

The SHRP 2 Naturalistic Driving Study

Addressing Driver Performance and Behavior in Traffic Safety

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Composite image showing a driver's head position in relation to the dashboard and windshield, calibrated with eyes forward (at left) and looking at the speedometer (at right). The SHRP 2 Naturalistic Driving Study has equipped participants' cars with data-collecting devices to gain a deeper understanding of driving behavior.

The central goal of the Naturalistic Driving Study (NDS) for the second Strategic Highway Research Program (SHRP 2) is to address the role of driver performance and behavior in traffic safety.¹ This involves understanding how the driver interacts with and adapts to the vehicle, the traffic environment, roadway characteristics, traffic control devices, and other environmental features. The NDS also provides the means to assess the changes in collision risk associated with each of these factors and their interactions.

Driving behavior is a critical factor in nearly all traffic crashes. Driver impairment—primarily due to alcohol—and driver inattention, distraction, drowsiness, and judgment-related errors are believed to be responsible for significant increases in crash risk. After-the-fact crash investigations, however, cannot determine accurately a driver's behavior before the crash.

The naturalistic driving method offers two key advantages: (a) detailed and accurate precrash information, including objective information about driving behavior, and (b) exposure information, including the frequency of behaviors in normal driving, as well as the larger context of contributing fac-

¹<http://onlinepubs.trb.org/onlinepubs/shrp2/RevisedSafetyResearchPlanMarch2012.pdf>.



PHOTO: SHRP 2

The in-vehicle data acquisition system (DAS) unit gathers and stores data from forward radar, four video cameras, accelerometers, vehicle network information, a Geographic Positioning System, and onboard computer vision algorithms.

tors. The larger context for exposure enables risk estimates for various driver behaviors and for other contributing factors. The information will support the development of new and improved safety countermeasures to prevent traffic collisions and injuries.

Recruiting Participants

The SHRP 2 NDS is the largest study of its kind ever conducted and is under way with nearly 2,360 participants on the road or having completed assignments as of September 2012. Participants are recruited in six sites across the United States, with each site hosting 150 to 450 participant vehicles. The sites, the coordinating groups, and the numbers of participating vehicles are as follows:

- ◆ Bloomington, Indiana—Indiana University: 150 vehicles;
- ◆ Central Pennsylvania—Pennsylvania State University: 150 vehicles;
- ◆ Tampa Bay, Florida—the research, development, and testing firm CUBRC and the University of South Florida: 441 vehicles;
- ◆ Buffalo, New York—CUBRC: 441 vehicles;
- ◆ Durham, North Carolina—Westat: 300 vehicles; and
- ◆ Seattle, Washington—Battelle: 409 vehicles.

Participants are recruited through call centers and traditional methods. The original study design



PHOTO: SHRP 2

required approximately equal numbers of participants across 16 age and gender groups. The Virginia Tech Transportation Institute (VTTI), which serves as the technical coordination and study design contractor for the NDS, operates a central call center for all sites; Battelle operates a separate call center in Seattle. The call centers use lists of household phone numbers for each NDS site, screened for licensed drivers and eligible vehicles.

Traditional recruitment consists of advertisements in various media, including the web-based Craigslist, flyers, presentations, mass mailings, and e-mails. Internet-based methods are particularly effective for younger drivers. The Washington State Department of Transportation (DOT), for example, ran an advertisement on its main traffic advisory web page with a link to the NDS recruiting site.

Traditional screening approaches offer the option of calling an 800 number to connect to the VTTI call center or of linking to a web-based screening tool supported by the call center. With the web tool, a potential participant who sees the ad does not need to speak with a study representative but can complete the screening questionnaire online and join the pool of participants to be scheduled at the nearest NDS site.

Preparing Participants and Vehicles

The SHRP 2 NDS adheres to appropriate informed consent and privacy requirements. Four of the NDS sites operate under their own Institutional Review Boards (IRB), and two operate under the VTTI IRB. The IRB of the National Academy of Sciences and the VTTI IRB provide oversight for the entire study. All available mechanisms—technological and legal—are being applied to prevent disclosure of the names or identities of participants to NDS data users or to the public.

Each NDS participant completes the informed consent process. The participant's vehicle is checked for suitability; many recent model-year passenger vehicles in good working order are eligible.

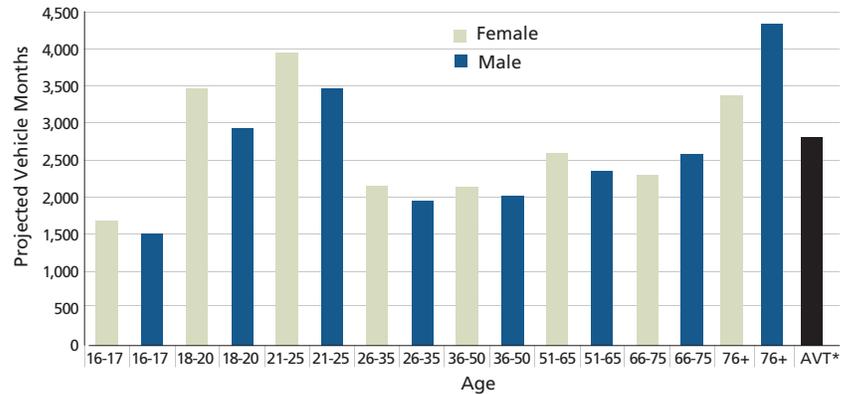


FIGURE 1 Projected participant-months by age and gender. (AVT = advanced vehicle technology.)

The participant's vehicle is taken to a field contractor's installation facility. While the data acquisition system (DAS) is being installed, the participant completes a variety of driver assessment tests. These include executive function and cognition; visual perception; visual-cognitive, physical, and psychomotor capabilities; personality factors; sleep-related factors; medicines; general medical condition; and driving knowledge. The tests include standard vision tests, a grip strength test, and a rapid-pace walk. Some are in the form of web-based questionnaires that the participant can complete at home. The driver assessment tests take 2 to 3 hours.

Each participant receives an annual incentive of \$500, paid in installments. Participation requires that the driver provide access to the vehicle, so that the hard drive with accumulated data can be removed and replaced every four to six months.

The SHRP 2 NDS accumulates 5 participant-years of driving in a single day. Data collection continues through November 2013. More than 1,840 participant-years of data have accumulated as of the end of August 2012, and by the end of the study, a total of 3,700 participant-years is expected from the nearly 2,600 total participants.

Some participants will remain in the study for the entire term, but others will be replaced with a new participant and vehicle after one year in the study. Figure 1 (above) shows participant-months of driving



(Left:) A forward radar unit, mounted near the license plate, is among the data-gathering devices installed in participant vehicles.

(Right:) A head unit, attached near the rear-view mirror, comprises cameras recording four different fields of view. It also receives data from accelerometers and a passive alcohol sensor.



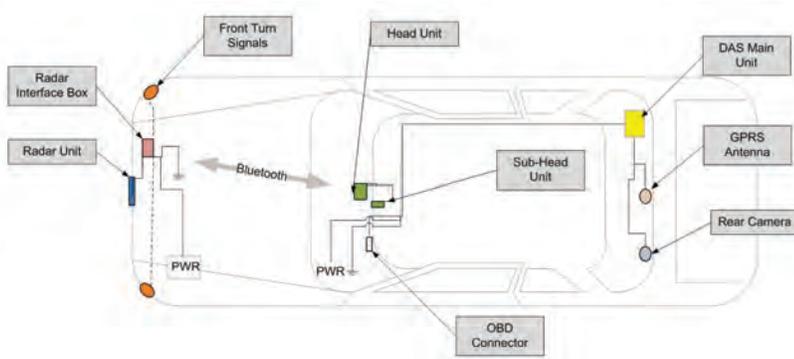


FIGURE 2 DAS schematic view.

as projected for the study by age group and gender. Ongoing recruitment is focusing on younger and older drivers, to increase the coverage of those age groups.

Data Acquisition System

VTTI developed the DAS for the study to support the research questions and objectives of the SHRP 2 program. Manufactured by American Computer Development, Inc., the DAS includes forward radar; four video cameras, including one forward-facing, color, wide-angle view; accelerometers; vehicle network information; Geographic Positioning System; on-board computer vision lane tracking, plus other computer vision algorithms; and data storage capability.

Data from the DAS are recorded continuously while the participant's vehicle is operating. This continuous recording allows for an exposure-based approach and is central to the SHRP 2 safety focus area.

Figure 2 shows a schematic of the DAS installation (above). Installation in the participant's vehicle takes approximately three hours. The central computer, or main unit, encrypts and records all data on a removable hard drive that must be replaced every four to six months. The forward radar communicates wirelessly to the main unit.

Four cameras are located away from the driver's

view in a head unit attached behind and to the right of the rear-view mirror. The head unit also includes accelerometers and a passive alcohol sensor. Figure 3 (below) shows a schematic of the field of view for each camera.

The DAS records information from the vehicle network through a connection under the dashboard to the on-board diagnostics port. A rear-facing camera and a cellular general packet radio service for data transmission with Wi-Fi antenna are attached to the rear window. The cellular capability allows the DAS to send regular "health checks" to VTTI, including the capacity of the hard drive.

The camera images are combined in a single frame and compressed for efficient storage as shown in the composite image on page 33. The color forward view is in the upper left, with the driver face view in the upper right, rotated to make better use of the available pixels. The lower left image presents a downward view of the instrument panel from the



The Optec 6500P is used to assess NDS participants' visual perception. Also tested are drivers' visual-cognitive, physical, and psychomotor capabilities; personality factors; sleep-related factors; health; and driving knowledge.

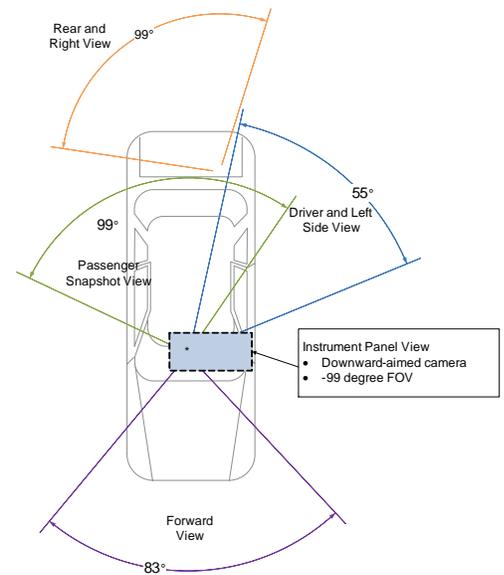


FIGURE 3 Fields of view for the DAS.

Data Acquisition System Channels

- ◆ Multiple videos
 - ◆ Machine vision
 - Eyes forward monitor
 - Lane tracker
 - ◆ Accelerometer data (3 axis)
 - ◆ Rate sensors (3 axis)
 - ◆ GPS: latitude, longitude, elevation, time, velocity
 - ◆ Forward radar
 - X and Y positions
 - X and Y velocities
- ◆ Cell phone
 - Automatic collision notification, health checks, location notification
 - Health checks, remote upgrades
- ◆ Illuminance sensor
- ◆ Infrared illumination
- ◆ Passive alcohol sensor
- ◆ Incident push button—audio (only on incident push button)
- ◆ Turn signals
- ◆ Vehicle network data
 - Accelerator
 - Brake pedal activation
 - Automatic braking system
 - Gear position
 - Steering wheel angle
 - Speed
 - Horn
 - Seat belt information
 - Airbag deployment
 - Many more variables

head unit near the rear-view mirror. The rear camera view is in the lower right. The views are recorded at 15 Hz and can be separated for analysis.

A fifth camera takes a still image of the interior every few seconds, showing passengers in the vehicle. The image is permanently blurred so that the passengers cannot be recognized. The DAS also runs a machine vision algorithm while the system is recording, to determine the direction the driver's head is facing. Sample video output is shown in the photo below. The primary DAS data channels are listed in the box on page 32.

VTTI provides technical coordination for the six NDS sites and houses all of the NDS data. Encrypted data are transferred via secure high-speed networks from each site to VTTI for processing, quality control, and addition to the NDS database. The final SHRP 2 NDS database is expected to approach 2 petabytes (2,000 terabytes) in size.

Roadway Information

Roadway information is necessary to relate driver actions to the roadway characteristics. Two additional projects are gathering this information for the six NDS sites. The Center for Transportation Research and Education (CTRE) of Iowa State University is developing the roadway information database. The database will combine roadway data from the state highway departments and other sources with data collected by Fugro Roadware—equipped vans, which measure roadway characteristics while traveling at posted speed limits on routes selected by SHRP 2.

The roadway data include the number of lanes, lane type and width, the grade, the superelevation, the beginning and end points of a curve, the curve radius, the lighting, the rumble strips, the median type, the width of the paved shoulder, the speed limit signs and their locations, the location of intersections, the number of approaches, and the traffic control devices. CTRE selects the routes to be measured and provides quality assurance of the roadway data collected.



Photo: SHRP 2

To assist in the route selection, VTTI prepared GPS traces of the roads traveled by the initial participants at each NDS site. Figure 4 (page 34) shows the routes measured and to be measured in Durham, North Carolina, by Fugro Roadware. Approximately 72 percent of the mileage will be rural and 28 percent urban. In contrast, in Seattle, Washington, 72 percent of the mileage will be urban. In all, approximately 12,000 miles of roadway will be measured in both directions for the six sites.

The four fields of view from the car's interior are combined in a single frame and compressed for efficient storage.

SHRP 2 NDS Analysis

The SHRP 2 NDS will support a comprehensive assessment of how driver behavior and performance interact with roadway, environmental, vehicular, and human factors and the influence of these factors and their interactions on collision risk, especially on lane departure and intersection collisions. Two central issues for the planned analysis are the statistical relationship of surrogate measures of collisions—such as conflicts, critical incidents, near-collisions, or roadside encroachments—with actual collisions, and the formulation of exposure-based risk measures using these surrogate measures.

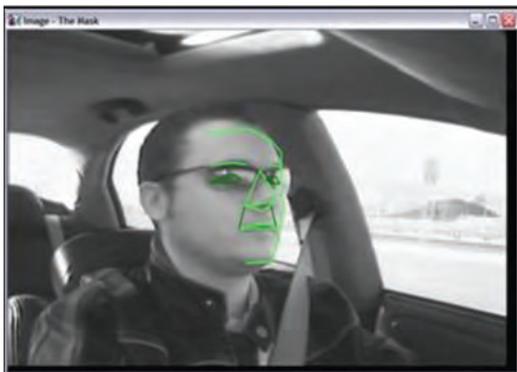


Photo: SHRP 2



Photo: SHRP 2

(Far Left:) In this still image from a video recording, a machine vision algorithm helps determine in which direction the driver's head is facing.

(Left:) A separate camera takes still images of passengers, permanently blurred, every few seconds.

Fugro Roadware's Automatic Road Analyzer vehicles collect data on roadway characteristics of routes selected by SHRP 2.



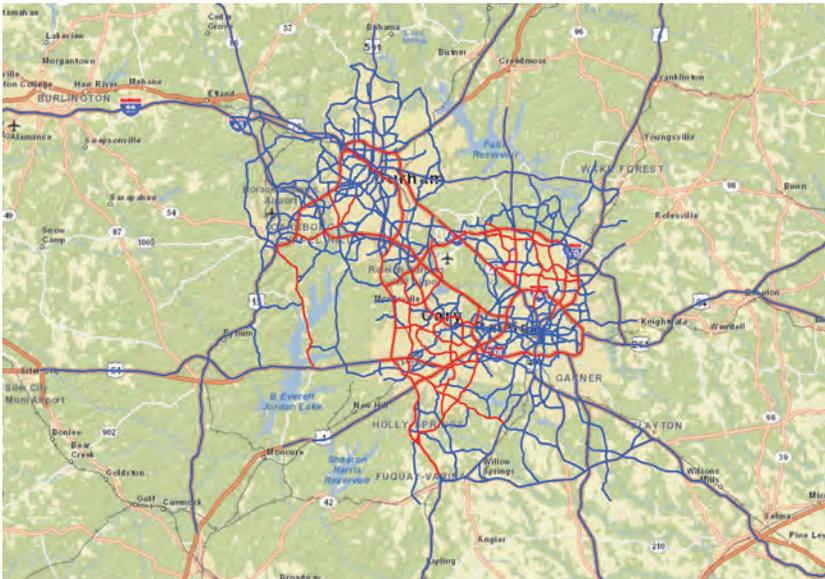
PHOTO: FUGRO ROADWARE

Crashes are rare events—time is needed to record enough crashes of any specific type to analyze. The use of surrogates for collisions—such as near-collisions, critical incidents, or traffic conflicts—would greatly increase the power of the field studies, because the surrogate events occur much more frequently than crashes and without harm.

Joseph I. Harris and Stuart R. Perkins of General Motors Corporation Research Laboratories introduced the first surrogate measure, traffic conflicts, in 1967. Interest in the use of surrogates increased with new data collection technologies that can support continuous measurement of crash margin measures such as the time-to-lane departure or time-to-collision. These kinds of measures can be used to form surrogate risk estimates for specific traffic maneuvers.

Key aspects of the analysis projects include the application of crash surrogate approaches, development of exposure-based collision risk measures, and the formulation of analytic methods to quantify the relationship of driver behavior and performance, vehicle, roadway, and environmental factors to collision risk.

FIGURE 4 Roads measured and to be measured in Durham, North Carolina.



Analysis Projects

Four analysis projects began in 2012 to address specific research questions using the already available SHRP 2 NDS and roadway data. Priority was given to projects that will have direct applications for safety. These projects address road departure, offset left-turn lanes, driver inattention, and rear-end collisions on congested freeways.

Phase I of the projects involves a trial of the research approach and will produce a detailed plan for the full analysis. Projects selected for Phase II will carry out the full analysis in 2013. Brief descriptions of the four analysis projects follow.

Safety on Curves

The Iowa State University CTRE project will address the relationship between driver behavior and safety on curves. Crash rates are three times higher on horizontal curves than on straight road sections. Various roadway measures are applied to improve safety on curves, such as warnings with signs and rumble strips, delineations with chevrons and pavement markings, and paved shoulders and guardrails to minimize the impact of road departures.

Information is lacking about how drivers respond to these roadway measures and about why these roadway measures work or do not work. The CTRE study will use the NDS trip and roadway data to examine how drivers interact with the roadway environment and what roadway cues and measures are the most effective in influencing driver behavior. The study will help highway departments implement more cost-effective measures to prevent or mitigate road departure crashes on curves.

Rear-End Crashes

The University of Minnesota Center for Transportation Studies (CTS) will address rear-end crashes on congested freeways. These kinds of crashes produce substantial traffic delays, as well as injuries and fatalities.

The CTS study will use the NDS trip and roadway data to explore how the likelihood of a crash in these circumstances depends on factors such as vehicle speed, following distance, driver reaction time, and driver attention and distraction. The results will help DOT officials reduce crashes by suggesting cost-effective methods for warning drivers of current or periodic congestion and perhaps for reducing driver distraction.

Driver Inattention

The SAFER Vehicle and Traffic Safety Centre at Chalmers University, Sweden, will address driver inattention and crash risk. Driver distraction and



Offset left-turn lanes are the subject of an MRIGlobal study utilizing NDS and roadway data.

inattention is implicated in at least one-quarter of all crashes, yet no methods are available for measuring driver inattention or for estimating the effect of inattention on crash risk. The SAFER study will use NDS data to develop a measure of driver inattention from observable driver actions, such as eye glances away from the road, and will estimate how driver inattention and the roadway environment combine to influence crash risk. The results will help in establishing guidelines for how long a driver can safely look away from the road and in designing in-vehicle technologies to measure driver inattention and warn inattentive drivers.

Offset Left-Turn Lanes

MRIGlobal will evaluate offset left-turn lanes. More than eight percent of all traffic fatalities involve left-turn crashes at intersections. Vehicles waiting in standard left-turn lanes, in which the roadway's centerline continues straight through the intersection, however, may have the view of oncoming through-traffic obstructed by vehicles in the opposing left-turn lane.

One way to address this problem is to offset the left-turn lanes to the left, so that vehicles waiting to turn left are positioned to the left of the centerline on the opposite side of the intersection. Highway designers have accepted offset left-turn lanes in principle but without any conclusive evidence of beneficial effects on driver behavior or crashes.

The MRIGlobal study will use NDS and roadway data to analyze how driver left-turn behavior—such as gap acceptance—is influenced by intersection and

traffic characteristics and in particular by offset left-turn lanes. This will help DOT officials design intersections that balance construction and maintenance costs against crash risk.

NDS Data Access

Activities are under way to support implementation of the SHRP 2 results. The priority for the SHRP 2 safety focus area is to make the naturalistic driving study data and the associated roadway data accessible and usable for a range of researchers.

A data dissemination and user support project started this year to address this task. VTTI has established a SHRP 2 data access forum website,² which offers a data access guide, documentation on all NDS data files, sample data, and a video viewing tool, in addition to the opportunity to ask questions and share information online about the NDS data. NDS data that have been approved for public access will be added to this site.

Another implementation priority is planning for the long-term stewardship of the NDS data, to ensure that the data will be available and accessible to researchers after SHRP 2 concludes. FHWA is conducting initial activities through a contract with the Volpe National Transportation Systems Center.

Resources

http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-S05-RR-1.pdf.
www.shrp2nds.us/.

²<http://forums.shrp2nds.us/>.

Rapid Renewal, Accelerated Construction Schedules, and Worker Fatigue

J. ELIZABETH JACKSON AND TOM SANQUIST

Predictions of labor demand for the next 10 years indicate that 25,000 to 29,000 workers will be engaged in rapid renewal highway construction projects annually nationwide. This workforce is expected to sustain up to 1,300 occupational injuries caused by fatigue each year.

Working conditions associated with rapid renewal projects include off-peak hours, continuous construction on weekends, extended nighttime operations, and work in zones adjacent to traffic. These working conditions can increase workforce fatigue and stress, reducing the levels of workforce safety and productivity.

Rapid renewal construction is designed to minimize the impact of projects on traffic flow. As adoption of the approaches expands, however, concern has grown about the effects on the health and safety of the highway construction workforce. Investigators at Battelle Memorial Institute in Seattle are working with the second Strategic Highway Research Program (SHRP 2) to evaluate the effects of rapid renewal construction approaches on workforce fatigue.^a

Phase 1 of the research characterized the rapid renewal construction landscape, identifying typical construction scenarios, investigating the extent of worker and manager fatigue and responses to fatigue, outlining potential countermeasures and other mitigation strategies for fatigue, and estimating the future extent of rapid renewal construction and related workforce needs. Researchers analyzed more than a dozen rapid renewal construction projects in six states and targeted several for detailed studies.

The team conducted in-depth interviews with 20 management personnel at contractors and state departments of transportation and administered comprehensive surveys to 47 workers at three projects in Florida, New York, and Washington State. The survey work used validated scales to measure worker fatigue.

Findings demonstrated that work schedules could change at short notice, that weekly overtime was the norm, and that fatigue levels were substantially higher with more demanding schedules—for example, during weekend closures after a full week of work. Fatigue was widely acknowledged, but methods for dealing with the problem were informal and did not include adequate training.

Using research findings from other areas of transportation, combined with findings from the interviews and survey, the team developed sets of mitigations—that is, preventive and operational countermeasures to fatigue—to implement at the individual level and as features of the safety management system at the organizational level.

Phase 2 of the research is concluding. Battelle is developing an integrated suite of products for fatigue management to meet the needs of laborers and managers in the private and public sectors. Industry-relevant training about fatigue will tar-



PHOTO: MISSOURI DOT

Rapid renewal projects require construction workers to work into the weekends, in traffic-adjacent areas, and at night—conditions that can increase stress and fatigue.

get the populations at risk and will focus on prevention and mitigation in the work setting. Guidance for organizational practices and project work practices, along with work scheduling aids, will provide tools for incorporating fatigue prevention and mitigation strategies into a contractor's safety management system.

An outreach program is in development to increase stakeholder understanding and support for implementing best practices for fatigue management. Communications strategies and materials will target industry participants and will determine appropriate channels for dissemination to raise awareness of the new support tools.

The authors are with Battelle Memorial Institute, Seattle, Washington. Jackson is Research Scientist, Battelle Center for Analytics and Public Health, and Sanquist is Research Scientist, Pacific Northwest National Laboratory, Richland, Washington.

^aSHRP 2 Project R03, <http://apps.trb.org/cmsfeed/trbnetprojectdisplay.asp?projectid=2676>.

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