehicles through National Highway Traffic Safety Administration (NHTSA) Federal Motor Vehicle Safety Standards (FMVSS) within four years, that is, by July 4, 2015.⁽⁴⁾

Disambiguation

The press, the regulatory community, and others have used the term “quiet vehicle” to refer specifically to EPVs only, excluding other vehicles that may operate with little noise. This report uses the term “quiet vehicle” (QV) in a broad sense to describe any vehicle that can operate at a lower noise level than that typically associated with a normal ICE-powered vehicle. Any vehicle that can operate in a purely electrically propelled mode (i.e., EPV) is considered to be a QV, as are most human-powered vehicles, some ICE vehicles, and others.

Report Scope

The primary intent of this report is to provide a comprehensive and concise overview of the apparent safety issues presented to pedestrians and pedalcyclists by the operation of QVs on roadways. The report provides background information to establish how this issue became the focus of safety research in the United States and elsewhere. It presents the findings of a literature review of notable major research and a review of related pending and established regulations. The report also describes implemented and proposed countermeasure methods in addition to opportunities for future potential research to address knowledge gaps and improve overall understanding of the issues.

CHAPTER 2. BACKGROUND

CALL TO ACTION

More than 20 million Americans suffer from visual impairment and approximately 1.3 million are legally blind. A subset of those who are legally blind, “independent travelers,” use canes and their other senses to navigate through daily life, including vehicular traffic.⁽⁵⁾ In July 2003, the National Federation of the Blind called on the NHTSA to “initiate research to be performed with significant participation by the National Federation of the Blind to investigate the effect of quiet cars on blind pedestrians and all pedestrians, with the aim of proposing safety-based solutions to the problem impacted.”⁽³⁾ This request, as well as many others from a variety of advocacy groups, has been repeated in various forms.

In June 2008, NHTSA held a public meeting of stakeholders, policy makers, and industry representatives in response to these appeals. NHTSA subsequently embarked on a dual-track research plan to address the growing recognition of the risk posed to pedestrians by EPVs. The first phase of work would characterize the risks of EPVs to pedestrians, including pedalcyclists. In the second phase of work, the John A. Volpe National Transportation Center would use the results of the first phase and conduct additional research to develop specifications for a Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE) warning sound as specified in FMVSS.⁽⁶⁾ When the PSEA was enacted in January 2011, NHTSA was already well into its second phase of research regarding the potential risks posed to pedestrians by EPVs.

Despite NHTSA’s stated concern about the increased risks posed to pedalcyclists by EPVs, bicycling advocacy groups have been uncharacteristically silent on this issue. Searches of literature and the Internet, as well as numerous inquiries to bicycling-related Transportation Research Board committees and national bicycle advocacy groups, reveal very little awareness or related concern. When contacted to discuss EPV risks to pedalcyclists, leaders of cycling advocacy from the Alliance for Biking & Walking, the Virginia Bicycling Federation, and the League of American Bicyclists were all either unaware of the issue or unresponsive. This is particularly troubling because the research conducted thus far indicates that pedalcyclists are at a significantly increased risk, especially at higher speeds where the likelihood of serious injury is greater.

NOTABLE RELATED RESEARCH

Incidence of Pedestrian and Bicyclist Crashes by Hybrid Passenger Vehicles, Hanna et al., September 2009⁽⁷⁾

This research was NHTSA’s initial attempt to determine whether the operation of EPVs creates elevated risks to pedestrians. In research performed by NHTSA’s Office of Traffic Records and Analysis, pedestrian and pedalcyclist injury rates reported to the State Data System (SDS) in 12 states were analyzed to determine odds ratio (OR) comparisons for conventional versus EPV vehicles for the years 2000 to 2007. Only the data from 12 states were used because the vehicle identification numbers (VINs) necessary for determination of vehicle type (EPV versus conventional) were known to be available in these states. Data for 8,387 Toyota Prius and Honda Insight EPV vehicles were compared to 559,704 conventional (i.e., ICE) counterpart vehicles

under various types of operation. In general, the results of this investigation support claims that EPVs pose an increased risk to pedestrians and pedalcyclists. For all operating conditions, researchers found that an EPV was 40% more likely to hit a pedestrian than was its ICE counterpart (OR of 1.4). An OR of 2.1 was found for one vehicle operation grouping that included pedestrian conflicts with vehicles that were slowing, stopping, backing, accelerating from a standstill, or parking. Pedalcyclists were also found to be at an increased risk (OR of 1.7) from EPVs for all maneuver types and for higher speed maneuvers where both the vehicle and pedalcyclist were going straight (OR of 1.8). Weather, lighting, and posted speed limits were also analyzed.

A primary limitation of this work, as noted by the authors, is the low statistical power related to the relatively low number of EPVs on the road and the relatively low number of conflicts with pedalcyclists and pedestrians. Only 77 and 48 incidents were reported between EPVs and pedestrians and pedalcyclists, respectively (Hanna, 2009). Other limitations, as noted by the authors and others, stem from potential bias from, but not limited to, the following:

- The availability of data from only 12 of 50 states
- The probability that EPV ownership is disproportionately high in urban areas where most conflicts between vehicles and pedestrians/pedalcyclists occur
- Demographics such as age, income, and gender—In a 2009 analysis of insurance records from 359,309 vehicles, Quality Planning found that hybrid owners tend to be older, more affluent women who live in cities (Quality Planning, 2009).⁽⁸⁾
- Driver characteristics such as vehicle miles driven, traffic citations, and crash occurrence—Insurance records indicate that owners of HEVs drive 25% more miles and receive more traffic citations than owners of conventional vehicles. This may be due in whole or in part to the increased distance that HEV drivers travel or the fact that urban drivers typically receive more traffic citations.⁽⁸⁾

Quieter Cars and the Safety of Blind Pedestrians: Phase 1, Garay-Vega et al., April 2010⁽⁵⁾

The U.S. DOT's Research and Innovative Technology Administration (RITA) commissioned researchers at the John A. Volpe National Transportation Center to establish the groundwork for creating specifications for PEDSAFE countermeasures to address the apparent issue of elevated threat of pedestrian strikes by QVs. The three primary objectives of this work were to characterize the sounds made by conventional vehicles and EPVs under typical operating conditions, conduct juried evaluation of audible vehicle detection by visually impaired participants, and investigate potential countermeasures that might be used in PEDSAFE specifications.

To characterize vehicle sounds that visually impaired pedestrians might use to navigate through traffic, researchers first reviewed a variety of data sources to determine the following safety-critical scenarios where auditory cues are required:

- Vehicle traveling at a constant low speed
- Vehicle backing at 5 mph
- Vehicle driving parallel to the listener and slowing from 20 to 10 mph while preparing for a right turn
- Vehicle accelerating from a stop

- Stationary vehicle operation

Three vehicle pairs, each consisting of an EPV and a conventional “twin” vehicle, were used in the evaluation. These pairs included the Toyota Prius/Matrix, the Toyota Highlander HEV/ICE, and the Honda Insight/Civic. Digital recordings and acoustic measurements of sound pressure (dB(A); dB = decibel) and spectral (frequency) distribution were collected using the Society of Automotive Engineers (SAE) draft procedure “Measurements of Minimum Noise Emitted by Road Vehicles” with minor deviations to accommodate study goals related to the defined safety-critical scenarios rather than “minimum noise emitted.” The SAE standards primarily specify recording instrumentation locations and environmental conditions.

These tests indicate that EPVs operate much more quietly when stationary, backing, or operating at a constant low speed of 0–6 mph. Similar sound levels were measured for both types of vehicles when decelerating, accelerating from a stop, and when traveling at constant speeds from 10–20 mph. Much of the sound produced by the Toyota vehicles during deceleration originated from the vehicles’ regenerative braking systems and occurred at higher frequencies (5–10 kHz)—unlike those typically associated with ICE vehicle operation—and thus may be detectable but not recognized as vehicle sounds.

Juried evaluation of the audible detectability of vehicles was conducted for three vehicle operating conditions and two ambient-noise-level conditions in laboratory settings using recorded vehicle sounds. Forty-eight visually impaired participants with varying levels of debility rated two EP/ICE pairs (Prius/Matrix and Highlander/Highlander) operating in the following modes:

- Vehicle backing at 5 mph
- Vehicle decelerating from 20 to 10 mph
- Vehicle approaching at a constant speed of 6 mph

Ambient noise levels used for evaluation were chosen to emulate quiet rural and moderately noisy suburban conditions, and detection distance was used as an evaluation metric. The research did not evaluate whether detected sounds were recognized as originating from vehicles.

The primary findings of this work indicate that EPVs are, in most situations, harder to detect using sound, and elevated background noise levels decrease detection distances. An exception to this occurred where the higher pitched noise associated with regenerative braking was detected at a greater distance than were the ICE vehicles during slowing maneuvers.

In a third track of study, researchers conducted literature reviews to identify potential vehicle-based, infrastructure-based, and V2P (vehicle-to-person or vehicle-to-pedestrian communication) based countermeasures. These were reviewed based upon the type of information they provided, user acceptance, and factors associated with implementation. The key findings of this review are as follows:

- Infrastructure-based countermeasures are expensive and will likely take an extended time to implement due to constraints on capital investment.

- The visually impaired community heavily favors synthetic vehicle sounds that emulate ICE sounds, and they object to a dependence upon personal electronic devices as countermeasures.
- Reduction of ambient noise levels through regulation will likely take an extended time to implement and would be hard to enforce.
- Standardized vehicle-based auditory countermeasures that emulate ICE sounds at lower speeds (below 20 mph) and vary in pitch and sound level relative to travel speed and ambient (background) noise levels, respectively, appear to be the most promising method for addressing conflicts between the visually impaired and EPVs.

Assessing whether Quiet Electric and Hybrid Vehicles Pose a Safety Risk To the Vision Impaired, Morgan et al., Jan. 2011⁽⁹⁾

In this work performed by the Transport Research Laboratory in the United Kingdom, researchers analyzed accident statistics, measured noise levels from conventional vehicles and EPVs, and assessed sounds from moving vehicles with a jury of visually impaired participants.

Using crash statistics from England for the years 2005–2008, researchers compared the overall occurrence of crashes by EPVs and conventional vehicles based on registration numbers and crash type. They found that EPVs were 30% less likely to be involved in a crash than were conventional vehicles when all types of crashes were considered. EPVs and conventional vehicles were equally likely to strike pedestrians. When comparing the relative occurrence of crashes to those including pedestrian strikes they found that proportionately more (30%) EPVs were involved than were conventional vehicles. Researchers cited potential bias and reduced statistical power related to urban versus rural vehicle usage patterns and relatively low population size. The researchers made no attempts to categorize relative risk under different vehicle maneuver types.

Researchers measured the sound produced by four EPVs and four conventional vehicles under various operating conditions and found that, at low and constant speeds, EPVs were, on average, 1 dB(A) quieter than ICE-powered vehicles, with the exception of one ICE vehicle, which was quieter than its EPV counterpart. In general, the researchers found that EPVs and conventional vehicles had similar noise levels, except for exhaust noises and when starting from a stop; in those cases, conventional vehicles were louder.

In a third track of testing, researchers had 10 visually impaired persons rate sounds from EPVs and conventional vehicles under various vehicle operating and ambient conditions. Increased risk exposure was assessed based on audible detection and safe vehicle stopping distances. The researchers' findings indicate that, based on these criteria only, pedestrians are at 30% and 40% increased risk from EPVs in urban and semi-rural settings, respectively. The higher risk posed in urban settings stems from elevated background noise levels and the resulting shorter audible detection distances.⁽⁹⁾

Incidence Rates of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles: An Update, Wu et al., October 2011⁽¹⁰⁾

This study updates Hanna’s previous work (Hanna, 2009) with analysis of six additional states and newly available SDS data. Hanna’s and Wu’s analyses used crash data from 12 and 16 states, respectively, to characterize the comparative risks of pedestrian/pedalcyclist strike by conventional and EP vehicles for the available years of data, as shown in Table 1.

Table 1. Comparison of SDS States and Reporting Years Used in Hanna, 2009 and Wu, 2011^(7,10)

| State | Hanna (years) | Wu (years) |
|----------------|---------------|----------------------|
| Alabama | 2000–2006 | 2000–2008 |
| Florida | 2002–2007 | 2002–2007 |
| Georgia | 2000–2006 | 2000–2006 |
| Illinois | 2000–2005 | 2000–2008 |
| Kansas | 2001–2006 | 2001–2008 |
| Kentucky | | 2000–2007 |
| Maryland | 2000–2007 | 2000–2008 |
| Michigan | 2004–2006 | 2004–2007 |
| New Jersey | | 2004–2008 |
| New Mexico | 2001–2006 | 2001–2008 |
| North Carolina | 2000–2006 | 2000–2006 |
| North Dakota | | 2003–2008 |
| Pennsylvania | 2000–2005 | 2000–2001, 2003–2008 |
| Washington | 2002–2005 | 2002–2007 |
| Wisconsin | 2000–2006 | 2000–2008 |
| Wyoming | | 2000–2007 |

As in Hanna’s work, Wu analyzed only EPVs with shape-equivalent models (twins) in order to counter any biases from wind noise (which is highly dependent on body shape). The analysis included 1,025,287 HEVs and 24,297 ICE vehicles. Vehicles studied included model-year 2000 and later Honda Accords, Honda Civics, and Toyota Camrys. Although a non-hybrid shape-equivalent version of the Toyota Prius is not available, the study included the Prius because of its popularity and used the Toyota Corolla as its comparable twin. The study used essentially the same analysis methods as those used in Hanna, 2009, in which crash data were compared on speed, location, and vehicle maneuver types. However, unlike Hanna, Wu’s study did not characterize events across lighting and weather conditions.⁽¹⁰⁾

The results of Wu et al.’s work basically support Hanna’s earlier findings that pedestrians and pedalcyclists are at a statistically increased risk of strike by EPVs when compared to conventional vehicles. When all scenarios are considered for EPVs and their conventional counterparts, pedestrians and pedalcyclists are at a 35% and 57% increased risk from EPV strike (ORs of 1.25 and 1.57), respectively. If all light vehicles are considered, including those without EPV counterparts, EPVs were found to be 22% more likely to strike a pedestrian. As in Hanna’s

work, Wu et al. found that most pedestrian conflicts occurred at lower speeds, with ORs as high as 1.67 in some scenarios, and that the majority of pedalcyclist conflicts occurred at speeds above 35 mph with an OR of 1.67.⁽¹⁰⁾

Quieter Cars and the Safety of Blind Pedestrians, Phase 2: Development of Potential Specifications for Vehicle Countermeasure Sounds, Hastings, October 2011⁽²⁾

NHTSA commissioned this work as a continuation of Garay-Vega's 2010 work, and it was conducted under the premise that mandated countermeasures will likely be vehicle-based acoustic generators that produce ICE-like sounds at levels at or below those of a typical ICE car. Primary research tasks included evaluation of sounds produced by 10 representative ICE vehicles, analytical and juried evaluation of nine proposed acoustic countermeasures, and development of preliminary specifications for future countermeasures.

Hastings conducted acoustic monitoring of 10 representative ICE vehicles for five operational modes and eight conditions as described below:

- Engine start-up, vehicle stationary
- Engine idle, vehicle stationary
- Vehicle acceleration from 0–10 mph
- Vehicle pass by at constant speeds of 6, 10, 15, and 20 mph
- Vehicle reverse pass by at 6 mph

These test conditions, based on prior NHTSA program work, represented those in which pedestrians are most likely at risk from QVs. All auditory measurements were performed in a quiet neighborhood to isolate vehicle sounds. Ten typical ICE vehicles were chosen randomly for testing. These vehicles ranged from model years 2000–2009 and included mid-sized sedans, a small sport-utility vehicle (SUV), a pickup truck, and a popular minivan. Sound measurements were made using procedures taken from SAE's *J2889 Measurement of Minimum Noise Emitted by Road Vehicles, Revision 2009*, with numerous modifications. Sound level (dB-A) and spectral distribution were analyzed and corrected based on ambient noise levels.

Hastings evaluated nine countermeasure sounds provided by original equipment manufacturers (OEMs) either as part of a vehicle or as a separate countermeasure system or recording file. Countermeasures not already installed in a vehicle were implemented in an EPV for field evaluation. The same EPV was used to establish baseline conditions. Human participants, including some who were visually impaired, evaluated countermeasure sounds for detection distance and recognition at two broadcast sound pressure levels in an urban ambient setting on the Volpe Center grounds. The sound levels were based on the results of prior ICE sound measurement. Provided countermeasures were also recorded and analyzed for spectral content and other auditory characteristics, including psychoacoustics. The sounds varied widely in content and ranged from recordings of ICE sounds only to purely synthetic non-ICE sounds. A jurying process was used for the development and selection of most of the sound countermeasures proposed by OEMs.⁽²⁾

The results of this work indicate that, in general, the audible countermeasure sounds created using psychoacoustics principles and that included ICE-like sounds performed best when

considering detection distance and recognition as a vehicle. In general, synthetically generated audible alerts that included typical vehicle sounds within the range of 300 to 5000 Hz were most effective. Participants recognized sounds that emulated ICEs and ICEs themselves at equivalent distances. Synthetic sounds that were created using psychoacoustic principles were found to have longer detection distances (up to twice as far). Synthetic sounds that included only single elements of ICE noise (such as exhaust system sounds) did not perform well. Sound pressure level and frequency distribution can be adjusted to optimize detection, but recognition of a sound as coming from a vehicle depends heavily on more complex and subtle acoustic characteristics, such as rise and decay time, pitch variation, and phase relationships between individual sound components. In this evaluation, visually impaired jurors were not better able to detect vehicles using only audible cues than were sighted participants.

Hastings recommended that countermeasure specifications should include sound output level, variations in pitch indicative of motor or vehicle speed, and other psychoacoustically based sound qualities that affect recognition of the sound as that of a vehicle. Hastings also suggests that the directivity and annoyance level of countermeasure sounds be considered in future research and specifications.⁽²⁾

CHAPTER 3. CONTRIBUTING TRENDS

Increased Numbers of EPVs

EPV sales for calendar year 2011 totaled 286,565 units, or 2.25% of all light vehicles sold in the United States,⁽¹⁾ and a J.D. Powers and Associates projection of future markets predicts that EPVs will comprise as much as 3.5% of the U.S. market by 2015.⁽¹¹⁾

On January 27, 2012, CARB announced adoption of its new Advanced Clean Cars program to promote public health through lowered emissions of model year 2017–2025 cars and light trucks sold in California. This program establishes emission standards for greenhouse gases (GHGs) and smog-forming (criteria) pollutants such as oxides of nitrogen (NO_x) as well as requirements for establishing the infrastructure for commercial provision of clean fuels such as hydrogen. The vehicle emission standards established will necessitate utilization of an increased number of low emission vehicles (LEV) and ZEVs. As a result of these regulations, 1.4 million ZEVs are expected to be in operation in California by 2025, and dramatically increased numbers of LEVs—such as plug-in hybrid electric vehicles (PHEVs), BEVxs, and high-efficiency ICE vehicles—will be required to meet interim emission requirements as the transition to ZEVs occurs.⁽¹²⁾

This program will have a major impact on overall EPV utilization in the United States because California has established itself as a bellwether with respect to vehicle effects on health and the environment and related vehicle technology. Of course, projections of future sales of EPVs vary widely and depend heavily on economic factors, fuel prices, incentives, and regulatory mandates.

Using a predictive model for new technology adoption and Energy Information Administration (EIA) predictions of future energy costs, EIA projects that sales of EPVs will reach 3%, 18%, 45%, and 64% of all light-vehicle sales in the United States in the years 2015, 2020, 2025, and 2030, respectively.⁽¹³⁾ Other projections are more conservative, but even the more conservative analysts expect extensive growth in the EPV market.

Driver Distraction

Drivers are more distracted than ever. According to NHTSA, the primary driver distractions include texting, use of a mobile phone, eating and drinking, reading, grooming, and interacting with vehicle-based navigation or entertainment systems. To address some of these concerns, NHTSA recently released distraction guidelines for automakers: *Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices*.⁽¹⁴⁾ However, all indications are that, unless education and enforcement efforts become widespread and effective, driver distraction will continue to be a problem.

Pedestrian Distraction

Like drivers, pedestrians and pedalcyclists are increasingly subject to distraction from a variety of sources that include mobile phones, tablet computers, personal media players, navigational aids, and heads-up displays such as Google's highly anticipated Glass. Increased pedestrian distraction is likely to contribute to increased levels of strikes by vehicles. Pedalcyclists are

increasingly using personal audio devices while riding, which decrease their perception of audible cues around them.⁽¹⁵⁾ Independently of conflicts with vehicles, injury rates have increased dramatically for pedestrians as they multi-task while navigating the urban landscape.^(16,17)

Increased Traffic Congestion

As the human population and vehicle ownership-per-capita grows, increased demands are placed on transportation systems constrained by space and funding. At the same time, more travelers are riding bicycles and walking to avoid traffic congestion, decrease their costs and environmental footprints, and improve their health. This inevitably leads to a higher density of vehicles, pedestrians, and pedalcyclists and an increased opportunity for conflict amongst them.

Increased Ambient Noise Levels

Overall ambient noise levels in urban areas are increasing due to increased vehicle traffic and equipment use.^(18,19) There has been much concern related to the impact of ambient noise levels in urban settings, and evidence is mounting that human health issues such as stress, hearing loss, and disease occur more often or with greater severity as noise levels increase.^(19,20) Higher ambient noise levels lead to decreased vehicle detection distances for pedestrians and a decreased response time for drivers.⁽²¹⁾

CHAPTER 4. REGULATIONS AND STANDARDS

UNITED STATES

The Pedestrian Safety Enhancement Act of 2010 (PSEA), signed into law on January 4, 2011, directs the DOT to determine whether QVs pose increased risk to pedestrians and to address the issue, if warranted, through a NHTSA FMVSS by January 3, 2014. OEM compliance is to be phased in by September 1 of the third year following issuance of the final rule, or no later than September 1, 2017. The law further requires that NHTSA investigate and report to Congress by January 3, 2015, as to whether a corresponding FMVSS safety need exists with respect to conventional (non-EP) vehicles. If so, subsequent rulemaking will be required.⁽²²⁾

This legislation also requires that NHTSA establish performance requirements for an alert sound to be emitted from EPVs traveling at lower speeds, which would allow pedestrians to detect them. This alert system would be required on all new EPVs sold in the United States. The following aspects of the alert are required:

- The specified alert sound be recognizable as an operating motor vehicle.
- No driver intervention is required for activation (i.e., it is automatic).
- OEMs must be allowed to implement one or more alerts that comply with the standard.
- The OEM alerts must be the same amongst the same makes and models.
- OEMs may not provide methods for cancellation or alteration of the alert mechanism other than to rectify FMVSS compliance issues.
- NHTSA must consider any additional adverse noise created by this equipment that would impact communities.

In conformance with the National Environmental Policy Act (NEPA), NHTSA is required to consider the potential environmental impact associated with rulemaking, including the PSEA. As part of this assessment, NHTSA must scope related issues and alternative standards, which must include an option for no action. The following alternatives are currently under consideration.

- No action—This is the baseline condition where inaction on the part of NHTSA is considered in comparison to the other alternatives. This alternative may be acceptable in circumstances where the perceived problem is addressed by another agency, by OEMs, or by other methods such as new technology. However, because the PSEA specifically directs NHTSA to develop a PEDSAFE standard, the “no action” alternative is not realistically viable.
- Emission of recorded ICE sounds—In this scenario, recordings of conventional vehicles at various forward and reverse speeds would be emitted at certain speeds and in specific operating conditions. These recordings would include ICE sounds only because both conventional vehicles and EPVs produce recognizable noises such as those from tires and wind. This alternative has the advantage of providing pedestrians with a familiar sound that will be immediately recognizable as a vehicle. However, the small speakers likely to be used with any warning system might not adequately replicate the lower frequency tones that ICEs emit.
- Synthesized ICE sounds—Artificial ICE sounds would be electronically synthesized and emitted at levels no louder than those of a conventional vehicle. The pitch and volume of

the produced sound would vary with vehicle speed and operating mode. An engineered synthesized sound provides potentially advantageous psychoacoustic factors such as recognizability and detectability and may enable effective use at a lower overall sound (pressure) level.

- Synthesized non-ICE sounds—This psychoacoustically based alternative would be based on a synthetic sound constructed for optimum detectability and recognizability while minimizing annoyance and contribution to existing ambient noise pollution. Key elements of pitch, timing, variance, and loudness are specified for this alternative. Unlike previous alternatives, the sound produced need not necessarily emulate that of an ICE. Disadvantages of this alternative stem from the requirement for learned recognition because these sounds may not resemble those that pedestrians already innately associate with vehicles, and sounds may vary greatly between vehicles and manufacturers.
- Combination of synthesized ICE and non-ICE sounds—This alternative provides a potentially synergistic fusion of the previous two alternatives, in which ICE sound components are combined with synthetic non-ICE sounds to provide better psychoacoustic properties while allowing easy recognition of common ICE sounds. This alternative allows for optimization of both detection and recognition without the requirement for learning to associate new, non-ICE sounds with vehicles.

To provide a more coherent progression of intervention, these alternatives have been presented here in a different order than they appear in the Federal Register.⁽⁴⁾

JAPAN

In 2010 the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) and the Japan Automotive Standards Internationalization Center (JASIC) jointly issued guidelines for vehicle sounds. Their recommendations include the following:

- An alert should be required below 20 km/h (12.2 mph) and any time the vehicle is in reverse, but not when stopped.
- Temporary deactivation by driver should be allowed.
- The alert sound should be continuous and not sound like a siren, chime, bell, melody, horn, or nature sounds.
- The sound should vary in volume or tone with speed to indicate the vehicle's rate of approach.
- The sound should not exceed that of a typical ICE operated at 20 km/h.⁽²³⁾

WORLD

In March 2011, the World Forum for Harmonization of Vehicle Regulations of the United Nations Economic Commission for Europe (UNECE) adopted guidelines very similar to those adopted in Japan.⁽²³⁾

NON-GOVERNMENTAL ORGANIZATION (NGO) SUPPORT

The Alliance of Automobile Manufacturers Trade Association, BMW Group, Chrysler, Ford, GM, Jaguar Land Rover, Mazda, Mercedes-Benz, Mitsubishi Motors, Porsche, Toyota, and Volkswagen have all publicly announced support for the PSEA.

NOISE MEASUREMENT STANDARDS

Historically, automotive engineers have worked to minimize in-cabin noise levels and transportation engineers designed to mitigate the external effects of noise produced by high-speed traffic. The concern over sound emanating externally from vehicles during low-speed (approximately 0–20 mph) operation and associated standards for its measurement have been driven largely by the increased presence of EPVs on roadways and their perceived danger to pedestrians.

The Vehicle Sound for Pedestrians (VSP) subcommittee of SAE is working with the International Organization for Standardization (ISO) and has drafted SAE J2889-1 “Measurement of Minimum Noise Emitted by Road Vehicles.” This specification provides an engineering method for measuring the physical characteristics of noise emitted by vehicles given specific ambient (background) sound levels and test site environmental conditions. Sound pressure level, the frequency spectrum, and the variability of both are measured while psychoacoustic properties such as detectability, annoyance, and recognizability are not. ISO has also worked separately to develop a very similar standard, ISO/NP 16254 “Measurement of Minimum Noise Emitted by Road Vehicles.”⁽²³⁾

CHAPTER 5. PROPOSED COUNTERMEASURES

Proposed countermeasures that allow pedestrians and others to detect QVs for conflict prevention fall into three categories: vehicle-, infrastructure-, and pedestrian-based (personal). Some have proposed the use of wireless electronic devices that communicate with vehicles to alert at-risk pedestrians of approaching vehicles, whether conventional or EPV. This type of deployment is envisioned as part of the DOT's *Connected Vehicle* program. However, advocates for the visually impaired have effectively rejected any type of intervention that requires pedestrians to depend upon a personal electronic device for navigation through vehicular traffic. Infrastructure-based countermeasures require extended development and implementation time, as well as large capital investments that preclude their effective use. Advocates for the control of noise pollution have proposed a fourth alternative, which, though many view it as unrealistic, warrants mention: regulatory, technological, and other means could be used to decrease ambient noise levels enough to enable audible detection of EPVs. Given the difficulties of this option as well as of infrastructure- and pedestrian-based countermeasures, the vast majority of countermeasures developed thus far are vehicle-based and auditory. A survey of current vehicle-based audible alert countermeasure systems from OEMs and aftermarket vendors follows.

VEHICLE-BASED COUNTERMEASURE SYSTEMS

OEM Systems

As mentioned previously, auto makers have long recognized that countermeasures may be required to mitigate unacceptable risks associated with QV operation and the potential for pedestrian strikes. Recognizing that EPVs may present an increased risk to pedestrians, almost all manufacturers of these types of vehicles have developed some sort of pedestrian alerting system. Non-OEM aftermarket systems have also been developed. A brief survey of these systems follows.

Audi

In anticipation of the upcoming release of various EPV models, Audi has developed their “e-sound” system, which generates a varying synthetic ICE sound using inputs of electric motor speed and load, vehicle speed, and other parameters. Audi acoustic engineers looked to a variety of sources for inspiration, including science fiction film soundtracks. Audi plans to implement a unique countermeasure sound for each car model.⁽²⁴⁾

Fisker

Fisker is reportedly planning to use a sound generator for pedestrian warning with speakers in the bumpers that emanate a futuristic alert that sounds like a cross between a starship and a Formula One race car.^(25,26)

Ford

Ford Motor Company produces numerous hybrid vehicles for sale in the United States and has released its first BEV, the Focus. As part of its countermeasure development, Ford has taken the

unique approach of using its fans on the popular social networking site, Facebook, as jurors for evaluation of potential countermeasure sounds.⁽²⁷⁾

General Motors

GM equipped the EV-1 with an audible backup alarm and worked with the National Federation of the Blind to develop an audible countermeasure system for the Chevrolet Volt PHEV.⁽²⁸⁾ The Volt is equipped with a turn signal control that, when activated by the driver, emits a short pulse of the vehicle's standard horn.⁽⁴⁾

Honda

Although Honda has incorporated many pedestrian safety features in their vehicles with the goal of preventing and mitigating the effects of impact between human and vehicle, information was not found regarding their implementation of an audible pedestrian warning on their FCX Clarity hydrogen vehicle; the Insight, Civic, or CR-Z HEVs; or the Fit BEV.

Hyundai

The Hyundai Sonata hybrid is equipped with an audible alarm that operates whenever the ICE is not running and vehicle speed is less than 12 mph, independent of driver input. In an interesting turn of events, roll-out of the HEV was delayed for a few weeks so that Hyundai could remove the ability of the driver to disable the warning system. Hyundai decided to implement these changes on the assembly line rather than recall the early production vehicles.⁽²⁹⁾

Lotus - Harmon

Although Lotus Cars Ltd. currently offers no hybrid vehicles, their research arm, Lotus Engineering, is working jointly with Harmon Becker Automotive Systems to develop their "Halosonic" system, which uses Electronic Sound Synthesis and noise cancellation technology to minimize road and engine noises for passengers while simultaneously providing a warning sound to pedestrians. The synthesized warning sound varies with road speed, is projected through front or rear speakers depending on direction of motion, and produces an engine idle noise when the vehicle is on and stationary and the handbrake is released.⁽³⁰⁾

Nissan

The Leaf, an EV, is equipped with Nissan's VSP (Vehicle Sound for Pedestrians), which produces synthesized high-pitch whirring sounds that increase in volume as the vehicle accelerates and is active only below vehicle speeds of 20 mph. This synthesized sound comprises various components in the 600–2,500-Hz frequency range targeted for psychoacoustic recognition. A second, beeping sound is used when the vehicle is traveling backward. The Leaf was first released with the capability for the driver to disable the VSP, but Nissan has since removed that capability.^(23,26) The Infiniti M35 HEV is also equipped with Nissan's VSP.⁽³¹⁾

Tesla

While Tesla took an early lead in development of EPVs, the company has been relatively slow to develop pedestrian warning systems for their vehicles. In a letter dated August 11, 2011, commenting on NHTSA plans to prepare an Environmental Impact Statement for PEDSAFE rulemaking, Tesla clearly defines its objections to the addition of audible alarms to vehicles, arguing that they will only exacerbate existing noise pollution and decrease the allure of EPVs in an already challenging marketplace. They also state that they plan to conform to any NHTSA regulations for such systems.⁽³²⁾ No information was found describing Tesla's countermeasure development efforts to date.

Toyota/Lexus

In August 2010 Toyota released its "Approaching Vehicle Audible System" for sale and retrofit on third-generation Prius HEVs, in conformance with MLIT guidelines. The system emits an electronic motor sound that varies in pitch with speed and is automatically activated at speeds below 15.5 mph (25 km/h) and in reverse. The system costs 12,600 yen (about \$150) and can be disabled by the driver.^(33,34) A version of this system was released in the United States as the Vehicle Proximity Notification System (VPNS) in the Lexus CT200h and 2012 Prius models.⁽³⁵⁾ The VPNS relies upon inputs from the engine's electronic control unit, brake pedal, shifter, and other sources to produce a varying-pitch, synthetic, and speed-dependent sound consisting of high and low frequencies at sound pressure levels lower than those of typical ICE-powered vehicles.⁽³⁶⁾

Volvo

Volvo plans to release its first EPV, the V60 PHEV, in 2014. Plans for inclusion of an audible pedestrian alert system on this vehicle have not been announced, though the current V60 is equipped with an advanced pedestrian collision avoidance system with auto-braking based on radar and video sensors.⁽³⁷⁾ Volvo is notably sensitive to pedestrian safety and the potential impact of QVs on pedestrian safety, as evidenced by findings of a demonstration study carried out by Volvo and Vattenfall, a major utility provider in Europe.⁽³⁸⁾ Volvo engineers are also experimenting with various sound effects for their EPVs, though current efforts target passenger experience and aesthetics.⁽³⁹⁾

Aftermarket Systems

Enhanced Vehicle Acoustics Corporation, with support from the National Federation of the Blind and others, is currently evaluating their prototype PANDA system in California. Their system uses multiple external speakers to generate a directional audible alert at low speeds when the ICE is disabled.⁽⁴⁰⁾ The Danish company ECTunes proposes a similar solution and addresses concerns about noise pollution by citing the directional capabilities of the system.⁽⁴¹⁾

CHAPTER 6. ADDITIONAL CONSIDERATIONS

TRANSPORTATION TRENDS

Quieter Vehicles

Although ambient noise levels in urban areas are increasing, the noise produced by individual vehicles is decreasing. Prior to 1972, the sound level of vehicles in the United States was commonly 90 dB. The U.S. Federal-Aid Highway Act of 1970 and the Noise Control Act of 1972 directed the Federal Highway Administration (FHWA) and the Environmental Protection Agency to develop standards for mitigating highway traffic noise by requiring modern vehicles sold in the United States to meet the European noise limit of 78 dB-A.^(42,43) This 12-dB decrease in vehicle sound emission (on average) has resulted in more than a 50% reduction in perceived noise level since 1972. Noise has been reduced as manufacturers have improved exhaust systems and brakes and employed electric radiator fans and sound-insulating materials in engine compartments.

Additional noise reductions have resulted as increasingly stringent corporate average fuel economy (CAFE) standards and consumer demand have led manufacturers to improve vehicle aerodynamics and tire rolling efficiency, reducing wind and tire noise and potentially elevating the crossover point. As a result of these technical advances and regulations, some ICE (conventional) vehicles now operate more quietly than even their electrically propelled counterparts.⁽⁹⁾

Increasing Prevalence of QVs in Urban Areas

As vehicle operating costs and environmental awareness increase, travelers are looking more often to alternative modes of transportation. In urban areas, these factors, as well as concerns for regional air quality, increased traffic congestion, and parking limitations, have contributed to an increased utilization of smaller, more efficient vehicles, including EPVs, public transportation, and personal modes of transportation such as bicycles and walking. The combination of these trends has led to increased exposure of pedestrians to QVs of all types, including cars, rear-engine buses, bicycles, EP trolleys, and Segway[®]s.

Technology Advances

Vehicle-based crash avoidance systems are currently seeing increased usage on many high-end models and are expected to make their way onto even low-end models as costs decrease, consumer expectations rise, and safety regulations expand. Some currently available systems included protection for pedestrians through forward sensing and auto-braking. Pedestrians and pedalcyclists may receive additional protection by being included in FHWA-RITA's *Connected Vehicle* program. Transceivers carried by pedestrians and pedalcyclists could be used to notify oncoming drivers of the presence of at-risk individuals. The same system could be used to present notifications to pedestrians or pedalcyclists that QVs are present.

UNINTENDED CONSEQUENCES

Numerous unintended consequences and potential associated disbenefits may occur if audible pedestrian alert systems are implemented, as now seems likely. These may include the following:

- EPV drivers, formerly cautious in the knowledge that their vehicle is quiet, or new drivers of EPVs may feel a false sense of security if an alert is being broadcast, reducing their attentiveness to potential pedestrian conflicts.
- As currently proposed, most alerts would be disabled at speeds above the crossover point, or at about 20 mph. Knowing this, EPV drivers may tend to drive at higher speeds than they normally would have (without an alert system) in order to minimize annoyance to themselves or others.
- Pedestrians, particularly the visually impaired, may become overly reliant on the alerts, resulting in more risk when older (pre-alert) EPVs or other QVs are encountered, or when traveling in countries where no alerts are required.
- Some manufacturers and proponents of EPVs are concerned that audible pedestrian alert systems will detract from the allure of the vehicles and may decrease their sales and long-term adoption.⁽³²⁾
- Drivers of older, non-compliant EPVs or those owners temporarily or permanently disabling their alerts may be exposed to criminal or civil liability.
- EPV owners or their agents might “hack” their alert systems, resulting in non-standard and/or unacceptably loud sounds.

CHAPTER 7. OPPORTUNITIES FOR ADDITIONAL RELATED RESEARCH

SHRP 2 NATURALISTIC DRIVING STUDY

Collection of an extensive data set of on-road driving and other data from approximately 3,100 participants is ongoing as part of the Second Strategic Highway Research Program (SHRP 2) *Naturalistic Driving Study* (NDS). Driving data are collected from vehicles operating in six different locations: Seattle, WA; Bloomington, IN; Buffalo, NY; State College, PA; Durham, NC; and Tampa, FL. As of March 2012, data were being collected from 1,968 vehicles, including 240 EPVs comprising eight different models. Although the primary goals of this study are to provide a better understanding of driver behavior and crash causation, this wealth of data may potentially be used to answer a variety of research questions.

A comprehensive data set is being collected in support of the NDS. Kinematic and video driver performance data are acquired from participants' vehicles as are respective demographic, vehicle characteristic, driver functional health assessment, and crash investigation information. Further description of the extensive NDS data set is listed below.

- **Demographics**
 - Age
 - Gender
 - Ethnicity (cultural)
 - Country of birth
 - Race (physical)
 - Education
 - Marital status
 - Household composition and age distribution
 - Home ownership and years of residence
 - Work status and vocation
 - Income
 - Location (postal code)
 - Household vehicle number and yearly travel estimates
 - Age of driving licensure
 - Vehicle use for business (type and purpose)
- **Vehicle characteristics**
 - Vehicle identification number (useful for identifying propulsion system type)
 - Make, model, production year
 - Style/trim level
 - Body style
 - Exterior color
 - Safety features (antilock braking system [ABS], stability control, airbags, collision warning system, lane departure warning system, adaptive cruise control)
 - Infotainment features such as OEM-installed navigation systems or entertainment systems

- **Video** – Four channels of video are recorded continuously as described below.
 - Forward color with high resolution, glare reduction, and pixel count. This view accounts for approximately 50% of the video recorded by viewable area.
 - Three separate gray-scale views of the driver’s head, instrument panel, and rear view from within the vehicle cabin. Periodic views of the vehicle’s interior are also recorded.
- **Kinematic** – These data are collected continuously from installed instrumentation and OEM vehicle sensors and systems.
 - Global Positioning System (GPS) time, location, and heading
 - Vehicle position on roadway, lane marking type, and roadway geometry
 - Vehicle linear and rotational acceleration from accelerometers and gyroscopes
 - Location and relative approach rate of forward external objects using radar
 - Ambient light levels
 - Turn signal operation
 - Steering, brake, and horn input and the status of onboard safety systems such as ABS, seat belts, and air bags
- **Driver psychological/physiological assessments** – Measures the functional capabilities and limitations of participants prior to driving surveillance.
 - Executive function and cognition: the planning, initiation, sequencing, and monitoring of complex goal-directed behavior
 - Visual perception (light sensitivity, acuity, depth and color perception, peripheral vision)
 - Visual-cognitive: spatial relationships, central vision and processing speed, and divided/selective attention
 - Physical: lower limb strength and mobility, upper body strength
 - Psychomotor and cognitive: memory and reaction time, dementia
 - Personality factors: risk perception and aversion, attention deficit hyperactivity disorder, driving style and behavior, risk seeking
 - Sleep-related factors: sleep quality questionnaire
 - Use of medications
 - Illness: medical conditions
 - Driving knowledge: based on state driving requirements
 - Driving history
- **Crash investigation:** performed on crashes meeting specific thresholds of severity, location, setting, etiology, or technology involvement
 - Police accident reports
 - Participant interview, including sleep, fatigue, stress, and emotional state
 - Location
 - Setting, including roadway type, weather, traffic, and obstructions
 - Other contributory factors
 - Vehicle and crash site photographs

NDS-Related Potential Research Topics

The NDS provides an opportunity to learn more about the causation of conflicts between pedestrians/pedalcyclists and EPVs. Extensive data are being collected for at least 240 EPVs and

their drivers. These data include crash and near-crash epochs; video and kinematic data preceding, during, and subsequent to the epochs; and police reports of incidents. A comparison of this EPV-related data to corresponding data collected for non-EPVs could be used to determine whether EPVs present a greater risk to pedestrians/pedalcyclists and, if so, what the contributory factors are. Although the incidence of NDS vehicle conflict with pedestrians and pedalcyclists is likely to be infrequent, the data that can be garnered from even a statistically insignificant number of events may still provide a quantum leap in our understanding of these issues.

The literature indicates that many biases may exist in analyses done thus far to determine whether QVs present an increased risk to pedestrians and pedalcyclists. Data collected for the NDS may potentially be used to address these biases through better characterization of their impact on the outcome of previous research.

It has been posited that EPVs may be misrepresented in statistical analyses of the incidence of conflict with pedestrians and pedalcyclists because of the following factors:

- EPVs are used more in the urban areas where pedestrians and pedalcyclists might be encountered than is indicated by vehicle registration data.
- EPVs, on average, are driven more miles each year than are their ICE counterparts, potentially increasing exposure rates.
- EPVs, though commonly thought to be purchased by younger consumers, are actually used by an older population whose driving habits or capacities may contribute to conflicts with pedestrians and pedalcyclists.⁽⁴⁴⁾
- Drivers of EPVs may be affected by the absence of audible cues from the engine, causing them to exceed their intended speed.⁽⁴⁵⁾ Audible countermeasures that are disabled at speeds above the crossover point (approximately 20 mph) may also lead to increased speeds as drivers intentionally or subconsciously attempt to avoid countermeasure sound generation. Increased speeds of EPVs—especially those above the crossover point—may contribute to conflicts, especially those involving pedalcyclists. This issue might also be investigated independently of the NDS.

The demographic, vehicle characteristic, and kinematic data collected in support of the NDS could be mined to answer research questions related to these issues, allowing a better overall understanding of the unique safety issues presented by QVs.

OTHER QVS

Although advocates of the visually impaired have adamantly requested that EPVs be equipped with audible alert systems, pedestrian conflicts with QVs such as bicycles are common and perhaps an even greater threat than that presented by EPVs. Electric motorcycles, electrically assisted bicycles, and personal mobility devices such as the Segway[®] run almost silently and at high enough speeds to be a significant threat to unwary pedestrians. Even transit buses, quieter now and equipped with rear-mounted engines and vertical exhaust pipes 40 ft. from the front of the vehicle, present a threat to pedestrians, an issue publicized by the U.S. Federal Transit Administration in recent calls for research.

The combination of greater numbers and types of QVs, along with elevated levels of distraction by both drivers and pedestrians—and increased traffic density and ambient noise levels—will almost certainly lead to more frequent mutual conflict with associated damages, injuries, and, potentially, fatalities. A better understanding of the overall threat of all types of QVs to pedestrians and pedalcyclists is needed.

ASSISTANCE ANIMALS

NHTSA's development of a specification for auditory alert systems for FMVSS has primarily focused only on human physiology and psychoacoustics for detection and recognition of vehicle sounds, respectively.⁽²⁾ However, many visually impaired persons depend on the assistance of guide dogs for navigation through traffic. Some assistance animal and rehabilitation schools use HEVs or surrogate vehicles such as electric golf carts to train guide dogs to identify EPVs.⁽⁴⁶⁾ However, those working to develop audible alerts for QVs have not reported that the vastly different hearing physiology and psychoacoustic characteristics of guide dogs are being considered, possibly because of the assumption that canine hearing is better than that of humans. The relevance of guide dog response to audible alerts specified through FMVSS may require further investigation.

TIRE TECHNOLOGY

Tires are utilized on all modes of surface transportation (with the exception of rail), including potential QVs such as buses, electric motorcycles and scooters, bicycles, and Segways[®]. The opportunity exists for development of tires that emit distinctive sounds only at low speeds to provide auditory alerts to pedestrians and pedalcyclists. Sounds produced by rolling tires could vary both in amplitude and frequency to provide audible information on range and rate of approach. Tires are readily replaceable, which would allow for retrofit application.

EXCEEDING COUNTERMEASURE CROSSOVER SPEED

A vehicle's travel speed at which wind and tire noise predominates over other vehicle noises is known as the crossover point. It is widely held that this phenomenon occurs at approximately 20 mph. Most proposed auditory alert systems operate at lower speeds and cease at speeds above the crossover point to avoid nuisance noise. Vehicle noise increases substantially once the crossover speed is reached, so it is assumed that either sufficient noise will be generated to inform pedestrians and pedalcyclists of the vehicle's approach or that interaction with pedestrians is not likely. Whether consciously or subconsciously, drivers may tend to exceed the speed at which the alert system is disabled in order to minimize their exposure, or that of others, to the alert sound. This increase in vehicle speed may present elevated risks to the drivers, and others, that negate the safety gains the countermeasure system provides. This issue could be investigated alone, or concurrently with other research work such as the NDS, in a counterbalanced study design where participants drive vehicles with and without audible countermeasures while speed and other performance data are recorded and analyzed.

REFERENCES

1. Baum and Associates. (2012, January 12). *Sales Dashboard*. Retrieved January 17, 2012, from hybridcars.com: <http://www.hybridcars.com/news/december-2011-dashboard-sales-still-climbing-35093.html>
2. Hastings. (2011). *Quieter Cars and the Safety of Blind Pedestrians, Phase 2: Development of Potential Specifications for Vehicle Countermeasure Sounds*. NHTSA. Retrieved from <http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811496.pdf>
3. Nuckols, B. (2007). Blind people: hybrid cars pose hazard. USA Today, 3. Retrieved http://usatoday30.usatoday.com/money/economy/2007-10-03-2698183585_x.htm
4. Federal Register. (2011). *Federal Register*. Retrieved January 15, 2012, from Notice of Intent to Prepare an Environmental Assessment for Pedestrian Enhancement Act of 2010 Rulemaking: <http://www.federalregister.gov/articles/2011/07/12/2011-17341/notice-of-intent-to-prepare-an-environmental-assessment-for-pedestrian-safety-enhancement-act-of>
5. Garay-Vega, L. (2010). *Quieter Cars and the Safety of Blind Pedestrians: Phase I*. Washington, DC: NHTSA. Retrieved from <http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2010/811304rev.pdf>
6. USDOT. (2011, Jan. 6). *Fast Lane*. Retrieved January 15, 2012, from U.S. Dept of Transportation: <http://fastlane.dot.gov/2011/01/nhtsa-working-to-fulfill-psea-of-2010.html>
7. Hanna. (2009). *Incidence of Pedestrian and Bicyclist Crashes by Hybrid Passenger Vehicles*. Washington: National Center for Statistics and Analysis.
8. Quality Planning. (2009). *Hybrids: Is a Little of the Green Rubbing Off?* Retrieved from <http://www.qualityplanning.com/news/2009-articles/hybrids-is-a-little-of-the-green-rubbing-off-.aspx>
9. Morgan, P. A. (2011). *Assessing Whether Quiet Electric and Hybrid Vehicles Pose a Safety Risk to the Vision Impaired*. United Kingdom Department of Transport: Transport Research Laboratory. Retrieved from http://www.trl.co.uk/online_store/reports_publications/trl_reports/cat_road_user_safety/report_assessing_the_perceived_safety_risk_from_quiet_electric_and_hybrid_vehicles_to_vision-impaired_pedestrians_.htm
10. Wu, J. A. (2011). *Incidence Rates of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles: An Update. (DOT HS 811 526)*. Washington, DC: National Highway Traffic Safety Administration.

11. DiBenedetto, B. (2010, June 21). *J.D. Power: Hybrid and EV Cars Will Be 3.5% of Sales by 2015*. Retrieved Jan 19, 2012, from : <http://www.triplepundit.com/2010/06/j-d-power-hybrid-and-ev-cars-will-be-3-5-of-sales-by-2015/#ixzz0rVWnbR59>
12. California Air Resources Board. (2012). *Advanced Clean Cars - New Standards for Tommorrow's Cars*. Retrieved February 21, 2012, from http://www.arb.ca.gov/msprog/consumer_info/advanced_clean_cars/consumer_acc.htm
13. Becker, T. A. (2009). *Electric Vehicles in the United States - A New Model with Forecasts to 2030*. University of California, Berkeley, Center for Entrepreneurship & Technology. Berkeley: Center for Entrepreneurship & Technology.
14. NHTSA. (2012). *What Is Distracted Driving?* Retrieved March 5, 2012, from <http://www.distraction.gov/content/get-the-facts/facts-and-statistics.html>
15. de Waard, D., Edlinger, K., & Brookhuis, K. (2011, July 27). Effects of listening to music, and of using a handheld and handsfree telephone on cycling behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour*, 14(6), 626-637. Retrieved from <http://www.sciencedirect.com/science/article/pii/S1369847811000684>
16. Nasar, J., Hecht, P., and Werner, R. (2008). Mobile Telephones, distracted attention, and pedestrian safety. *Accident Analysis & Prevention*, 40(1), 69-75.
17. Richtel, M. (2010). *Forget Gum. Walking and Using the Phone is Risky*. Retrieved March 5, 2012, from Technology: <http://www.nytimes.com/2010/01/17/technology/17distracted.html>
18. Moudon, A. (2009). Real Noise from the Urban Environment: How Ambient Community Noise Affects Health and What Can Be Done About It. *American Journal of Preventive Medicine*, 37, 167-171.
19. Bluhm, G.N. (2004). Road traffic noise and annoyance – an increasing environmental health problem. *Noise & Health*, 43-49.
20. Fuhs, A. E. (2009). *Hybrid Vehicles: and the Future of Personal Transportation*. Boca Raton: CRC Press.
21. Garay-Vega, L.P. (2010). *Auditory Detectability of Hybrid Vehicles by Pedestrians who are Blind*. Volpe National Transportation Systems Center. Retrieved from http://ntl.bts.gov/lib/35000/35800/35870/GarayVega_AuditoryDetectability.pdf
22. GovTrack. (2011). *GovTrack.us*. Retrieved from Pedestrian Safety Enhancement Act of 2010: <http://www.govtrack.us/congress/bill.xpd?bill=s111-841>

23. NHTSA. (2011, July). Notice of Intent to Prepare an Environmental Assessment for Pedestrian Safety Enhancement Act of 2010 Rulemaking. *Docket No. NHTSA-2011-0100*. Washington, DC.
24. DesignBoom News. (2012). *Audi e-sound for electric cars*. Retrieved April 5, 2012, from <http://www.designboom.com/weblog/cat/16/view/20272/audi-e-sound-for-electric-cars.html>
25. The Economist. (2009). *The Sound of Silence*. Retrieved March 5, 2012, from http://www.economist.com/node/13606446?story_id=13606446
26. Motavalli, J. (2009). *Hybrid Cars May Include Fake Vroom for Safety*. Retrieved March 5, 2012, from The New York Times - Automobiles: http://www.nytimes.com/2009/10/14/automobiles/14hybrid.html?_r=3
27. Gordon-Bloomfield. (2011). *Ford to Facebook Fans: "How Should the 2012 Focus Electric Sound?"* Retrieved from Green Car Reports: http://www.greencarreports.com/news/1062410_ford-to-facebook-fans-how-should-the-2012-focus-electric-sound
28. O'Dell, J. (2009). *GM Says Volt Crew Working to Resolve 'Silent EV' Sound Safety Issue*. Retrieved March 5, 2012, from <http://www.autoobserver.com//2009/11/gm-says-volt-crew-working-to-resolve-silent-ev-sound-safety-issue.html>
29. Voelcker. (2011). *Hyundai Sonata Hybrid Delay: Deciding to Make it Make Noise, Always*. Retrieved from Green Car Reports: http://www.greencarreports.com/news/1055789_hyundai-sonata-hybrid-delay-deciding-to-make-it-make-noise-always
30. Harmon Becker Automotive Systems. (2012). *Halosonic™ Technology Makes Driving Safer and More Enjoyable*. Retrieved March 6, 2012, from <http://www.harman.com/EN-US/Newscenter/Pages/HALOSonicFeature.aspx>
31. Infiniti. (2012). *Infiniti M - Specs & Options*. Retrieved March 5, 2012, from Infiniti USA: http://www.infinitiusa.com/m/specs-options?next=M.Key_Features.Specs
32. Chen, J. (2011). *Letter: Comments to NHTSA Notice of Intent to Prepare an Environmental Assessment for Pedestrian Safety Enhancement Act of 2010 Rulemaking, 76 Red. Re. 40,860*. Washington, DC: Tesla Motors, Inc. Retrieved from <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDEQFjAA&url=http%3A%2F%2Fwww.regulations.gov%2FcontentStreamer%3FobjectId%3D090000648122e4c2%26disposition%3Dattachment%26contentType%3Dpdf&ei=pMp-UaPyBpOg0gHerYC4DQ&usg=AFQjCNFNEJWC3rzvKk9QpnLOUF9Rwec2TA&sig2=OfUPh1qfV4I6XQOZls15Ow&bvm=bv.45645796,d.dmQ&cad=rja>

33. Toyota Motor Corporation. (2010, August 24). *TMC to Sell Approaching Vehicle Audible System for Prius*. Retrieved March 15, 2012, from <http://www2.toyota.co.jp/en/news/10/08/0824.html>
34. Toyota Motor Corporation. (2012). *Approaching Vehicle Audible System*. Retrieved March 15, 2012, from http://www.toyota-global.com/innovation/safety_technology_quality/safety_technology/technology_file/active/audible.html
35. Club Lexus. (2012). *Lexus Announces Prices for 2012 Models*. Retrieved April 5, 2012, from http://www.clublexus.com/articles/news/lexus-announces-prices-for-2012-models.php?option=com_content&task=view&id=694&Itemid=155
36. Smith, D. (2011, September). *Vehicle Proximity Notification System*. Unknown: Toyota Technical Center. Retrieved from <http://www.slideshare.net/esqcommunications/vehicle-proximity-notification-system>
37. Volvo Car Corporation. (2010). *Volvo V60 - Model Year 2011*. Retrieved March 16, 2012, from <https://www.media.volvocars.com/global/enhanced/en-gb/Models/2011/V60/Model/Home.aspx>
38. Vattenfall, A.B. (2010). *Business Intelligence for E-Mobility*. Stockholm: Vattenfall Programme on Electricity to Vehicles.
39. Hammerschmidt, C. (2011). *Volvo Engineers Mull Over the Perfect Sound for E-Cars*. Retrieved March 16, 2012, from <http://www.eetimes.com/electronics-news/4230034/Volvo-engineers-mull-over-perfect-sound-for-e-cars>
40. Enhanced Vehicle Acoustics Corporation. (2008). *Product Solution*. Retrieved March 16, 2012, from <http://evacoust.startlogic.com/product.html>
41. ECTunes. (2011). *Warning Sound Systems*. Retrieved March 16, 2012, from <http://ectunes.com/p/products/electric-hybrid-cars>
42. Weiner WR, L. G. (1997). *Foundations of Orientation and Mobility* (2nd ed.). New York: AFB Press.
43. Federal Highway Administration. (1995). Retrieved June 29, 2012. *Highway Traffic Noise Analysis and Abatement Policy and Guidance*. Washington, DC: FHWA. Retrieved from <http://www.fhwa.dot.gov/environment/polguid.pdf>
44. HybridCars. (2006). *Profile of Hybrid Drivers*. Retrieved April 30, 2012, from <http://www.hybridcars.com/hybrid-drivers/profile-of-hybrid-drivers.html>
45. Evans. (1970). Speed Estimation from a Moving Automobile. *Ergonomics* 13, 219-230.

46. Flandez. (2007). Blind Pedestrians Say Quiet Hybrids Pose Safety Threat. *The Wall Street Journal*. Retrieved from <http://www.nfb.org/nfb/NewsBot.asp?ID=150&MODE=VIEW>

BIBLIOGRAPHY

- American Association of State Highway and Transportation Officials. (2004). *Guide for the Planning, Design, and Operation of Pedestrian Facilities, 1st Edition*. Washington, D. C.
- Association for Education and Rehabilitation of the Blind and Visually Impaired. (2006, September 18). *Resolution 2004 - Quiet vehicles*. Retrieved March 22, 2012, from AERBVI.org:
<http://quietcars.nfb.org/2004%20AER%20resolution%20Quiet%20cars.htm>
- Baum and Associates. (2012, January 12). *Sales Dashboard*. Retrieved January 17, 2012, from hybridcars.com: <http://www.hybridcars.com/news/december-2011-dashboard-sales-still-climbing-35093.html>
- Becker, T. A. (2009). *Electric Vehicles in the United States - A New Model with Forecasts to 2030*. University of California, Berkely, Center for Entrepreneurship & Technology. Berkely: Center for Entrepreneurship & Technology.
- Bluhm, G. N. (2004). Road traffic noise and annoyance-an increasing environmental health problem. *Noise & Health*, 43-49.
- Boyd, C. (2011, June 27). *Adding Sounds to the Silence of Electric Cars*. Public Radio International. Retrieved from The World: <http://www.theworld.org/2011/06/adding-noise-to-electric-cars/>
- California Air Resources Board. (2012). *Advanced Clean Cars - New Standard's for Tommorrow's Cars*. Retrieved February 21, 2012, from http://www.arb.ca.gov/msprog/consumer_info/advanced_clean_cars/consumer_acc.htm
- Chen, J. (2011). Letter: Comments to NHTSA Notice of Intent to Prepare and(sic) Environment(sic) Assessment for Pedestrian Safety Enhancement Act of 2010 Rulemaking, 76 Red. Re. 40,860. Washington, DC: Tesla Motors, Inc. Retrieved from <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDEQFjAA&url=http%3A%2F%2Fwww.regulations.gov%2FcontentStreamer%3FobjectId%3D090000648122e4c2%26disposition%3Dattachment%26contentType%3Dpdf&ei=pMp-UaPyBpOg0gHerYC4DQ&usg=AFQjCNFNEJWC3rzv>
- Club Lexus. (2012). *Lexus Announces Prices for 2012 Models*. Retrieved April 5, 2012, from http://www.clublexus.com/articles/news/lexus-announces-prices-for-2012-models.php?option=com_content&task=view&id=694&Itemid=155
- de Waard, D., Edlinger, K., & Brookhuis, K. (2011, July 27). Effects of listening to music, and of using a handheld and handsfree telephone on cycling behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour*, 14(6), 626-637. Retrieved from <http://www.sciencedirect.com/science/article/pii/S1369847811000684>

- DesignBoom News. (2012). *Audi e-sound for electric cars*. Retrieved April 5, 2012, from <http://www.designboom.com/weblog/cat/16/view/20272/audi-e-sound-for-electric-cars.html>
- DiBenedetto, B. (2010, June 21). *J.D. Power: Hybrid and EV Cars Will Be 3.5% of Sales by 2015*. Retrieved Jan 19, 2012, from TriplePundit: <http://www.triplepundit.com/2010/06/j-d-power-hybrid-and-ev-cars-will-be-3-5-of-sales-by-2015/#ixzz0rVWnbR59>
- Droll JA, K. T. (2009). An analysis of low-speed pedestrian crashes involving electric-powered and combustion-powered vehicles. *Human Factors and Ergonomics Society 53rd Annual Meeting Proceedings 53(27)* (p. 202). Human Factors and Ergonomics Society.
- ECTunes. (2011). *Warning Sound Systems*. Retrieved March 16, 2012, from <http://ectunes.com/p/products/electric-hybrid-cars>
- Emerson, R. W. (2008). Detecting Approaching Vehicles at Streets with No Traffic Control. *Journal of Visual Impairment and Blindness, 102(12)*, 747-760.
- Enhanced Vehicle Acoustics Corporation. (2008). *Product Solution*. Retrieved March 16, 2012, from <http://evacoust.startlogic.com/product.html>
- Evans. (1970). Speed Estimation from a Moving Automobile. *Ergonomics 13*, 219-230.
- Federal Highway Administration, 1995. Retrieved June 29, 2. f. (1995, June 29). *Highway traffic noise analysis and abatement policy and guidance*. Washington, DC, USA: FHWA. Retrieved from <http://www.fhwa.dot.gov/environment/polguid.pdf>
- Federal Register. (2011). *Federal Register*. Retrieved 1 15, 2012, from Notice of Intent to Prepare an Environmental Assessment for Pedestrian Enhancement Act of 2010 Rulemaking: <http://www.federalregister.gov/articles/2011/07/12/2011-17341/notice-of-intent-to-prepare-an-environmental-assessment-for-pedestrian-safety-enhancement-act-of>
- Flandez. (2007). Blind Pedestrians Say Quiet Hybrids Pose Safety Threat. *The Wall Street Journal*. Retrieved from <http://www.nfb.org/nfb/NewsBot.asp?ID=150&MODE=VIEW>
- Fuhs, A. E. (2009). *Hybrid Vehicles and the Future of Personal Transportation*. Boca Raton: CRC.
- Garay-Vega, L. (2010a). *Quieter Cars and the Safety of Blind Pedestrians: Phase I*. Washington, DC: NHTSA. Retrieved from <http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2010/811304rev.pdf>
- Garay-Vega, L. P. (2010b). *Auditory Detectability of Hybrid Vehicles by Pedestrians who are Blind*. Volpe National Transportation Systems Center. Retrieved from http://ntl.bts.gov/lib/35000/35800/35870/GarayVega_AuditoryDetectability.pdf

- Goodes, P. (2009). *Investigation into the Detection of a Quiet Vehicle by the Blind Community and the Application of an External Noise Emitting System (2009-01-2189)*. SAE International. Retrieved from http://www.soundanswers.net/Tech_Papers/SAE%202009-01-2189.pdf
- Gordon-Bloomfield. (2011). *Ford to Facebook Fans: "How Should the 2012 Focus Electric Sound?"* Retrieved from Green Car Reports: http://www.greencarreports.com/news/1062410_ford-to-facebook-fans-how-should-the-2012-focus-electric-sound
- GovTrack. (2011). *GovTrack.us*. Retrieved from Pedestrian Safety Enhancement Act of 2010: <http://www.govtrack.us/congress/bill.xpd?bill=s111-841>
- Hammerschmidt, C. (2011). *Volvo Engineers Mull Over the Perfect Sound for E-Cars*. Retrieved March 16, 2012, from <http://www.eetimes.com/electronics-news/4230034/Volvo-engineers-mull-over-perfect-sound-for-e-cars>
- Hanna, R. (2009). *Incidence of Pedestrian and Bicyclist Crashes by Hybrid Passenger Vehicles*. Washington: National Center for Statistics and Analysis.
- Harmon Becker Automotive Systems. (2012, 3 6). *Halosonic™ Technology Makes Driving Safer and More Enjoyable*. Retrieved 3 6, 2012, from <http://www.harman.com/EN-US/Newscenter/Pages/HALOSonicFeature.aspx>
- Hastings. (2011). *Quieter Cars and the Safety of Blind Pedestrians, Phase 2: Development of Potential Specifications for Vehicle Countermeasure Sounds*. NHTSA. Retrieved from <http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811496.pdf>
- Holzman, D. C. (2011). Vehicle Motion Alarms: Necessity, Noise Pollution, or Both? *Environmental Health Perspective*, 119, 30-33. Retrieved from <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3018517/>
- Hoogeveen, L. (n.d.). *A Silent Future Research - Road Traffic Safety of Silent Electric Vehicles*. Retrieved from <http://igitur-archive.library.uu.nl/student-theses/2011-1004-201437/L.V.J.%20Hoogeveen%203315592.pdf>
- HybridCars. (2006). *Profile of Hybrid Drivers*. Retrieved April 30, 2012, from <http://www.hybridcars.com/hybrid-drivers/profile-of-hybrid-drivers.html>
- Infiniti. (2012). *Infiniti M - Specs & Options*. Retrieved 3 5, 2012, from Infiniti USA: http://www.infinitiusa.com/m/specs-options?next=M.Key_Features.Specs
- Japanese Automobile Standards Internationalization Centre. (2009). *A Study on Approach Warning Systems for Hybrid Vehicle in Motor Mode. 49th World Forum for Harmonization of Vehicle Regulation (WP.29), Working Group on Noise (GRB)-49*.

- Manning, R. (2010). *Audible detection of approaching hybrid and petrol powered vehicles in the urban environment*. RACQ vehicle Technologies. Retrieved from http://www.racq.com.au/__data/assets/pdf_file/0017/57212/Noise_testing_report.pdf
- Morgan, P. A. (2011). *Assessing whether Quiet Electric and Hybrid Vehicles Pose a Safety Risk to the Vision Impaired*. United Kingdom Department of Transport: Transport Research Laboratory. Retrieved from <http://www.google.com/url?sa=t&rct=j&q=assessing%20whether%20quiet%20electric%20and%20hybrid%20vehicles%20pose%20a%20safety%20risk%20to%20the%20vision%20impaired&source=web&cd=1&ved=0CBsQFjAA&url=http%3A%2F%2Fassets.dft.gov.uk%2Fpublications%2Fassessing-t>
- Motavalli. (2010, June 17). *Wheels*. Retrieved 15, 2012, from The New York Times: <http://wheels.blogs.nytimes.com/2010/06/17/blind-advocates-disappointed-in-nissan-e-v-sounds-for-pedestrians/?ref=automobiles>
- Motavalli, J. (2009, 10 13). Hybrid Cars May Include Fake Vroom for Safety. Retrieved 3 5, 2012, from *The New York Times - Automobiles*: http://www.nytimes.com/2009/10/14/automobiles/14hybrid.html?_r=3
- Motavalli, J. (2010, June 21). *Anti-Noise Activists Oppose Sounds for Electric Cars*. Retrieved July 2, 2010, from New York Times -Wheels: <http://wheels.blogs.nytimes.com/2010/06/21/anti-noise-activists-oppose-sounds-for-electric-cars/?scp=9&sq=warning%20sound%20electric%20car&st=cse>
- Moudon, A. (2009). Real Noise from the Urban Environment: How Ambient Community Noise Affects Health and What Can Be Done About It. *American Journal of Preventive Medicine*, 37, 167-171.
- Nasar, J., & Peter Hecht, R. W. (2008). Mobile telephones, distracted attention, and pedestrian safety. *Accident Analysis & Prevention*, 40(1), 69-75.
- National Federation for the Blind. (2011, Oct. 3). *Blind People: Hybrid Cars Pose Hazard*. Retrieved Jan 19, 2012, from National Federation for the Blind: <http://www.nfb.org/nfb/NewsBot.asp?MODE=VIEW&ID=222>
- National Federation of the Blind. (2012). *Committee on Automobile and Pedestrian Safety/Quiet Cars*. Retrieved February 21, 2012, from <http://quietcars.nfb.org/>
- National Highway Traffic Safety Administration. (2008, June 23). Sound Measurement and Mobility. *Transcript of the Quiet Cars Public Meeting Docket ID NHTSA-2008-0108-0023*, 53-65. Retrieved from <http://www.regulations.gov/contentStreamer?objectId=0900006480e79548&disposition=attachment&contentType=pdf>
- NHTSA. (2011, July). Notice of Intent to Prepare an Environmental Assessment for Pedestrian Safety Enhancement Act of 2010 Rulemaking. *Docket No. NHTSA-2011-0100*. Washington, DC.

- NHTSA. (2012). *What is Distracted Driving*. Retrieved 3 5, 2012, from <http://www.distracted.gov/content/get-the-facts/facts-and-statistics.html>
- Nyeste. (2008). On Adding Sound to Quiet Vehicles. *Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting - 2008*. Retrieved from http://www.hfes.org/web/HFESNews/HFES08_Sound_Quiet_Vehicles.pdf
- O'Dell, J. (2009, 11 25). *GM Says Volt Crew Working to Resolve 'Silent EV' Sound Safety Issue*. Retrieved 3 5, 2012, from <http://www.autoobserver.com//2009/11/gm-says-volt-crew-working-to-resolve-silent-ev-sound-safety-issue.html>
- Quality Planning. (2009). *Hybrids: Is a Little of the Green Rubbing Off*. Retrieved from <http://www.qualityplanning.com/news/2009-articles/hybrids-is-a-little-of-the-green-rubbing-off-.aspx>
- Rakauskas, M. R. (2011). *Development of Mobile Accessible Pedestrian Signals (MAPS) for Blind Pedestrians at Signalized Intersections*. Retrieved from <http://www.its.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=1552>
- Richtel, M. (2010, 1 16). *Forget Gum. Walking and Using the Phone is Risky*. Retrieved 3 5, 2012, from Technology: <http://www.nytimes.com/2010/01/17/technology/17distracted.html>
- Rosenblum, L. (2008, April 28). *Hybrid Cars Are Harder to Hear*. Retrieved from University of California, Riverside - Newsroom: <http://newsroom.ucr.edu/1803>
- Salomon, W. (2001). Improving the operating safety of shared-use pathways. In Local Government Road Safety Conference, 5th, 2001, Sydney (pp. 52-7). *Local Government Road Safety Conference, 5th,,* (pp. Salomon, W. (2001). Retrieved from <http://www.jcu.edu.au/soc/bug/resources/Salomon%20-%20Shared%20use%20pathways%20PRINT.pdf>
- Smith, D. (2011, September). *Vehicle Proximity Notification System*. Toyota Technical Center. Retrieved from <http://www.slideshare.net/esqcommunications/vehicle-proximity-notification-system>
- The Economist. (2009, 5 7). *The Sound of Silence*. Retrieved 03/05/2012, from http://www.economist.com/node/13606446?story_id=13606446
- Toyota Motor Corporation. (2010, August 24). *TMC to Sell Approaching Vehicle Audible System for Prius*. Retrieved 3 15, 2012, from <http://www2.toyota.co.jp/en/news/10/08/0824.html>
- Toyota Motor Corporation. (2012). *Approaching Vehicle Audible System*. Retrieved March 15, 2012, from http://www.toyota-global.com/innovation/safety_technology_quality/safety_technology/technology_file/active/audible.html

- USDOT. (2011, Jan. 6). *Fast Lane*. Retrieved 1 15, 2012, from US Dept of Transportation: <http://fastlane.dot.gov/2011/01/nhtsa-working-to-fulfill-psea-of-2010.html>
- Van Allen, F. (2012). *Your First Electric Car Will Sound Like a Gas Guzzler*. Retrieved April 5, 2012, from <http://news.yahoo.com/blogs/technology-blog/first-electric-car-sound-gas-guzzler-172541603.html>
- Vattenfall AB. (2010). *Business Intelligence for E-Mobility*. Stockholm: Vattenfall Programme on Electricity to Vehicles. Retrieved from http://www.vattenfall.com/en/file/content/2011_E-mobility_Chronicle_19988279.pdf
- Voelcker. (2011). Hyundai Sonata Hybrid Delay: Deciding to Make it Make Noise, Always. Retrieved from *Green Car Reports*: http://www.greencarreports.com/news/1055789_hyundai-sonata-hybrid-delay-deciding-to-make-it-make-noise-always
- Volvo Car Corporation. (2010). *Volvo V60 - Model Year 2011*. Retrieved March 16, 2012, from <https://www.media.volvocars.com/global/enhanced/en-gb/Models/2011/V60/Model/Home.aspx>
- Wadha, L. C. (2003, January 16). *Roundabouts and Pedestrians with Visual Disabilities: How Can We Make Them Safer?* Washington, DC, USA. Retrieved from <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDQQFjAA&url=http%3A%2F%2Fwww.k-state.edu%2Froundabouts%2Fresearch%2FROUNDBABOUTS%2520AND%2520PEDESTRIANS%2520WITH%2520VISUAL%2520DISABILITIES.doc&ei=oMt-Uee7BYjo0gGMsIGABw&usg=AFQjCNGxtyv>
- Wall Emerson, R. N. (2011). A pilot study of pedestrians with visual impairments detecting traffic gaps and surges containing hybrid vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour* 14.2, 117–127.
- Weiner W. R. (1997). *Foundations of Orientation and Mobility* (2nd ed.). New York: AFB Press.
- Wiener W. R., (2006). The impact of hybrid vehicles on street crossings. *RE:view. v38:65–78. Rehabilitation and Education for Blindness and Visual Impairment*, 38, 65-78.
- Wiener W. R. (1997). Audition for the traveler who is visually impaired. (W. W. Welsh R, Ed.) *Foundations of Orientation and Mobility. 2nd ed*, 104–169.

- Wogalter, M. O. (2001). On the risk of quiet vehicles to pedestrians and drivers. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting* (pp. 1685-1688). Raleigh, NC: Department of Psychology North Carolina State University 27695-7801 USA. Retrieved from http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CDQQFjAA&url=http%3A%2F%2Ffaculty.piercecollege.edu%2Fflimrw%2FHFES2001.pdf&ei=N89-UfnyMKLF0QGk-IHgCQ&usg=AFQjCNEcB_4Fem8bntaMTuDF39VBX4aaXw&sig2=oPXIjyOtKISItLYxPqOKFw&bvm=bv.4564
- Wu, J. A. (2011). Incidence Rates of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles: An Update. (DOT HS 811 526). Washington, DC: National Highway Traffic Safety Administration.