Quieter Cars and the Safety of Blind Pedestrians:

A Research Plan

April 2009

Executive Summary

Background

Representatives of organizations for the blind community have expressed concern that the proliferation of new propulsion technologies, such as those used in all-electric or hybrid electric vehicles (HEV), can negatively affect pedestrian safety, especially blind pedestrians. At low to moderate speeds, these vehicles are relatively quiet and therefore make it difficult for blind pedestrians to hear approaching vehicles since they depend on sound cues to detect them. After learning of this problem, NHTSA began working through the SAE to learn more about the problem and identify ways to address the safety issue. In June 2008, the National Highway Traffic Safety Administration (NHTSA) held a public meeting of interested stakeholders to discuss the safety of blind pedestrians encountering quieter cars and the relevant technical and safety policy issues. At the conclusion of the meeting NHTSA agreed to establish a docket for information on the issue and draft a research plan that it would share with the National Federation of the Blind and the auto companies before it was finalized. NHTSA developed this plan to fully examine this safety concern and to identify how to minimize risks to blind pedestrians.

Goals and Objectives

The goals of this plan are to examine the blind pedestrian safety risk associated with quieter cars, to identify possible countermeasures, and evaluate their potential effectiveness and acceptability. To address these goals, the following objectives are proposed:

1. Characterize the safety problem
2. Identify requirements for blind pedestrians' safe mobility (emphasizing acoustic cues from vehicles and ambient conditions)
3. Identify potential countermeasures and describe their advantages and disadvantages

Key Tasks

1. Identify critical safety scenarios where pedestrian vehicle-conflicts are likely to occur
2. Identify blind pedestrian mobility needs and the acoustic cues needed for safe pedestrian travel
3. Review test procedure for acoustic measurement of vehicles developed by the Society of Automotive Engineers (SAE) and adapt as needed
4. Measure acoustic parameters for a sample set of vehicles and ambient sound for critical safety scenarios
5. Measure pedestrian response to vehicle acoustic parameters under various ambient conditions
6. Identify potential countermeasures in addition to acoustic options
7. Review potential countermeasures to identify strengths and limitations

Figure 1 shows the objectives, key tasks, task sequence and interaction with activities of interested organizations. The key tasks are summarized below. Additional description is included in this plan. Figure 2 shows the task timeline.

First, critical safety scenarios where pedestrian-vehicle conflicts are likely to occur will be identified (Task 1). A critical scenario is defined as the range of facilities and conditions under which the safety of blind pedestrians could be affected by quieter vehicles. This includes for example, interactions with vehicles approaching at low speeds in a parking lot or a vehicle backing out of a driveway. Crash data analyses, information exchange with orientation and mobility instructors and blind pedestrians, and information from organizations for the blind community would facilitate the identification of scenarios for testing.

Mobility needs for blind pedestrians with emphasis on acoustic information needed for independent travel will be examined (Task 2). Information exchange with orientation and mobility instructors, cognitive walkthroughs, and review of existing literature will provide information on the use of traffic sound for independent travel. This information will be used to identify variables to be examined and controlled in the studies to evaluate this safety issue. The evaluation includes acoustic measurement of vehicles and ambient sound, and measurement of pedestrian response to the acoustic characteristics in various scenarios.

NHTSA will review the draft test procedure for acoustic measurement of vehicles proposed by SAE. NHTSA will adapt it or identify alternative procedures as needed to allow for data collection that can be used to examine pedestrian responses in critical scenarios (Task 3). The test procedure will specify operating conditions that will mimic vehicle emissions associated with critical safety scenarios. An acoustic measurement test procedure will also contain provisions for measuring the ambient sound levels that are typical for critical safety scenarios. Once a test procedure is identified, acoustic parameters for vehicles and ambient sound will be measured (Task 4) in a subset of critical scenarios. Acoustic measurement will be used to quantify the acoustic characteristics, including overall sound level and spectral shape of a sample set of vehicles and ambient conditions. Vehicles would include, for example, hybrid electric vehicles and their internal combustion engine (ICE) counterparts (for example: Honda Civic (HEV/ICE), Ford Escape (HEV/ICE)). The Toyota Prius will also be included.

Acoustic measurement will provide acoustic recordings suitable for human performance testing in a laboratory setting. Human performance testing will evaluate pedestrian response to acoustic parameters of vehicles and ambient sounds for critical safety scenarios (Task 5). Participants will listen to binaural recordings of the sounds that various vehicles make with realistic urban sounds superimposed. This task will document the acoustic parameters that allow for detection, recognition, and localization of vehicles in critical safety scenarios.

Pedestrian response in critical scenarios, existing regulations, and practical constraints will be considered to identify potential countermeasures including technology and acoustic options (Task 6). The most promising options will be identified and a review of these countermeasures including their strengths and limitations will be completed (Task 7).

The results of this effort are expected to provide a basis for understanding the significance of the current and future safety concern and identify information gaps that need to be addressed to determine what actions are necessary to assure that the safety of blind pedestrians will not be compromised in the future by quieter vehicles.

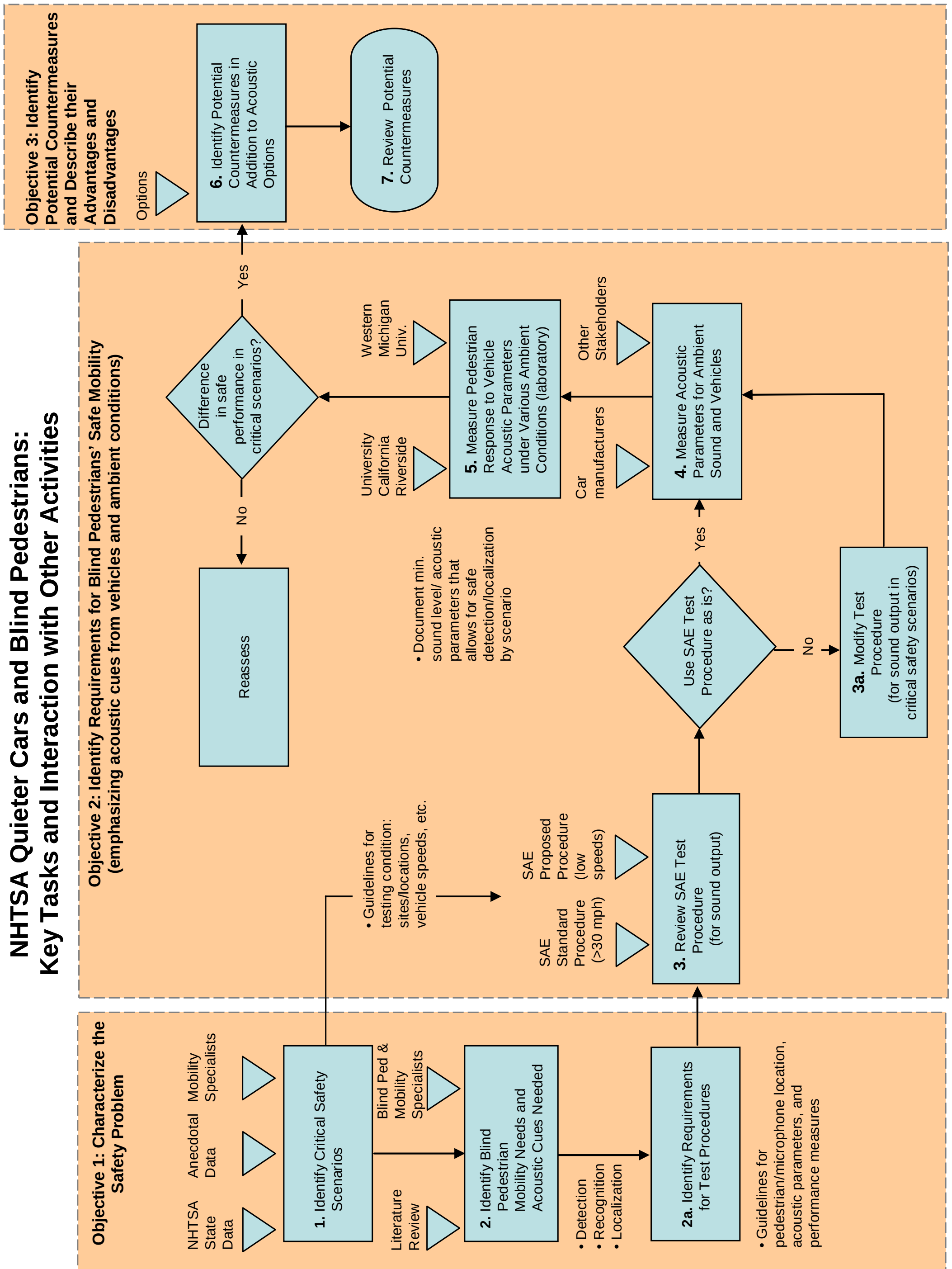

Figure 1 Project tasks and interaction with activities of outside organizations.

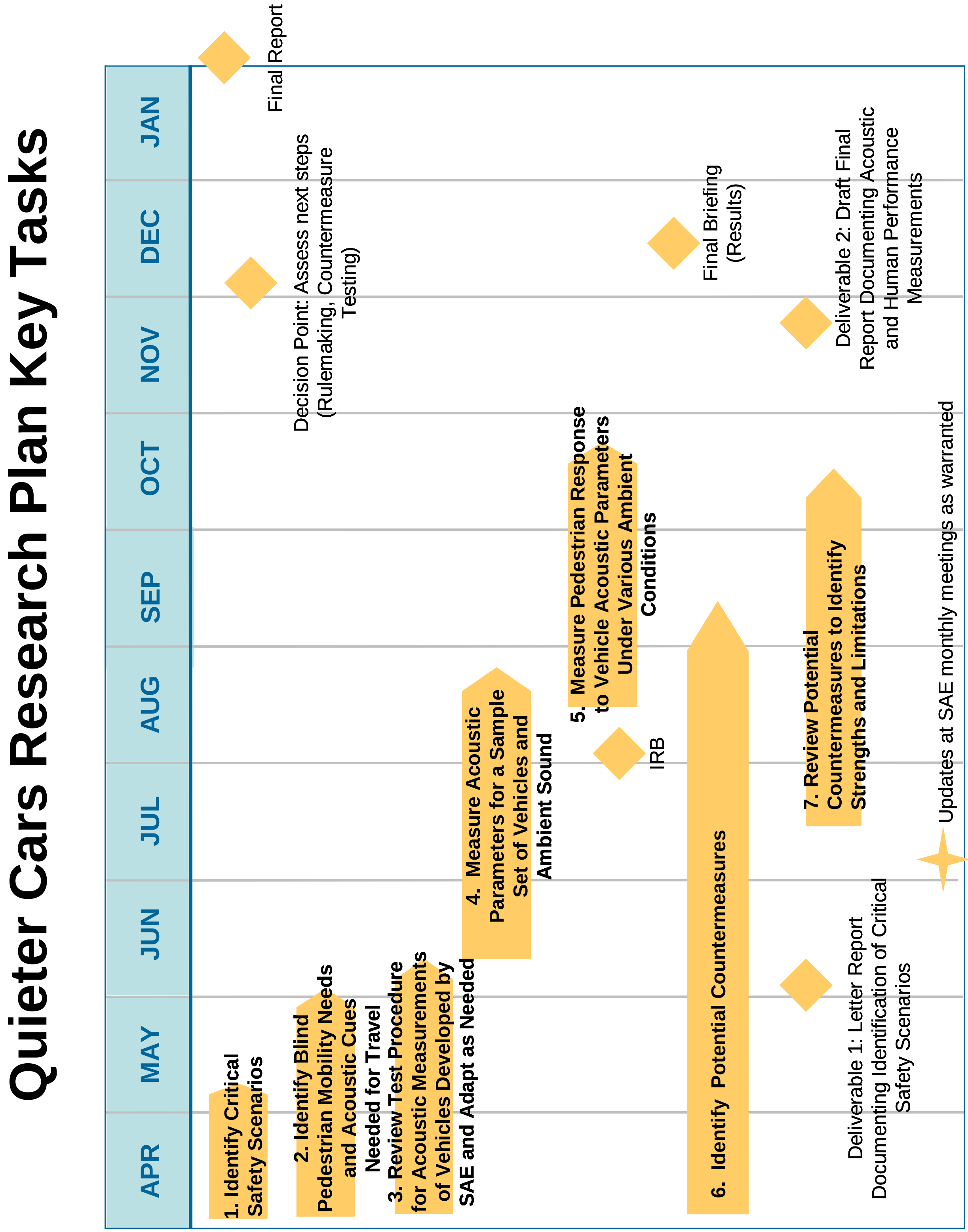

Figure 2 Quieter Cars Research Plan: key tasks and timeline.

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1. Introduction

The increasing use of vehicle propulsion technologies using all-electric or hybrid electric motors has generated concern by advocates for the blind community about blind pedestrian safety. When these vehicles operate at low to moderate speeds, they produce minimal sounds. This quieter sound profile may have an adverse effect on the safety of blind pedestrians because they must depend on sound cues to help them navigate. This research plan describes the initial actions to be undertaken by the National Highway Traffic Safety Administration (NHTSA) to more fully examine this safety issue and to identify how to minimize the risks. The research plan is focused on examining the safety of blind pedestrians.

This plan provides background on the overall issue as well as the topics that need to be examined to better understand the complexity of the issue. In addition, the plan identifies specific tasks to be accomplished to achieve the goals of this plan including considerations for the design and evaluation of potential solutions.

This plan includes input from personnel with expertise in human factors, acoustic measurements, and cost-benefit assessment to identify issues and make recommendations for how these issues should be addressed. The plan also considered the input provided by interested parties at the Public Meeting held on June 23, 2008 and to the docket “Quiet Cars-Notice and Request for Comments.”

2. Background

Representatives of organizations for the blind community have expressed concern that the proliferation of new quieter propulsion technologies, such as those used in all-electric or hybrid electric vehicles (HEVs), can negatively affect pedestrian safety, especially blind pedestrians. They indicate that these quieter cars are more difficult to detect and localize than conventional vehicles due to their reduced sound signature.[1] A conventional vehicle is operationally defined as a vehicle powered by an internal combustion engine (ICE). Current HEVs are powered with an ICE and an electric motor that may run independently or concurrently. The term quieter cars refer to both HEVs and all-electric vehicles in this plan. A safety problem may arise when quieter cars are operated at slow-to-moderate speeds because (a) this is when an HEV is more likely to operate on its electric motor system, resulting in minimal engine sound and (b) other auditory cues from tires and wind noise may be diminished at such speeds. The reduced sound signature of hybrid electric vehicles may present a safety concern in other situations such as when the vehicle is in parking lots, emerging from driveways, and at intersections when decelerating, stopping, and starting up.[2]

While quieter cars may have safety implications for all pedestrians, blind pedestrians are particularly affected because they rely heavily on auditory cues to navigate. For example, blind pedestrians use the sound of vehicles to determine the location of a street, to

[1] National Federation of the Blind (2008). Resolution 2008-02 Regarding Momentum Toward Solving the Quiet Cars Crisis. The Braille Monitor August/September 2008

[2] Kent Stein, D. (2005) “Stop, Look, and Listen: Quiet Vehicles and Pedestrian Safety”. The Braille Monitor

traverse the crosswalk properly, and to identify a safe time to cross.[3] Any reduction in or lack of auditory information may delay decision-making and/or increase the risk of an unsafe decision.

The U.S. Government has undertaken a number of preliminary steps to better understand this issue. In December 2007, NHTSA met with representatives of the National Federation of the Blind (NFB) to discuss the issue. In April 2008, the Pedestrian Safety Enhancement Act was introduced in the United States House of Representatives.[4] This bill was reintroduced in the United States House of Representatives in January 2009. If enacted, this bill would direct the Secretary of Transportation to study and establish a motor vehicle safety standard that provides for a means of alerting blind pedestrians to consequential motor vehicle operations. [5] On June 23, 2008, NHTSA held a public meeting to provide an opportunity for interested parties to exchange information. They provided comments about the technical, safety, and policy issues that may arise when blind pedestrians are in the vicinity of quieter cars. Participants and the public were invited to submit their comments to a docket "Quiet Cars - Notice and Request for Comments."[6]

In addition, since August 2007 NHTSA has been monitoring the work of the Society of Automotive Engineers (SAE) to identify ways to address this emerging issue.[7] In November 2007, the Vehicle Sound for Pedestrian (VSP) subcommittee was formed by the members of the Alliance of Automobile Manufacturers, the Association of International Automobile Manufacturers and the SAE Human Factors Committee. The VSP subcommittee was created in response to a request from the NFB regarding their concern about blind pedestrians involved in traffic incidents with hybrid vehicles operating at low speeds. The goals of the subcommittee are to: (1) gather technical information to define the issue; (2) understand the conditions where these types of incidents are likely to occur; and, (3) propose and evaluate possible solutions.[8] The VSP subcommittee includes representatives of the blind community, a liaison to NHTSA, as well as members from academia and automakers.

Several researchers and other groups have begun to examine certain aspects of this issue. Researchers at the University of California, Riverside are focused on the audibility of HEVs.[9] Researchers at Western Michigan University collected vehicle sound data and are determining how it relates to actual decisions made by pedestrians with visual impairments in performance of normal tasks in daily travel. Other researchers are

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[3] Blash, Wiener and Welsh (1997) "Foundations of Orientation and Mobility" 2nd Edition AFB:Press; Barlow, Bentzen and Bond (2005) Blind Pedestrians and the Changing Technology and Geometry of Signalized Intersections: Safety, Orientation, and Independence. Journal of Visual Impairment & Blindness. AFB Vol. 99 No. 10.
[4] Pedestrian Safety Enhancement Act of 2008. http://thomas.loc.gov
[5] Pedestrian Safety Enhancement Act of 2009. http://thomas.loc.gov
[6] Quiet Cars - Notice and Request for Comments (2008) Docket ID NHTSA-2008-0108 http://www.regulations.gov
[7] Federal Register Vol. 73, No 105 http://www.regulations.gov
[8] SAE Press Room Vehicle Sound for Pedestrians (VSP) Subcommittee (April 9, 2008). Available at: www.sae.org
[9] Hybrid Cars Are Harder to Hear (April 2008), University of California Riverside News Release.

proposing alternative solutions. For example, Stanford University-based researchers have developed a sound-emitting device to alert people to the presence of quietly-operating vehicles.[10] Researchers at the North Carolina State University, Raleigh examined preferences for sounds that might be used to provide auditory cues to pedestrians in proximity to quieter cars.[11] A few training schools for pedestrians with visual impairments have added HEVs to their orientation and mobility training programs in California,[12] Oregon,[13] and New Jersey.[14] In 2006, the Land, Infrastructure and Transport Ministry of Japan issued a report in which it pointed out the safety problem and recommended study of the matter. The Japan Automobile Manufacturers Association (JAMA), established by the government and automakers, is therefore examining the safety problem and considering countermeasures even though no recommendations have yet been made. [15]

The magnitude and details of any impact of quieter cars on the safety of blind pedestrians are not well documented in the literature. Action is needed to identify risks and evaluate potential safety countermeasures if there appears to be an increased risk. This plan also recognizes the need to determine information about the circumstances under which the safety of blind pedestrians could be affected by quieter cars. This information needs to include the role of the driver, pedestrian, vehicles, and environment (for example, roadway, ambient sound, weather conditions).

3. Objectives

In order to address the safety concern that quieter cars may present to blind pedestrians, the following objectives are proposed:

1. Characterize the safety problem (Section 3.1)
2. Identify requirements for blind pedestrians' safe mobility (emphasizing acoustic cues from vehicles and ambient conditions) (Section 3.2)
3. Identify potential countermeasures and describe their advantages and disadvantages (Section 3.3)

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[10] Enhanced Vehicle Acoustics http://evacoust.startlogic.com/index.html
[11] Nyeste, P. and Wogalter, M.S. (2008). On Adding Sound to Quiet Vehicles. In Proceeding of the Human Factors and Ergonomic Society 52nd Annual Meeting 2008 pp. 1747
[12] Blind pedestrians may not hear hybrid cars (March 29th) Los Angeles Times http://www.latimes.com/
[13] Oregon guide dogs trained to detect the silent danger of hybrid cars (May 11, 2008) http://www.oregonlive.com/news
[14] The Seeing Eye Inc. 2007 Annual Report. Seeing Eye Department of Communications. http://www.seeingeye.org/aboutUs/default.aspx?M_ID=396
[15] Hybrid Cars, Too Quiet to be free from Blind Spot. (June 25, 2006) J-Cast Business News. Available at http://en.j-cast.com/2007/06/25008527.html.

3.1 Objective 1: Characterize the Safety Problem

3.1.1 Identify Critical Safety Scenarios (Task 1)

Background

Identifying safety critical scenarios is essential for developing hypotheses about potential countermeasures and for specifying the conditions under which they need to be tested and evaluated. The term critical scenario is operationally defined as the range of facilities and conditions of interest for evaluation of countermeasures. Critical scenarios can be developed by combining several key dimensions, including type of facility (e.g., parking lot, driveway, mid-block crosswalk, stop-controlled intersections), vehicle maneuver (e.g., backing, turning, traveling in a straight line), vehicle speed and operating condition (e.g., approaching at a constant speed, acceleration from stop), pedestrian characteristics (e.g., age, experience, mobility aid used), weather, and background noise (e.g., urban, residential, single versus multiple vehicles), among others.

Critical scenarios have been tested in various studies. For example, a recent study documented the perceptual problems faced by blind pedestrians at complex non-controlled locations such as roundabouts.[16] The perceptual problems at these facilities are due in part to the masking of critical auditory cues by moving traffic. Blind pedestrians often have considerable difficulty locating crosswalks, reliably identifying crossable gaps, and detecting vehicles that have yielded for them. Results show that blind pedestrians took significantly longer[17] to report crossable gaps at single-lane roundabouts when compared to sighted pedestrians (on average 3 to 4 seconds more). In some instances this crossing delay significantly reduced the available crossable gap creating a critical safety problem (since the vehicle is now closer to the pedestrians when he/she decided to initiate the crossing).[18] Their assessment is affected by the characteristics of the site, such as the geometry and traffic volume. For example, a low-volume, single-lane roundabout was about as safe for blind as sighted pedestrians since the gaps were sufficiently long that the increased detection latency for the blind was negligible. This study highlights the variability in pedestrian response due to traffic characteristics such as traffic volume, intersection geometry and visual impairment.

Vehicles traveling at low speeds have also been identified as a factor in some critical scenarios. For example, a series of experiments conducted at the University of California, Riverside suggest that a HEV traveling at 5 mph is harder to localize when compared to an internal combustion engine vehicle at similar speed. Vehicles were

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[16] Guth, D. Ashmead, D., Long, R., Wall, R., and Ponchillia, P. (2005) Blind and Sighted Pedestrians' Judgments of Gaps in Traffic at Roundabouts". Human Factors Volume 47, No 2.

[17] Delay or gap-detection latency was calculated as the time between the lead vehicle leaving the crosswalk and a participant pressing a button (as an indication of detection of crossable gap).

[18] Safety margin were computed based on the time when the button is pressed (as an indication of detection of crossable gap), the remaining time until the next vehicle entered the crosswalk, and how long it would have taken the pedestrian to cross at a walking speed of 4ft/sec.

binaurally recorded [19] approaching a listener at 5 mph (ear height position not reported). Vehicles approached from the left or the right, traveled 110 feet and passed 5 feet in front of the listener. Recordings were completed in a quiet parking lot and later played to blindfolded listeners over headphones in a laboratory. Measures included listeners' ability to identify the direction of a vehicle (percent of correct responses) and the response time in identifying the oncoming vehicle. Listeners were able to localize ICE and HEVs equally well. However, the reaction time for correct response in identifying a vehicle was significantly different between vehicle types. HEVs were localized later (between 1 to 3.3 seconds before arrival) than ICE vehicles (between 3.0 to 5.5 seconds before arrival). Longer reaction times were similar to experiments where the background noise was increased by 8 dB (the sound of two ICE vehicles idling).

Hogan[20] completed an initial crash data analysis related to quieter cars and pedestrian safety to answer the following questions: (1) How many blind pedestrians have been killed by hybrid vehicles in the US?, (2) How many pedestrians, blind or sighted, have been killed in crashes involving hybrids?, (3) Are hybrids involved in pedestrian deaths at a disproportionate rate?, and (4) Is there any information to suggest that blind pedestrians are more at risk for injury than others? The Fatality Analysis Reporting System (FARS) was the primary source of crash data used for the analysis. The analysis includes fatal crashes reported from 2002 to 2006. The data was extracted from FARS by combining variables to determine whether or not the fatality was a legally blind person. On average, five legally blind pedestrians per year were killed in motor vehicle crashes in the US from 2002 to 2006. The study focused on fatal crashes, which are likely to occur at travel speeds higher than 30 mph. A model describing the relationship between pedestrian injuries and speed suggests that five percent of pedestrians would receive fatal injuries if they were struck by a vehicle traveling at 20 mph (compared to fatality rates of 40, 80, and nearly 100 percent for striking speeds of 30, 40, and 50 miles per hour or more, respectively).[21] Because pedestrian fatal crashes are thus more likely to occur at higher vehicle speeds and quieter vehicles emit comparable sounds to ICE vehicles at these speeds, this analysis of FARS data has limited relevance to the question of what pedestrian fatalities are associated with the quieter sound from hybrid vehicles.

Because of the limitations of FARS data, future crash data analyses needs to consider all crashes, not only fatal crashes. Of particular interest are injury crashes as well as pedestrian incidents in driveways or parking lots, which are traditionally not covered in

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[19] Sound is recorded using microphones that are placed in position corresponding to each ear. The measurement has two signals which can have different phase and magnitudes. These two different signals help us to localize sounds. Used to study localization of a sound source (sound direction and time).

[20] Hogan C. (July 2008). Analysis of Blind Pedestrian Deaths and Injuries from Motor Vehicle Crashes, 2002-2006. Available at: Quiet Cars - Notice and Request for Comments (2008) Docket ID NHTSA-2008-0108-0007 http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&o=09000064806296bd

[21] Leaf, W.A. and Preusser, D.F. (1999) "Literature review on vehicle travel speeds and pedestrian injuries". Report No. DOT HS 809 021.

these data sets, but presumably are a common point of conflict for pedestrians, particularly, in the low-speed situations relevant to this study.

Hogan also examined the type of vehicles involved. The Toyota Prius was the only vehicle identified as a hybrid within FARS because other hybrid vehicles cannot be identified by vehicle model. For all pedestrian deaths reported during the analysis period (26,647), eleven involved a Toyota Prius. Twenty-eight legally blind pedestrians were killed in motor vehicle crashes during the analysis period; none of these involved a Toyota Prius. The analysis did not provide information related to contributing factors for these crashes.

In order to identify critical scenarios it is necessary to examine how pedestrian-vehicle conflicts can be affected by the following factors: pedestrian, driver, vehicle, roadway/crossing, traffic and ambient characteristics.

Questions

The following are some research questions related to identifying critical scenarios:

1. What driver-related factors might contribute to increased risk of colliding with blind pedestrians?
2. To what extent do vehicle dynamics (e.g., vehicle maneuver, speed) and vehicle type (conventional and quieter) contribute to blind pedestrians' risk?
3. To what extent do roadway characteristics such as crossing location contribute to blind pedestrians' risk?
4. To what extent do rural and urban locations contribute to blind pedestrians' risk?

Subtasks

The following tasks are identified to examine the questions listed above:

1. *Crash Data Analysis*: This task consists of an analysis of crashes involving pedestrians and hybrid vehicles to document the contributing factors. A list of currently available hybrid electric vehicle models as well as vehicle registration by year should be considered in future crash data analyses.

Crash databases should contain records for non-injury, minor injury, serious injuries, and fatal crashes, vehicle information to allow distinction between quieter and ICE vehicles, and relevant variables (e.g., location [urban vs. rural], type of traffic control, vehicle maneuver, pedestrian age) to investigate contributing factors. The State Data Systems (SDS), administered by NHTSA, includes all incidents reported to the police regardless of the crash outcome, and the vehicle make and model can be identified using vehicle identification numbers (VIN). A preliminary analysis to compare hybrid to non-hybrid vehicles in relation to pedestrian, bicyclists and animal crashes has been prepared by NHTSA. Once additional data become available in the SDS and the sample size increases, the analysis will be updated to control for variables that contribute to crashes. Additional SDS data should be available in 2009. Crash databases and resources possibly available at the state and local level will also be considered.

A large portion of pedestrian-vehicle crashes, including back over collisions are still underreported due to crashes that occur in non-roadway locations.[22, 23] In addition, some issues that present a challenge in estimating the safety issue include: (1) the relatively small number of hybrid vehicles; (2) the lack of exposure data; (3) the relatively small population of pedestrians with visual impairment, and (4) other potential contributing factors in addition to those reported in crash databases (e.g., ambient sound levels).

2. *Analyze Conflicts*: Review information gathered from anecdotal accounts involving blind pedestrians and quieter cars to provide insight into specific instances. The SAE VSP subcommittee is currently compiling information pertinent to this type of analysis.[24] They developed a questionnaire for blind pedestrians who have experienced a crash or conflict.

3. *Define Critical Scenarios for Acoustic Measurement and Human Performance Testing:* Define representative scenarios using input from prior research, crash data, and information exchange with experts. This activity will define the elements of the scenarios including the type of pedestrian-vehicle interaction, vehicle type and operating conditions such as speed, position of pedestrian relative to conflicting vehicle(s), and ambient sound.

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[22] Hunter, W. and Stuttts, J.C. (1999) Injuries to Pedestrians and bicyclist: An Analysis Based on Hospital Emergency Department Data. FHWA-RD-99-078

[23] The Not-in-Traffic Surveillance (NiTS) System is a data collection system that includes fatalities and injuries that occurred in nontraffic crashes on private roads, driveways and parking facilities. This data system will be reviewed.

[24] SAE Vehicle Sound for Pedestrians Subcommittee Meeting. October 2008

3.1.2 Identify Blind Pedestrian Mobility Needs and the Acoustic Cues Needed for Travel (Task 2)

Background

An attempt to characterize the safety impact of quieter cars on pedestrian safety requires an understanding of what groups are at risk, what walking scenarios are most critical, and why. This effort must identify the characteristics and capabilities of blind pedestrians, what information is needed by blind pedestrians, how the information is perceived, and how a reduction of auditory cues from traffic may impact blind pedestrian decisions. Similarly, there is a need to understand the risks associated with the judgments and decision making strategies employed by blind pedestrians in various scenarios.

The ability to avoid pedestrian-vehicle conflicts depends on the ability to perceive the characteristics of the immediate surroundings accurately. Basic abilities required for independent travel include: (1) perceiving the needed information, (2) making judgments regarding distance, speed, and time needed to cross the road, and (3) using this information and understanding to make good decisions.[25] People gather information about the environment for interpretation and action through multiple perceptual input channels. The sounds of a vehicle, for example, can provide information about its position, direction of travel, rate of acceleration, and speed at which it is likely to move. As this auditory information is used by all non-deaf pedestrians as well, its reduction or elimination may have a broader safety impact as an expected information cue is no longer present. Blind pedestrians must rely much more heavily on auditory information to gather information about their surroundings. Vehicle sounds are used by blind pedestrians, for example, to determine the location of a street, to establish a heading towards the opposite side of the street, to identify an appropriate time to cross, and to travel in a straight line across streets within the crosswalk.[26]

A recent study found that, when crossing channelized turn lanes, blind pedestrians make more decisions, require more time, to make crossing decisions and reject more gaps than sighted pedestrians. [27] Channelized lanes refer to the physical separation of conflicting traffic movements into distinct paths of travel. Travel paths are separated by a traffic island or pavement markings. Channelized turn lanes are particularly

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[25] Lee, D.N., Young, D.S. and McLaughlin, C.M. (1984). A roadside simulation of road crossing for children. *Ergonomics, 27,* 1271-1281; Demetre, J.D., Lee, D.N., Pitcairn, T.K., Grieve, R., Thomson, J.A. and Ampofo-Boateng, K. (1992).Errors in young children's decisions about traffic gaps: Experiments with roadside simulations. *British Journal of Psychology,* 83,189-202.

[26] Blash, Wiener and Welsh (1997) “Foundations of Orientation and Mobility” 2nd Edition AFB: Press; Barlow, J.M., Bentzen, B.L., and Bond, T. (2005) Blind Pedestrians and the Changing Technology and Geometry of Signalized Intersections: Safety, Orientation, and Independence. Journal of Visual Impairment & Blindness. AFB Vol. 99 No. 10.

[27] Schroeder, B.J., Rouphail, N.M. and Wall Emerson, R. (2006) Exploratory Analysis of Crossing Difficulties for Blind and Sighted Pedestrians at Channelized Turn Lanes. Transportation Research Records No. 1956, pp94-102.

problematic for blind pedestrians because they are designed to permit continuous traffic flow. The perceptual problems at these facilities (e.g., channelized turn lanes and roundabouts) are due in part, to the masking of critical auditory cues by moving traffic. These results suggest that hearing-based judgments may be more difficult and therefore more prone to error than vision-based judgments. Two types of perceptual errors are of primary concern: detection and localization of vehicles. Detection error is operationally defined as a mistake in judging the presence of a relevant object or event and a localization error is a mistake in judging the direction of an object relative to a pedestrian. The likelihood of perceptual errors by pedestrians is influenced by several factors including degraded or missing information, expectations and prior training, lack of perceptual or motor skill, inattention, and a willingness to take risks.[28]

Questions

In order to identify how quieter cars affect the safety of blind pedestrians the following types of questions related to perception and decision-making will be reviewed:

1. What information do blind pedestrians need for safe mobility?
2. What strategies do blind pedestrians use for various walking situations?
3. How is the decision-making process of blind pedestrians affected by a reduction or elimination of perceptible auditory cues from vehicular traffic?

Subtasks

Some of the questions above have been addressed in the literature, and some are under investigation. The following methods are identified to gather information about these topics:

1. *Cognitive walkthroughs*. Observe how blind pedestrians are trained to navigate in safety critical scenarios. Ask blind pedestrians to describe the strategies they use as they encounter various walking situations. It is critical to understand how blind pedestrians use their sensory input to navigate different pedestrian/vehicle environments. This information will also support the evaluation of the risks and countermeasures.
2. *Literature review.* Review literature regarding blind pedestrian navigation in the vicinity of quieter cars.
3. *Information retrieval from institutional centers of expertise*. Compile lessons learned from previous and ongoing research on crossing decisions for blind pedestrians in complex situations including intersections and situations where information cues are compromised or reduced. Some of the previous and ongoing projects in this area include Bioengineering Research partnership funded by the National Eye Institute, National Institute of Health which quantifies crossing experience among blind and sighted pedestrians at complex intersections; ongoing studies on the audibility of hybrid vehicles at the University of California, Riverside funded by the NFB; and studies on the detectability of hybrid and conventional vehicles in various

[28] Blash, Wiener and Welsh (1997) “Foundations of Orientation and Mobility” 2nd Edition AFB: Press

noise backgrounds (taking into account detection distance and stopping distance) recently completed by the Noise Pollution Clearinghouse.

4. *Subject matter expert opinions*. Leverage knowledge from blind pedestrians and experts in mobility training for blind pedestrians. Conduct interviews and/or focus groups with blind pedestrians and representatives of national organizations such as the NFB, the American Foundation for the Blind (AFB), U.S. Access Board, and American Council of the Blind.

3.2 Objective 2: Identify Requirements for Blind Pedestrians Safe Mobility (emphasizing acoustic cues from vehicles and ambient conditions)

Once the critical scenarios are identified, acoustic measurements and human performance studies can be conducted to address various questions.

3.2.1. Measure Acoustic Parameters of Vehicles and Ambient Sound (Task 4)

Acoustic measurements are needed to quantify acoustic characteristics for a sample set of vehicles under operating conditions similar to the identified critical safety scenarios. Vehicles would include, for example, several hybrid electric vehicles and their ICE counterparts (Honda Civic (HEV/ICE), Ford Escape (HEV/ICE), and the Toyota Prius. Additional ICE vehicles will be tested for comparison, including one considered comparable to the Prius in size, weight, and horsepower.

Measurements are also needed to quantify acoustic characteristics for a sample set of ambient conditions similar to identified critical safety scenarios. At a minimum, acoustic measurements should be conducted to quantify the overall A-weighted sound levels and spectral shape. Acoustic measurements should provide vehicle and ambient acoustic recordings for subsequent human performance testing.

<u>Question</u>

1. What are typical acoustic characteristics (signatures) for quieter cars in various critical scenarios?

<u>Subtasks</u>

The following subtasks are identified to address this question:

1. Identify candidate vehicles for testing
2. Specify operating conditions for acoustical measurements
3. Specify environments for acoustical measurements
4. Measure acoustical characteristics for a sample set of vehicles under specified operating conditions with minimal noise contamination from external sound sources. These measurements will quantify the overall A-weighted sound level[29] and spectral shape.
5. Measure ambient sound in specified environments. These measurements will quantify the overall A-weighted sound level and spectral shape.

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[29] A-weighted sound level is the sound level when the component frequencies of the sound have been weighted with the A-weighting filter (A-weighted curve). It is an approximation to the perceived loudness (perceived volume of a sound).

6. Combine acoustic recordings of ambient and vehicles to create acoustic representations of critical scenarios.
7. Create acoustic recordings suitable for subsequent human performance testing.

3.2.2 Review Test Procedure for Acoustic Measurement of Vehicles Developed by the Society of Automotive Engineers (SAE) and Adapt as Needed (Task 3)

A test procedure is needed to assure that vehicle acoustic parameters are evaluated consistently. This test procedure should be as practical as possible while still accurately evaluating sound emissions. It is important that the test procedure specify measurements at a location relative to the vehicle. It is equally important that the test procedure specify operating conditions that will mimic the emissions associated with critical scenarios in a consistent manner. SAE is currently developing a test procedure that is relevant to this task and it will be reviewed and considered for use in this study if appropriate, once complete. Based on data needs, modifications to the test procedure (if applicable) or an alternative test procedure may be used to examine vehicle and ambient sound characteristics and pedestrian response in critical safety scenarios.

At a minimum, a comprehensive acoustic measurement test plan should contain provisions for acoustic measurements of vehicles under operating conditions that reflect the operating conditions in critical scenarios. Possible operating conditions include idle, several constant speeds, and acceleration from rest. An acoustic measurement test plan should also contain provisions for measuring the ambient sound levels that are typical for critical scenarios. Examples of typical ambient conditions may include quiet neighborhoods, quiet city streets, and busy city streets. As detectability is of interest, narrow band measurements with a minimum resolution of one-third octaves are necessary. As localization[30] is also of interest, recordings should be conducted using a binaural head.

3.2.3. Measure Pedestrian Response to Vehicle Acoustic Parameters under Various Ambient Conditions (Task 5)

<u>Background</u>

Human performance testing is needed to assess whether quieter cars are significantly more difficult to perceive, resulting in faulty decision making compared to conventional vehicles under various critical scenarios. An understanding of blind pedestrians' crossing strategies in critical scenarios is essential for the design of human performance studies. This information will be used to identify specific hypotheses, performance measures, characteristics of test participants, and test procedures.

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[30] Localization of a sound source requires information about its direction and its distance

Questions

Once the critical scenarios and acoustic measurements are specified, human performance studies can be conducted to address various questions. The primary questions are the following:

1. Under what critical scenarios is it more difficult for pedestrians to perceive acoustic information from vehicles?
2. Is there a minimum sound level for vehicles (considering background noise) that allows for safe detection and localization?
3. What is the effect of sound level and spectral characteristics[31] on detection, recognition, and localization under different ambient conditions?

Subtasks

The plan for conducting human-performance testing would include the following steps:

1. Measure blind pedestrians' response to acoustic parameters of ICE vehicles under ambient sound conditions of safety critical scenarios. For example, measure the ability of blind pedestrians to detect, recognize, and localize a nearby vehicle. Measures may include percent of correct detection, confusion with other sounds, correct localization, and response time relative to vehicle time-to-arrival.
2. Measure blind pedestrians' response to acoustic parameters of quieter cars (to be specified in work conducted under Section 3.2.1) under similar ambient sound conditions as above.
3. Examine how different sound levels and spectral content (considering ambient sound and critical scenario) affect vehicle detection, recognition, and localization.
4. Develop a quantitative estimate of how much sound of what spectral content is needed to ensure vehicles will be detected and localized by a blind pedestrian in critical scenarios.

Testing will be conducted under a controlled environment to minimize the influence of extraneous variables on the results. The limitation of controlled environments is that it does not allow for testing pedestrians' strategies and behaviors when faced with real-world dangers. Naturalistic or quasi-naturalistic field tests are more suited to address real-world decision making questions. For example, if it is determined that variations in crossing strategy may be important in determining whether blind pedestrians will be able to safely judge gaps, then it may be important to use a real-world testing environment in which behavioral responses under different traffic scenarios (e.g. vehicle types and maneuvers, intersection types) can be observed. However, such testing is beyond the scope of this plan.

[31] Spectral shape refers to the contour of the frequency spectrum. Sounds with the same A-weighted sound level may be more or less detectable depending on their spectral shape.

3.3 Objective 3: Identify Potential Countermeasures and Describe their Advantages and Disadvantages

Background

Several aids designed to improve orientation and mobility for pedestrians, including blind pedestrians, are currently available or have been designed and prototyped and may come into the market soon. Table 1 classifies these countermeasures as infrastructure-based (e.g., accessible pedestrian signals, tactile surfaces), vehicle-based (e.g., sound emitted from vehicles, pedestrian detection technologies), pedestrian-based (e.g., electronic travel aids), environmental (e.g., initiatives to reduce ambient noise), and educational (e.g., orientation and mobility training). Some of these aids provide auditory cues to pedestrians and facilitate aspects of the street crossing task, such as detecting the crossing location or identifying the crossing interval. Examination of promising infrastructure-based countermeasures will be coordinated with FHWA. Other aids are designed to provide information to the driver. For example, driver assistance systems have been developed to detect dangerous situations involving pedestrians. A comprehensive safety approach usually includes a combination of engineering, education, and enforcement strategies.

In terms of specific countermeasures, Lotus Engineering has developed and prototyped a noise generating system to provide a warning to pedestrians. The Lotus Safe and Sound Hybrid consists of a noise generating module that uses input on vehicle speed to produce a synthetic sounding engine noise. The sound is emitted from waterproof speakers mounted behind the front grille of the vehicle. In addition, the system produces an idle noise when the vehicle is powered but stationary and a warning beep when the vehicle in reverse. If the engine starts operating, the system automatically stops the external synthesis. Long-term developments may include the ability to adjust the emitted sound relative to background noise levels.[32]

Another sound emitted system, the Pedestrian Awareness Noise –Emitting Device and Application (PANDA) has been designed and developed by Enhanced Vehicle Acoustics (EVA). This particular system can emit sound from one of multiple speakers designed to provide sound consistent with the direction of travel of the vehicle (including right, left, reverse maneuvers). The system has been prototyped in Northern California.[33]

Creative Performance Products, Inc has proposed a system consisting of two components: (1) a transmitter to be carried by blind pedestrians and (2) receiver to be installed on vehicles. Communication would be initiated when the vehicle and blind pedestrians are within 25 to 30 feet from each other. The system would provide an

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[32] Quiet Cars - Notice and Request for Comments (2008) Docket ID NHTSA-2008-0108 http://www.regulations.gov. Lotus Engineering http://www.grouplotus.com/engineering/downloads/videos.html

[33] Enhanced Vehicle Acoustics http://evacoust.startlogic.com/index.html; Quiet Cars - Notice and Request for Comments (2008) Docket ID NHTSA-2008-0108 http://www.regulations.gov

audible warning to the pedestrian with the potential to provide relevant information regarding vehicle's location and speed. Similarly, a warning would be issued to the driver indicating the presence of a blind pedestrian.

The development of requirements and performance criteria for potential countermeasures necessitate an understanding of the problem, including operational conditions, context of use, user cognitive capabilities and limitations, human factors considerations, user acceptance and expected safety benefits. The intent of this section is not to recommend countermeasures. Rather, the goal is to document some of the countermeasures (implemented or proposed) designed to improve safety and mobility for blind pedestrians.

Table 1 Pedestrian Safety Countermeasures

Category	**Countermeasure**	**Description**	**Potential Benefits**	**Shortcomings /Challenges**	**Development Status**
Infrastructure-based	Accessible pedestrian signals[34]	Device that communicates information about pedestrian timing in non-visual format such as audible tones, verbal messages, and/or vibrating surfaces	Allow more accurate judgments of the onset of the walk interval, reduce the number of crossings begun during the "Don't Walk Interval", and reduce pedestrian delay	Disagreement among blind people on the need for, and effectiveness of, audible pedestrian signals. Noise pollution and community opposition.	Available
	Tactile surface[35]	Various patterned, tactile ground, or floor surfaces	Provide directional and hazard warning information to pedestrians who are blind or visually impaired		Available

[34] Harkey, D.L., Carter, D.L., and Barlow, J.M. Accessible Pedestrian Signal: A Guide to Best Practices. NCHRP 117A (Web-Only Document). Available at: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w117a.pdf

[35] Blash, Wiener and Welsh (1997) "Foundations of Orientation and Mobility" 2nd Edition AFB: Press Hugues, R. An Update on NCHRP 3-78A. Treatments for Channelized Turn Lanes, Single and Multi-Lane Roundabouts. http://www.teachamerica.com/RAB08/RAB08S9AHughes/index.htm

Category	Countermeasure	Description	Potential Benefits	Shortcomings /Challenges	Development Status
	Automatic pedestrian detection systems for uncontrolled approaches[36]	Uncontrolled crosswalks are fitted with automated detection devices that activate flashing beacons, in-pavement raised markers with LED strobe lights, or other active warnings	Alert drivers when pedestrians are present	Detection accuracy to reduce the number of false alarms and missed calls	Prototyped
	Rumble strips/sound strips[37]	Located near the crosswalk generates sound as vehicles pass by alerting the pedestrian of the presence of a vehicle.	Alert pedestrian when vehicles are approaching the crosswalk	May cause noise pollution and community opposition.	Available
Education & Enforcement	Orientation and mobility training for blind pedestrians and guide dogs[38]	Train guide dogs to learn to respond to quieter cars. Identify and evaluate alternative teaching strategies for complex situations such as the absence of auditory cues from vehicles	If the dog senses danger, it can ignore a command to cross the street, or alert its owner to possible impediments.	Limited to those pedestrians using dogs for mobility aid	Prototyped

[36] Pedestrian Report to Congress. FHWA. Assessment of Developmental and Pre-deployment Advanced Technologies http://safety.fhwa.dot.gov/ped_bike/pedrpt/pedrpt_0808/chap_3.htm
[37] Hugues, R. An Update on NCHRP 3-78A. Treatments for Channelized Turn Lanes, Single and Multi-Lane Roundabouts. http://www.teachamerica.com/RAB08/RAB08S9AHughes/index.htm

[38] Blind pedestrians may not hear hybrid cars (March 29th) Los Angeles Times http://www.latimes.com/; Oregon guide dogs trained to detect the silent danger of hybrid cars (May 11, 2008); http://www.oregonlive.com/news; The Seeing Eye Inc. 2007 Annual Report. Seeing Eye Department of Communications. http://www.seeingeye.org/aboutUs/default.aspx?M_ID=396

Category	Countermeasure	Description	Potential Benefits	Shortcomings /Challenges	Development Status
Environmental Regulation	Initiatives to Reduce Ambient Noise	Ambient sound levels are low due to improved signal-to-noise ratios	Sounds may become more detectable due to improved signal-to-noise ratios	It is difficult to reduce ambient levels due to non-vehicular sources (e.g. construction, pedestrians, animals and wind)	Proposed
Vehicle-based	Artificial engine sound[39]	A system synthesized external sound on electric and hybrid vehicles to make then more audible when vehicle is operating using electric power.	It would provide same minimum amount of information as ICE vehicles.	May cause noise pollution and community opposition; may cause increase in vehicle cost; concerns about driver acceptance	Prototyped
Vehicle-Pedestrian Communication	Proximity warning system	Battery-operated transmitter that would be carried by the pedestrian and a receiver mounted on the vehicle. Warning emitted to both, pedestrian and driver	Provides information to both the driver and pedestrian about a potential conflict.	Requires integration with other in-vehicle warning systems. Concerns about driver and pedestrian acceptance of such technology. Concerns about type, reliability of information provided, and cost	Prototyped
Pedestrian-Based[40]	Electronic Travel Aids	Handheld or attached to the cane. Provide tactile or audio output to inform pedestrians about their surroundings and nearby vehicles.	Provide information for avoidance of obstacles and/or vehicles, Detection of distance and direction of obstacles and/or vehicles	Range of detection. User acceptance. Battery replacement. May require additional training. Cost.	Available/ Conceptualized

[39] Enhanced Vehicle Acoustics (EVA). Vehicular Operations Sound Emitting Systems

3.3.1 Review Potential Countermeasures to Identify Strengths and Limitations (Task 6, Task 7)

It is necessary to assess potential countermeasures to estimate how they might improve safety as well as whether users will accept them. Safety improvements may include an increase in pedestrians' ability to localize a vehicle, a reduction in the time needed to judge gaps in traffic, or a reduction in pedestrian-vehicle conflicts.

This assessment needs to use a set of relevant criteria and consider critical scenarios. The assessment must identify any unintended consequences associated with a countermeasure use in an unexpected or incorrect manner and their impact on safety. Current and emerging options will be documented but there is no field testing planned at this time.

Questions

These are some questions on how to assess potential countermeasures:

1. What are the expected safety improvements to be attained by the target population?
2. What is the level of acceptance of each countermeasure by the blind community, car manufacturers, and the public?
3. What are the unintended consequences associated with countermeasure use in an unexpected or incorrect manner; what are the impacts on safety?

Subtasks

The following subtasks are identified to assess countermeasures:

1. *Document current and emerging countermeasures.* Identify countermeasures that have the potential to provide the anticipated safety benefits. This countermeasure research will include both national and international resources. Some of the available resources include but are not limited to: (1) The Pedestrian Countermeasure Selection System (PEDSAFE), an online tool that provides a list of engineering, education and enforcement countermeasures to improve pedestrian safety[41]; (2) The National Cooperative Highway Research Project (NCHRP) 3-78 A project, aimed at identifying and evaluating treatment solutions to improve safety for pedestrians with vision impairments at roundabouts and channelized turn lanes; (3) The NCHRP 3-71 project report which provides an overview of countermeasures to improve pedestrian safety at signalized and unsignalized crossings[42]; (4) Countermeasures suggested by orientation and mobility training

[40] Roentgen et. al. (2008). Inventory of Electronic Mobility Aids for Persons with Visual Impairments: A Literature Review. *Journal of Visual Impairment & Blindness.*

[41] University of North Carolina Highway Safety Research Center. Pedestrian Countermeasure Selection System. Available at: http://www.walkinginfo.org/pedsafe/index.cfm

[42] Fitzpatrick, Kay, et al. (2006), Improving Pedestrian Safety at Unsignalized Intersections. TCRP Project D-8/NCHRP Project 3-71. Transportation Research Board, Washington, D.C. 2006; NCHRP Web-Only Document 91: Contractors' Final Report-Appendices B to O.

professionals and blind pedestrians, car manufacturers, and other interested parties. The work conducted by the World Forum for Harmonization of Vehicle Regulation (WP.29), Working Party on Noise will be included in the review[43].

2. *Define criteria to review potential countermeasures.* In order to provide a basis for comparing potential countermeasures, key evaluation criteria will be identified, such as cost, compliance and harmonization with existing regulations, usability, user and public acceptability, and suitability in critical scenarios. Weighting scales for the different criteria will be developed in order to derive a relative ranking of potential countermeasures for selection of those that may merit possible further evaluation. This analysis will also help to identify knowledge gaps.

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[43] United Nations Economic Commission for Europe (UNECE). World Forum for Harmonization of Vehicle Regulation (WP.29) GRB Working Party on Noise.
http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29age.html

4. Roadmap for Quieter Cars Research

Table 2 illustrates the key elements of the evaluation plan (i.e., objectives, tasks, subtasks and expected outcomes of the evaluation plan. The plan breaks evaluation objectives into research questions (documented in this report) and supporting tasks to address these questions. A series of subtasks describing the technical approach are listed for each of the tasks. The last column provides a high level description of the expected outcomes. Figure 2 on page iv shows the timeline for the key tasks.

Table 2 Roadmap for Quieter Cars Research Plan

Objective	Tasks	NHTSA Proposed Subtasks	Other Previous or Ongoing Activities by Others	Outcome
3.1. Characterize the safety problem	3.1.2 Identify critical safety scenarios	• Analyze crash data and anecdotal accounts to identify variables that increase risk to blind pedestrians • Define critical scenarios for acoustic measurement and human performance testing	• SAE Task Force 2: Review crash data to define crash scenarios to be used to evaluate proposed countermeasures. Collect anecdotal data involving blind pedestrians and HEVs.	• Identify factors contributing to crashes between quieter cars and pedestrians • Specify acoustic and human performance testing conditions
	3.1.1 Identify blind pedestrian's mobility and the acoustic cues needed for travel	• Cognitive walkthroughs • Review literature • Retrieve information from institutional centers of expertise and • Conduct interviews with SME's	• SAE Task Force 1: Identify populations to benefit • Western Michigan University- Pedestrian decisions in actual crossings at intersections with HEVs and conventional vehicles)	• Information needed by blind pedestrians • Effect of change in vehicular traffic auditory cues • Support to safety assessment and countermeasure evaluation

Objective	Tasks	NHTSA Proposed Subtasks	Other Previous or Ongoing Activities by Others	Outcome
3.2 Identify requirements for blind pedestrians safe mobility (emphasizing acoustic cues from vehicles and ambient conditions)	3.2.1 Measure acoustic parameters of vehicles and ambient sound	• Measure acoustic characteristics of a sample set of vehicles under specified operating conditions • Measure ambient sound in specified environments. • Create acoustic representation of critical scenarios • Provide acoustic recording for subsequent human performance studies	• SAE Task Force 3: Test procedures for acoustic measurements of vehicle sound	
	3.2.2 Measure pedestrian response to vehicle acoustic parameters under various ambient conditions	• Conduct laboratory experiment to evaluate vehicle detection, recognition and localization in various ambient and critical scenarios • Develop quantitative estimate of how much sound of what spectral content is needed for detection and localization in critical scenarios	• University of California Riverside – detectability of HEVs and ICE vehicles by noise backgrounds • Noise Pollution Clearinghouse – detectability of HEVs and ICE vehicles by detection distance and stopping distance	• Acoustic profiles of quieter cars by scenarios • Determination of difference in sound characteristics between conventional and quieter cars in critical scenarios • Determine how sound characteristics affect blind pedestrians' safety

Objective	Tasks	NHTSA Proposed Subtasks	Other Previous or Ongoing Activities by Others	Outcome
3.3 Identify potential countermeasures and describe their advantage and disadvantages	3.3 Identify potential countermeasures and to identify strengths and limitations.	• Document potential countermeasures • Define criteria to assess countermeasure • Produce relative ranking of potential countermeasures	• NCHRP 3-78A – Evaluating solutions to improve blind pedestrian safety at complex intersections. • Lotus Engineering: proposed solution • EVA: proposed solutions • Volvo (EU): proposed solution	• Identify potential countermeasures to reduce risk to blind pedestrians