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NSTSCE

National Surface Transportation Safety Center for Excellence

Assessing the Safety Impact of Roadway Improvements Using Naturalistic Driving Data – Feasibility Study

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Technology
Impairment
Mobility
Infrastructure

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

EXECUTIVE SUMMARY

This project was sponsored by the National Surface Transportation Safety Center for Excellence (NSTSCE) to explore the feasibility of using Second Strategic Highway Research Program (SHRP 2) data, including the Roadway Information Database (RID), to evaluate the effectiveness of roadway safety improvements where traditional crash data are limited. During this project, the research team conducted two case studies based on naturalistic driving study (NDS) data from 200 trips. The two case studies evaluated the safety effects of a paving project with newly installed pavement and markings, and a median barrier replacement project with a newly installed and restored concrete median. The availability and suitability of SHRP 2 data for evaluating safety improvement projects were also assessed. During the case studies, a number of safety surrogate measures were used to develop a comprehensive understanding of how driver behavior changed with and without the safety treatment. The surrogate measures included speed, acceleration, lane-keeping, and car-following variables.

SUMMARY OF CASE STUDY FINDINGS

To assess the feasibility of using SHRP 2 safety data for effective evaluation of the safety impacts of roadway improvement projects, the research team conducted the following two case studies:

- **Case study #1 – Paving project:** A section of I-5 near Lakewood, Washington, 1.3 miles south of Berkeley Street to Gravelly Lake Drive. This project involved adding a pavement overlay on an approximately 3-mile long segment of northbound I-5. The project underwent construction in 2011. The purpose of this case study was to assess the safety impact of newly constructed pavement and pavement markings on daytime and nighttime driver behavior. Due to the limited before-construction data available in the SHRP 2 safety database, the research team compared safety data for the case study segment with data of a comparable freeway segment that did not undergo pavement rehabilitation.

  The case study results suggest that the new pavement and markings had an impact on driver safety behavior. Better pavement and pavement markings coincided with more significant differences in travel behavior during the nighttime than during the daytime. In addition, the newly rehabilitated section in general had slower speeds, more speed uniformity, and less longitudinal acceleration, but more and/or faster lane changes. In addition, the results indicate that the lane-keeping metrics were better for the freeway segment with improved pavement and markings, particularly during the nighttime.

- **Case study #2 – Concrete median barrier replacement project:** A section of I-5 near DuPont, Washington, from Mounts Road to Thorn Lane. The project's objective was to improve safety by installing better-designed concrete barriers and replacing previously damaged concrete barriers. This section of roadway closely resembles typical urban freeway settings, where both directions of traffic are separated by concrete median barriers with a narrow left shoulder on each side. The research team compared driver behavior before and after the improvement.

The results suggest that the barrier replacement also had some impact on driver behavior. The replacement of the median barrier seemed to result in higher mean speeds during both the daytime and nighttime, which suggests a perceived improvement in driving conditions by users. The median improvement also resulted in a higher mean lateral acceleration rate during the daytime and higher lateral acceleration variance during the nighttime, which seems to indicate more and/or faster lane changes. The results also suggest higher lane deviation to the left side but lower lane deviation variance during both the daytime and nighttime.

The two case studies illustrate two different methods for studying the effectiveness of roadway improvements on safety. The paving project case study compared driver behavior data collected at the project site after the roadway improvement with data from an adjacent site with similar roadway conditions but without the pavement improvement. The median barrier project case study compared data on the same segment of road before and after the improvement project. The two different methods illustrate the flexibility available with SHRP 2 safety data.

Note that both case studies were based on limited sample data. The findings of impact on driver behavior may change when a full data set is used.

DATA AVAILABILITY AND SUITABILITY FOR FULL ANALYSES

This research also assessed the availability and suitability of SHRP 2 data for evaluating the safety impact of roadway improvements:

- SHRP 2 time series data contain rich information depicting vehicle kinematics and driver behavior. In particular, the database contains accurate and high-frequency data on speeds, longitudinal and lateral accelerations, and to a lesser extent, lane offsets. Such data are the basis for several common safety surrogate measures that previous research has found to be closely related to crash frequency and severity.

- SHRP 2 events data can provide valuable information on how drivers act in relation to the same types of roadway improvements during crashes or near-crashes. However, due to the relatively rare nature of such events, the SHRP 2 database contains a limited number of crashes and near-crashes for certain roadway locations. To conduct meaningful research based on SHRP 2 events, a sufficiently large mileage of roadway should be used. This fact limits the study of roadway improvements to those that were applied to a very long section of road or to a large number of sections. The two case studies in this research collectively involved data for approximately 8 miles of roadway. The research team could not identify a sufficient number of crashes and near-crashes for analysis.

- The RID information should be complemented by data directly from states in some cases. Particularly for this study, RID contained limited information about roadway projects and was not sufficient for the two cases studies. The research team had to collect additional information on the projects directly from state data sources.

- The RID crash data can be used for suitable studies that involve a sufficiently large mileage of roadway. The SHRP 2 RID database contains crash data for three years (i.e., 2011–2013). When analyzing an individual roadway section of sufficient length or analyzing multiple roadway sections that are collectively of sufficient length, the crash data can provide valuable information about the safety impacts of roadway improvements. However, in these two case studies the research team did not identify a sufficient number of crashes on the studied roadways.

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CHAPTER 1. INTRODUCTION

BACKGROUND

Traffic safety continues to be a major concern for the traveling public, government agencies, and transportation professionals. According to Fatality Analysis Reporting System (FARS) data, a total of 32,719 people died in traffic crashes in 2013, which translates to approximately 4 traffic-related fatalities every hour.[(1)] In addition, vehicle crashes remain the leading cause of death for Americans aged 34 years or younger. Motor vehicle crashes across the nation result in a total annual societal cost of more than $230 billion.[(2)]

Each year, federal and state transportation agencies devote significant resources to the safety and mobility of the nation's roadway network. Examples of safety-related projects range from pavement rehabilitations, roadway expansions, and geometric realignments and modifications, to traffic control improvements. With such a range of choices, transportation agencies need to be able to assess the effectiveness of specific safety improvements to facilitate planning. A variety of methods are traditionally used for such evaluations:

- Crash comparison studies. These studies usually involve before-after or with-without comparison analysis of actual or statistically derived (e.g., empirical Bayes) crash rates, characteristics, and/or severity ratios.

- Safety surrogate studies. When crash data are not available or are insufficient, researchers frequently rely on analyses of safety surrogate measures such as speed, acceleration, and time-to-collision (TTC). These studies typically compare changes in safety surrogate variables for traffic before and after the safety improvements or between sites with and without the safety improvements. Favorable changes in such variables are used to indicate the effectiveness of the safety improvements.

- User opinion surveys. User surveys are frequently used to complement crash or safety surrogate analyses when evaluating the effectiveness of safety improvements. Questionnaires are sent out to collect user feedback on safety improvements for aspects such as effectiveness, user-friendliness, and/or user preferences.

Safety evaluation studies with traditional methods, such as those listed above, are frequently subject to a number of data and methodological limitations.

- Crash sample sizes are frequently not large enough. Crashes are low-probability events. To obtain a large sample of crash data, studies need to involve significant spatial coverage (i.e., a large number of roadways) and/or temporal coverage (i.e., several years). Individual safety improvements are frequently applied to point locations or a relatively short segment of roadway. Therefore, it can be extremely difficult to obtain crash data to support statistically significant results.

- Traffic data collection can be time-consuming and resource-demanding. In order to calculate safety surrogate measures, researchers need to collect field data such as vehicle kinematics, traffic data, and driver behavior data. Such data collection requires specialized equipment and can require significant staff time and resources.

- Crashes are studied as single events instead of sequences of events. Traditional crash data treat each crash as a single record, describing the results and characteristics of the crash event. Such data sometimes lack information describing exactly how the crash took place, such as the sequence of events before and during the crash and how certain factors played a role in the entire event sequence. As such, safety treatment evaluations based on traditional crash data may reach a conclusion about *whether* a treatment is effective but not *how* the treatment is effective.

- It is difficult to track individual drivers with traditional data. Traditional traffic data are collected based on locations instead of vehicles. Most data collection devices are installed at fixed locations, and data collected in this manner reflect "snapshots" of specific locations. It is typically difficult to track large numbers of individual vehicles with such methods due to the limited number of vehicles making repeated passes at the same location and the reliability of available recognition techniques.

Recently, the Second Strategic Highway Research Program (SHRP 2) carried out a large mobile data collection effort as part of the Naturalistic Driving Study (NDS) project.(3) The collected naturalistic driving data contain detailed information about driver behavior, driver demographics, and vehicles. A parallel effort, the SHRP 2 Roadway Information Database (RID), provides relatively detailed traffic and roadway information for the six NDS sites.(3) The linkages between the driving and roadway data allow researchers to effectively identify driving data on particular road segments of interest.(4) It is noteworthy that the RID also includes historic crash data and transportation project data. Thus, together the SHRP 2 data sets enable a large variety of safety and traffic-related analyses.

Objective and Scope

This project was sponsored by the National Surface Transportation Safety Center for Excellence (NSTSCE) to explore the feasibility of using SHRP 2 data for evaluating the effectiveness of roadway safety improvements. The study focused on SHRP 2 time series data, event data, and RID data.

CHAPTER 2. SHRP 2 NDS AND RID DATA

SHRP 2 NDS DATA

The NDS field studies were conducted between 2010 and 2014. Data collection efforts were carried out at six sites:[5]

- Bloomington, Indiana;
- Central Pennsylvania;
- Tampa Bay, Florida;
- Buffalo, New York;
- Durham, North Carolina; and
- Seattle, Washington.

During data collection, each study vehicle was instrumented with a data acquisition system (DAS) consisting of a forward radar, four video cameras, accelerometers, Global Positioning System (GPS) receivers, computer vision lane-tracking capability, and data storage equipment (Figure 1).

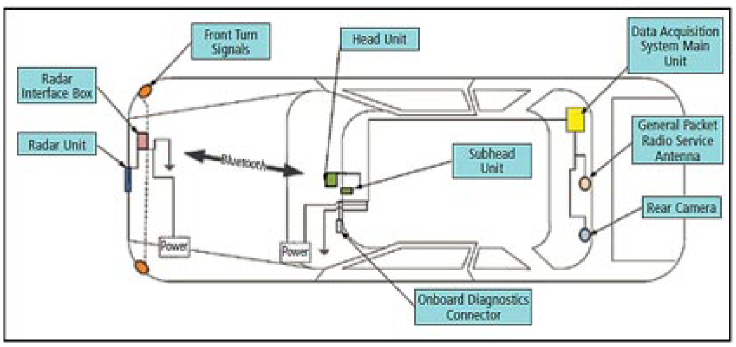


Figure 1. Diagram. NDS DAS schematic view.[5]

The final NDS data set contains several types of data files collected based on approximately 3,400 vehicles and 3,600 drivers (including unregistered drivers).[6] The following is a summary of the major data files in addition to the recorded video and imagery data in the current NDS database:[6]

- Trip summaries, which contain summary information of continuous driving data files based on the time series data collected in the field. Each record describes the basic characteristics of an individual trip such as its origin and destination, duration, distance, critical timestamps, and maximum speed. Currently, the SHRP 2 database contains information about approximately 5.4 million trips. Figure 2 through Figure 7 illustrate the distribution of the NDS trips for the six SHRP 2 sites, respectively.

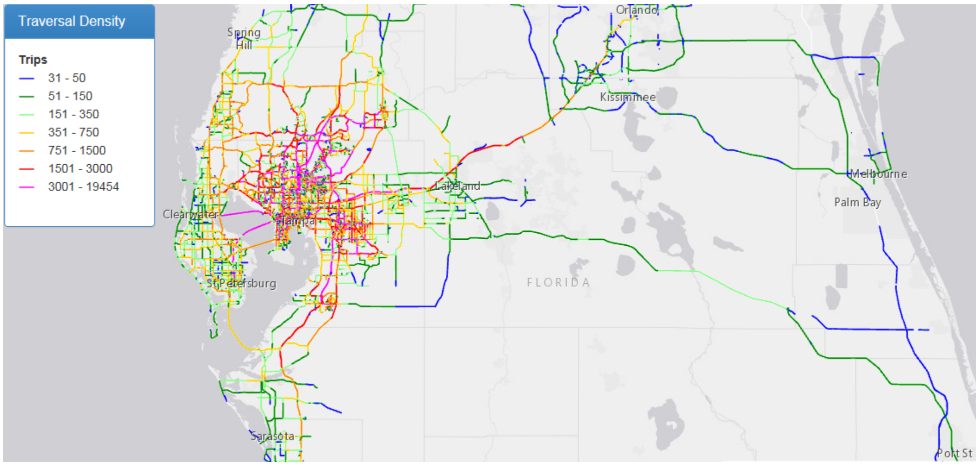


Figure 2. Map. SHRP 2 trip density for Florida.[6]

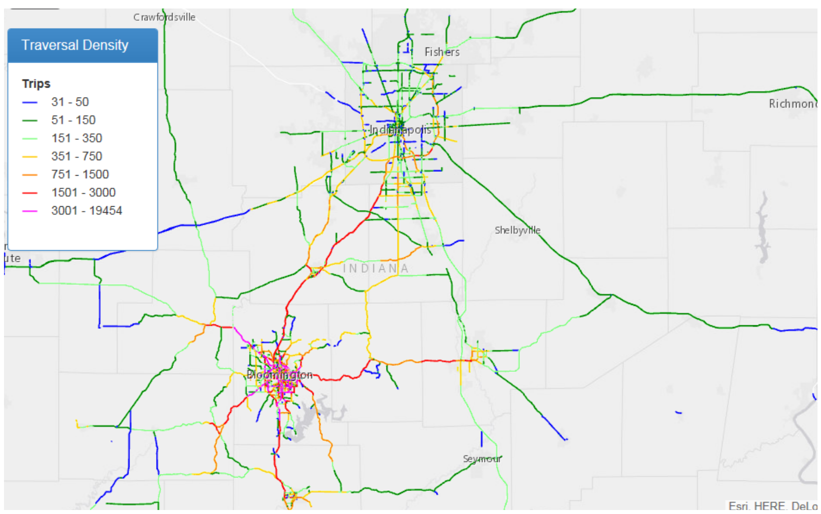


Figure 3. Map. SHRP 2 trip density for Indiana.[6]

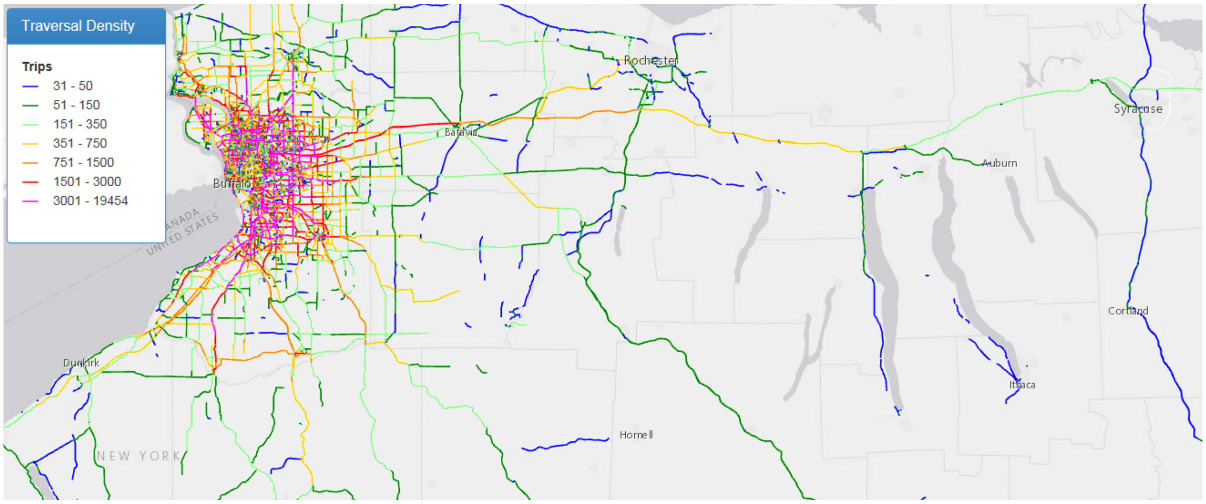


Figure 4. Map. SHRP 2 trip density for New York.[6]

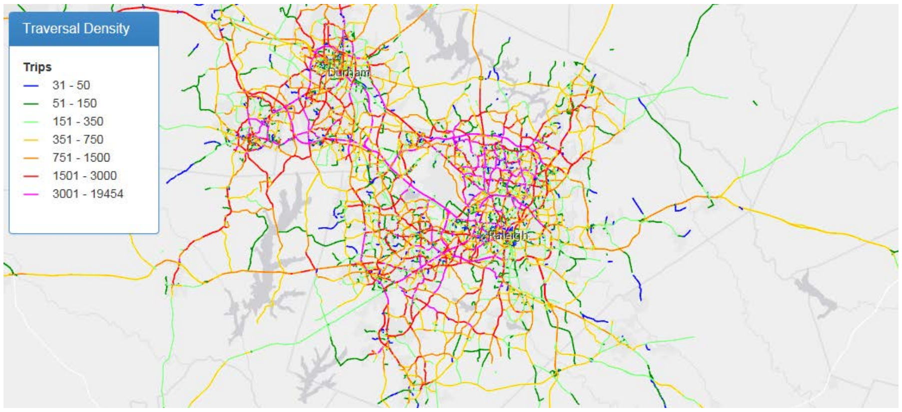


Figure 5. Map. SHRP 2 trip density for North Carolina.[6]

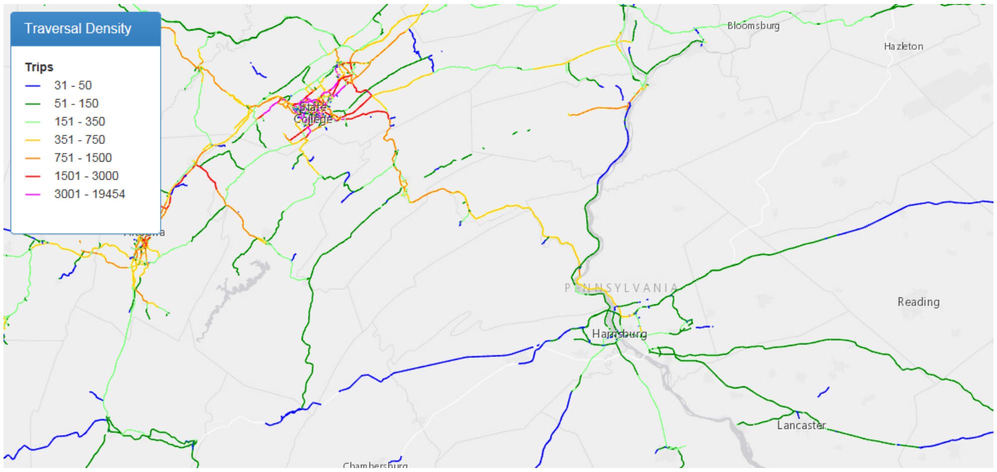


Figure 6. Map. SHRP 2 trip density for Pennsylvania.[6]

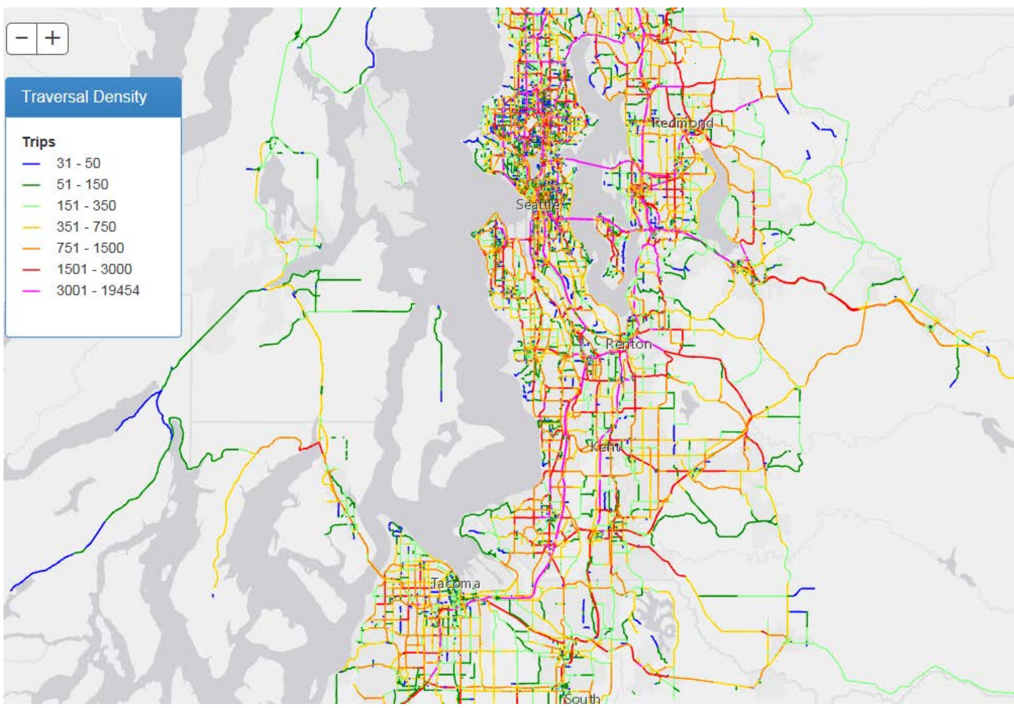


Figure 7. Map. SHRP 2 trip density for Washington.[6]

- Driver data, which describe the study participants with demographic information, driving history and skills, and physical and psychological characteristics that may affect driving. Figure 8 and Figure 9 show the number of drivers who participated the SHRP 2 study by age group and the number of trips collected by driver age group, respectively.

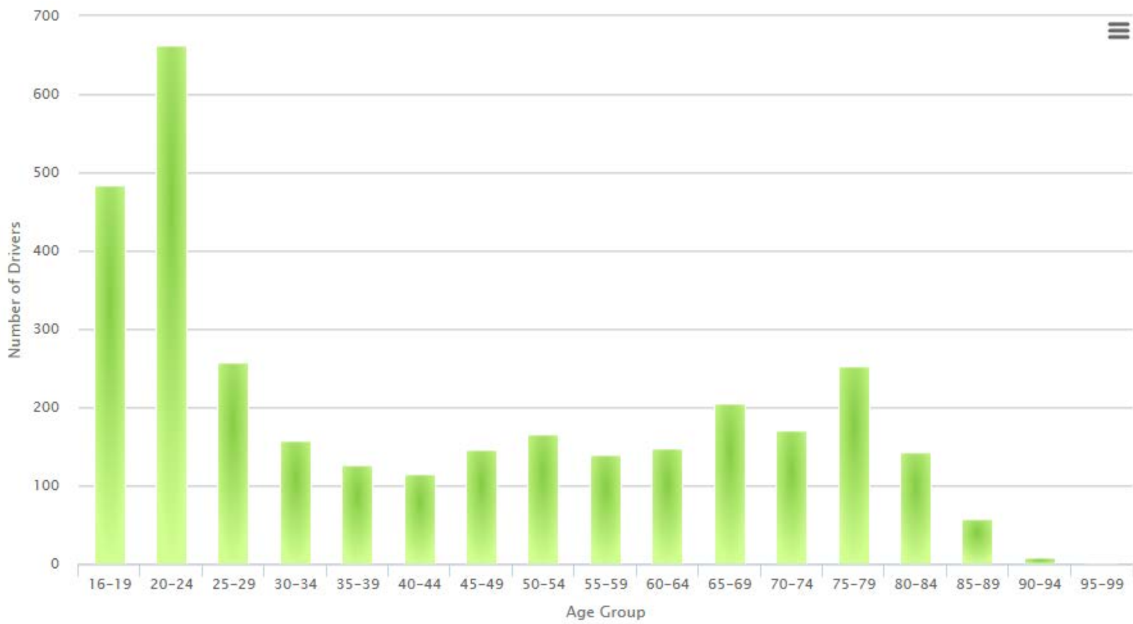


Figure 8. Graph. Number of participants by age group.[6]

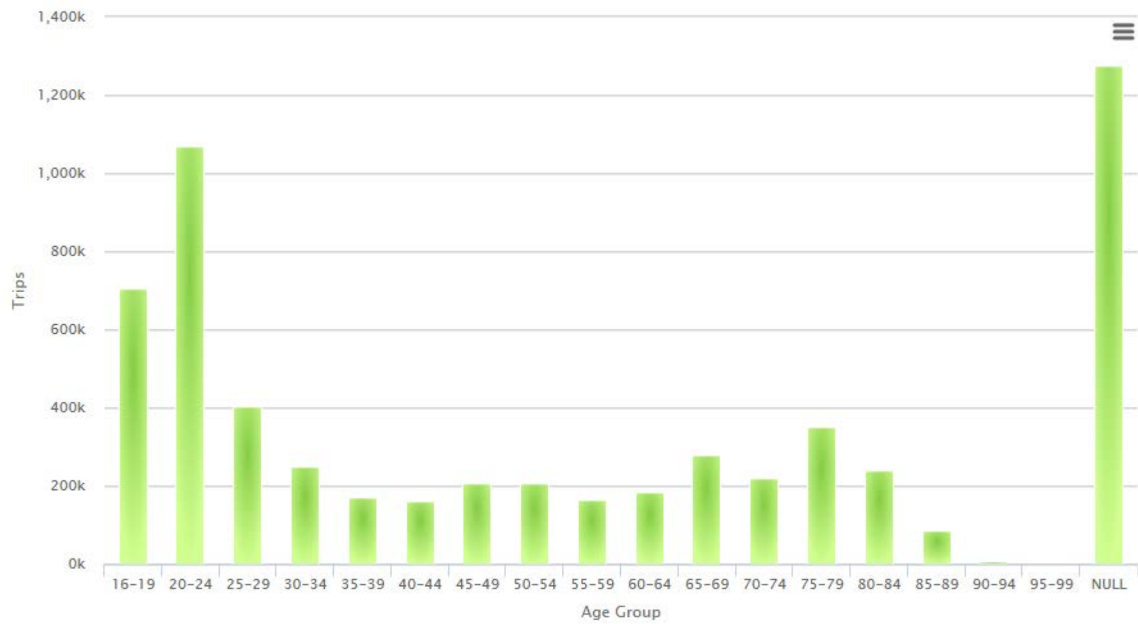


Figure 9. Graph. SHRP 2 trips collected by driver age group.[6]

- Vehicle data, which include detailed variables describing each vehicle that participated in the study.

- Time series data, which include a large set of vehicle and event descriptors collected from the participating vehicles with the onboard DAS at various frequencies, such as timestamps, speeds, acceleration rates, coordinates, and vehicle conditions. All data points of the same time series file were assigned to the same file ID. Depending on the particular sensor characteristics, time series data were collected at their native frequencies. For example, GPS coordinates and vehicle kinematic data from GPS receivers were collected at a frequency of 1 Hz. Data from many other onboard sensors were collected at a frequency of 10 Hz.

- Event data, which include video files and descriptive information of all identified events of interest, such as crashes, near-crashes, and baseline events. A near-crash is defined as any circumstance that requires a rapid, evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash. Baseline events are epochs of data selected for comparison to crashes and near-crashes. Table 1 lists the number of events by data collection site and event type.

Table 1. SHRP 2 events by event severity and data collection site.

Event Severity	Crash	Near-Crash	Crash-Relevant	Non-Conflict	Non-Subject Conflict	Baseline	Total
Florida	414	678	4	1	19	7,386	8,502
Indiana	117	143	1	0	1	2,480	2,742
New York	298	489	3	0	14	7,149	7,953
North Carolina	224	400	3	0	7	5,235	5,869
Pennsylvania	74	92	1	0	0	2,394	2,561
Washington	326	873	2	0	15	7,281	8,497
Total	1,453	2,675	14	1	56	31,925	36,124

The NDS data are currently hosted at the Virginia Tech Transportation Institute (VTTI) International Center for Naturalistic Driving Data Analysis.(7) In the Center, a 48-node compute cluster moves data between the field and the data center, decrypts data, prepares data files for ingestion to a 500 TB scientific data warehouse, processes video files, and provides a platform for advanced analytical processing. A peta-scale IBM® high performance computing (HPC) storage system facilitates the long-term storage of raw data and processes NDS data while maintaining data in an online status. To improve efficiency, the NDS data are stored in an IBM DB2-based relational database structure that supports data analysis and retrieval through Structured Query Language (SQL).

SHRP 2 ROADWAY INFORMATION DATABASE

RID data incorporate both roadway and safety data originated at state Departments of Transportation (DOTs) and data collected by instrumented vehicles on selected routes. There are three major types of data in the RID database:

- Roadway data describing basic characteristics of selected roadways at all study sites, such as horizontal and vertical curvature, grade, cross-slope/superelevation, travel lanes, shoulder, and the presence of certain traffic control measures;
- Historical crash data and crash-data-related documents;
- Historical transportation project data for Washington;
- List of safety-related traffic laws for all SHRP 2 states;
- Aerial imagery data between 2011 and 2013 for all SHRP 2 states;

- Weather-related data (e.g., daily/hourly precipitation and weather station locations) for all SHRP 2 states;
- List of safety campaigns conducted by state DOTs during the SHRP 2 NDS study in Indiana, North Carolina, Pennsylvania, and Washington;
- Work zone and lane use information for Florida and New York.

For each NDS state, the roadway data are organized in an Esri® file geodatabase as several feature classes with database tables listing the values for their key attribute fields. Using data for North Carolina as an example, among the various RID feature classes, the Links Polyline feature class depicts all state-maintained roadways and local roadways for selected counties in the Durham-Raleigh region (Figure 10). The key attribute of this feature class is LINKID, which is a unique road segment identifier used across different types of SHRP 2 data. Examples of the other attributes of the Links feature class include from- and to-node IDs, route name, and functional class.

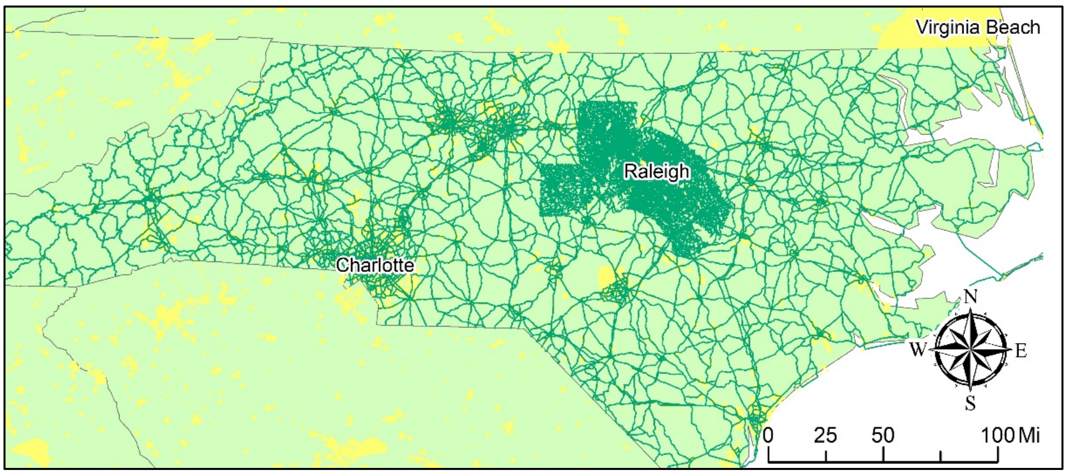


Figure 10. Map. RID Links feature class for North Carolina.

Other feature classes included in the RID database for North Carolina are:

- Routes, which is a Polyline M feature class with the same coverage as that of the Links feature class. The Routes feature class is intended to be used as the route layer for linearly referencing RID roadway data onto the corresponding roadways. The major attributes of the feature class include route name, and from and to measures.
- Sections, which is a Polyline M feature class containing roadway segments (many overlapping), each of which depicts one of the following variables: through lanes, ownership, maintenance operations, facility type, county code, functional system, urban code, access control, and average annual daily traffic (AADT). This feature class covers only state roadways.
- TOPS, which is a Polyline feature class depicting several types of information for a scattered sample of roadway segments, such as traffic information (e.g., AADT), roadway geometry (e.g., curves and lanes), pavement condition (e.g., rutting and

pavement thickness), and other general roadway information (e.g., functional class and facility type).

- Shoulder, which is a Polyline feature class indicating if a paved shoulder is present for selected roadway segments.
- Lighting, which is a Polyline M feature class indicating the segments of selected routes that have roadway lights.
- Alignment, which is a Polyline feature class that depicts roadway alignment elements such as tangents, curves, and superelevation for a selected sample of roadways.
- Barrier, which is a Polyline feature class depicting roadside barrier information (e.g., barrier type and start/end treatment type) for selected roadways.
- Lane, which is a Polyline M feature class that depicts the lane configuration for selected routes, such as number of lanes, presence of turn and acceleration/deceleration lanes, and lane width.
- Location, which is a Polyline M feature class depicting the roadway grade and cross slope values along the selected routes shown.
- MedianStrip, which is a Polyline M feature class depicting the roadway median type along the selected routes.
- RumbleStrip, which is a Polyline M feature class depicting the location and type of rumble strips along the selected roadways.
- RouteIntersections, which is a point feature class depicting the locations and other basic information of the intersections along the selected roadways.
- Signs, which is a point feature class depicting the location and type of traffic signs along the selected roadways.
- Nodes, which is a point feature class depicting the locations of beginning and ending points based on the Link feature class.

CHAPTER 3. METHODOLOGY AND DATA COLLECTION

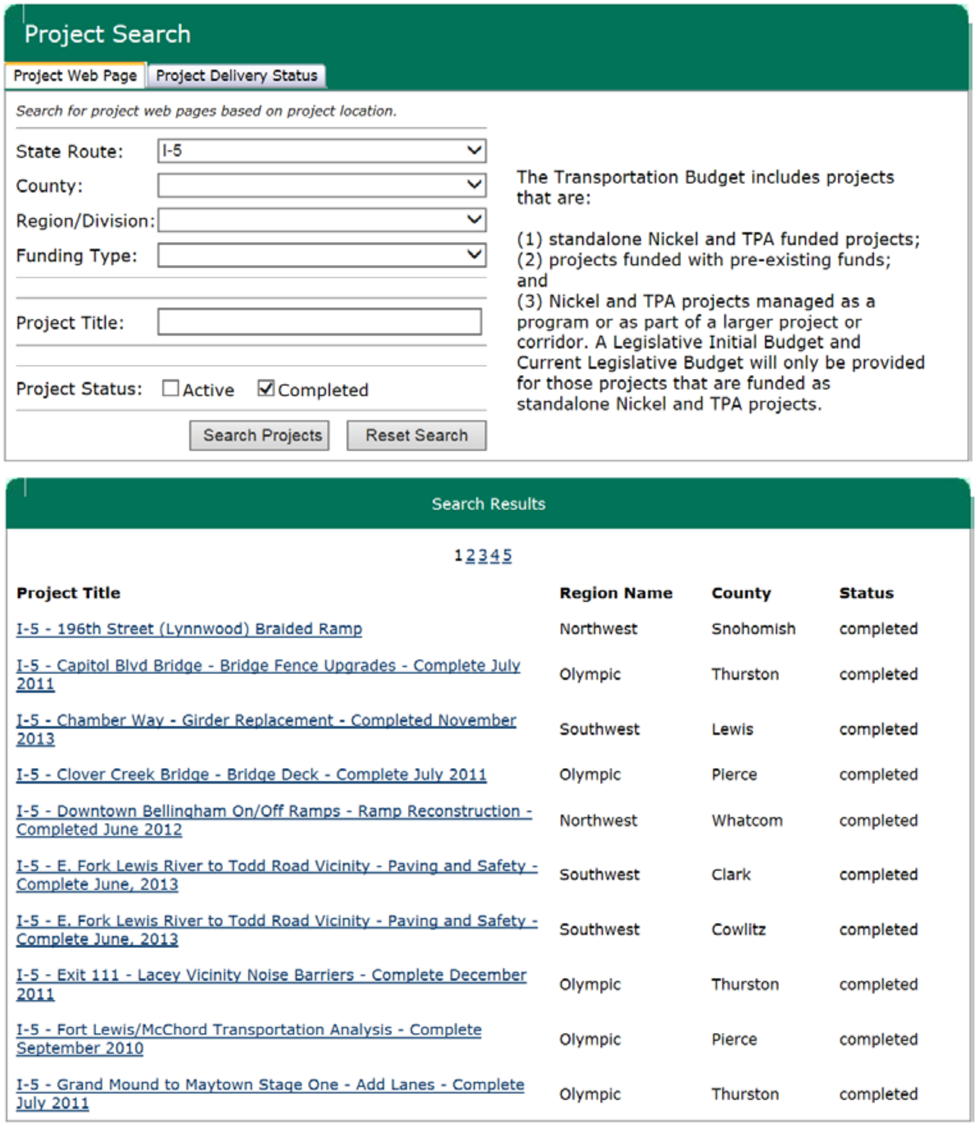
To assess the feasibility of using SHRP 2 safety data for evaluating the safety effectiveness of roadway improvements, the research team conducted several tasks. In addition to the SHRP 2 and RID data review described in Chapter 2, the research team identified two suitable roadway improvement projects for case studies, requested and processed the needed SHRP 2 data, conducted two case studies, and developed conclusions and recommendations based on the findings.

ROADWAY IMPROVEMENT PROJECT IDENTIFICATION

Project Identification Process

For the purpose of this project, the research team only used transportation projects from the Washington State Department of Transportation (WSDOT). The RID database included relatively comprehensive roadway and related data for Washington, including a list of and brief information on historical WSDOT roadway projects. However, the projects in the RID database were represented as Point features without showing detailed project limits. In addition, the RID project data included only two timestamps for the projects: advertising date and completion date. Frequently, months may pass from the date a project is advertised until construction actually starts. Clearly, the limited project information in the RID was not sufficient for this study.

Per conversations with WSDOT officials and through online searches, the research team identified a WSDOT website[(8)] that allowed queries of statewide active and completed transportation projects (Figure 11). Most projects were linked with a project website that provided more-detailed information, including a brief description of the work involved, project location, project start and completion dates, total expenditures, and the engineer in charge of the project. This data source was used to supplement the RID project data.


Project Search

Project Web Page | Project Delivery Status

Search for project web pages based on project location.

State Route: I-5

County:

Region/Division:

Funding Type:

Project Title:

Project Status: ☐ Active ☑ Completed

Search Projects | Reset Search

The Transportation Budget includes projects that are:

(1) standalone Nickel and TPA funded projects;
(2) projects funded with pre-existing funds; and
(3) Nickel and TPA projects managed as a program or as part of a larger project or corridor. A Legislative Initial Budget and Current Legislative Budget will only be provided for those projects that are funded as standalone Nickel and TPA projects.

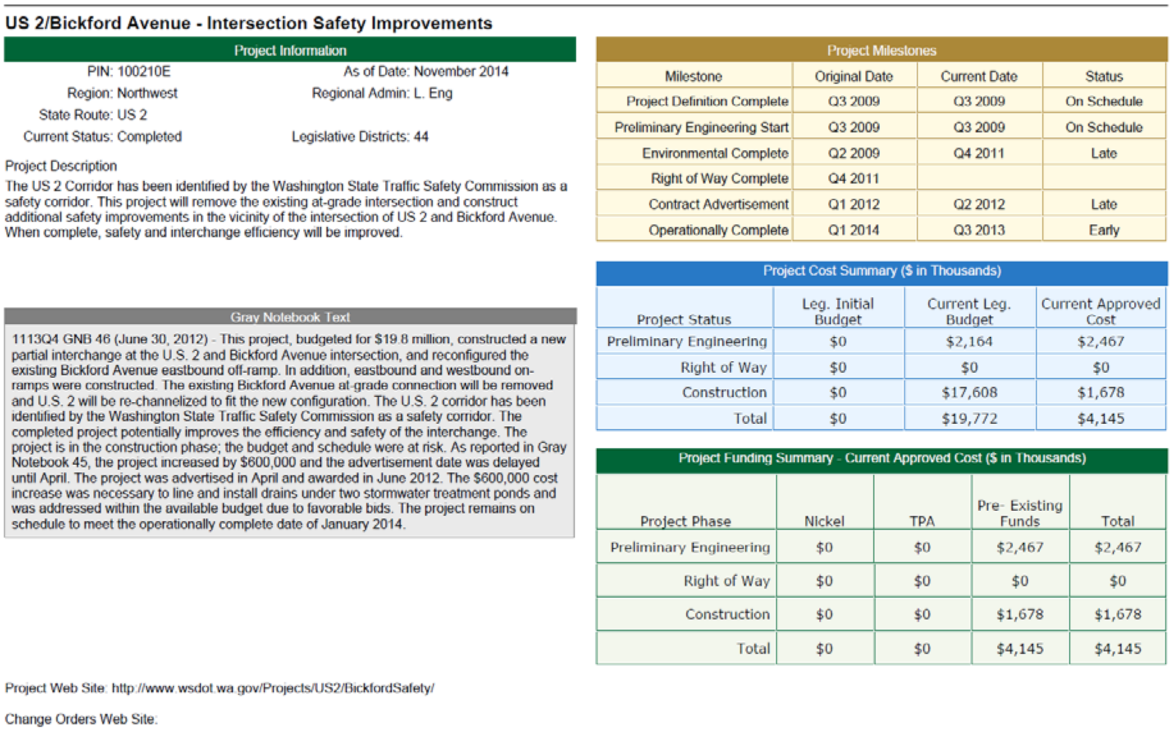
Search Results

1 2 3 4 5

Project Title	Region Name	County	Status
I-5 - 196th Street (Lynnwood) Braided Ramp	Northwest	Snohomish	completed
I-5 - Capitol Blvd Bridge - Bridge Fence Upgrades - Complete July 2011	Olympic	Thurston	completed
I-5 - Chamber Way - Girder Replacement - Completed November 2013	Southwest	Lewis	completed
I-5 - Clover Creek Bridge - Bridge Deck - Complete July 2011	Olympic	Pierce	completed
I-5 - Downtown Bellingham On/Off Ramps - Ramp Reconstruction - Completed June 2012	Northwest	Whatcom	completed
I-5 - E. Fork Lewis River to Todd Road Vicinity - Paving and Safety - Complete June, 2013	Southwest	Clark	completed
I-5 - E. Fork Lewis River to Todd Road Vicinity - Paving and Safety - Complete June, 2013	Southwest	Cowlitz	completed
I-5 - Exit 111 - Lacey Vicinity Noise Barriers - Complete December 2011	Olympic	Thurston	completed
I-5 - Fort Lewis/McChord Transportation Analysis - Complete September 2010	Olympic	Pierce	completed
I-5 - Grand Mound to Maytown Stage One - Add Lanes - Complete July 2011	Olympic	Thurston	completed

Figure 11. Screen capture. WSDOT website listing statewide active and completed projects.(8)

Using the project website, the research team generated a report of all completed projects contained in the project database, which resulted in a PDF file listing 644 WSDOT projects finished prior to November 2014. For each project, the list included information such as project description, location, project milestones by quarter, cost summary, and project funding (Figure 12). Note that the WSDOT project website did not have the ability to allow users to query completed projects by critical timestamps (e.g., construction start date or completion date).



US 2/Bickford Avenue - Intersection Safety Improvements

Project Information

PIN: 100210E
As of Date: November 2014
Region: Northwest
Regional Admin: L. Eng
State Route: US 2
Current Status: Completed
Legislative Districts: 44

Project Description

The US 2 Corridor has been identified by the Washington State Traffic Safety Commission as a safety corridor. This project will remove the existing at-grade intersection and construct additional safety improvements in the vicinity of the intersection of US 2 and Bickford Avenue. When complete, safety and interchange efficiency will be improved.

Gray Notebook Text

1113Q4 GNB 46 (June 30, 2012) - This project, budgeted for $19.8 million, constructed a new partial interchange at the U.S. 2 and Bickford Avenue intersection, and reconfigured the existing Bickford Avenue eastbound off-ramp. In addition, eastbound and westbound on-ramps were constructed. The existing Bickford Avenue at-grade connection will be removed and U.S. 2 will be re-channelized to fit the new configuration. The U.S. 2 corridor has been identified by the Washington State Traffic Safety Commission as a safety corridor. The completed project potentially improves the efficiency and safety of the interchange. The project is in the construction phase; the budget and schedule were at risk. As reported in Gray Notebook 45, the project increased by $600,000 and the advertisement date was delayed until April. The project was advertised in April and awarded in June 2012. The $600,000 cost increase was necessary to line and install drains under two stormwater treatment ponds and was addressed within the available budget due to favorable bids. The project remains on schedule to meet the operationally complete date of January 2014.

Project Milestones

Milestone	Original Date	Current Date	Status
Project Definition Complete	Q3 2009	Q3 2009	On Schedule
Preliminary Engineering Start	Q3 2009	Q3 2009	On Schedule
Environmental Complete	Q2 2009	Q4 2011	Late
Right of Way Complete	Q4 2011		
Contract Advertisement	Q1 2012	Q2 2012	Late
Operationally Complete	Q1 2014	Q3 2013	Early

Project Cost Summary ($ in Thousands)

Project Status	Leg. Initial Budget	Current Leg. Budget	Current Approved Cost
Preliminary Engineering	$0	$2,164	$2,467
Right of Way	$0	$0	$0
Construction	$0	$17,608	$1,678
Total	$0	$19,772	$4,145

Project Funding Summary - Current Approved Cost ($ in Thousands)

Project Phase	Nickel	TPA	Pre- Existing Funds	Total
Preliminary Engineering	$0	$0	$2,467	$2,467
Right of Way	$0	$0	$0	$0
Construction	$0	$0	$1,678	$1,678
Total	$0	$0	$4,145	$4,145

Project Web Site: http://www.wsdot.wa.gov/Projects/US2/BickfordSafety/

Change Orders Web Site:

Figure 12. Screen capture. Project information included on the generated project list.

A preliminary examination of the NDS database showed that the NDS data collection activities in Washington took place between February 23, 2011, and December 3, 2013. To allow for a sufficient window of NDS data collected before and after each project, the research team selected only those projects for which construction took place between July 2011 and September 2013, resulting in 129 candidate projects. A further analysis of the projects is shown in Table 2.

Table 2. List of WSDOT roadway improvement projects by type.

Project Category	Description	No. of Projects
Added capacity projects	Projects that increase existing capacity, such as roadway expansion, construction of new roadways, and addition of through lanes at intersections	8
Bridge-related projects	Bridge structure and related improvements	11
Intersection safety improvement projects	Intersection improvement projects with safety as the primary goal, such as adding turning lanes, conversion to roundabouts, and adding traffic signals	9
Roadway operations/safety improvement projects	Traffic control and roadway improvements mainly for the purpose of improving operations and safety	19
Pedestrian/bicycle-related projects	Construction of new or improved pedestrian or bicycle facilities, such as adding/replacing bicycle-related signs and markings, and construction of sidewalks or crosswalks	5
Pavement-related projects	Projects to improve pavement condition, such as pavement resurfacing, crack sealing, chip sealing, and patching	52
Other projects	Projects that do not fall in any of the above categories	25

Final Projects Used for Analysis

The researchers selected two case study projects based on project type, construction time, and SHRP 2 trip density. The two projects were:

- Case study #1: A paving project on a segment of I-5 near Lakewood, Washington, 1.3 miles south of Berkeley Street to Gravelly Lake Drive. This project involved pavement overlay on an approximately 3-mile segment of northbound I-5. Construction of the project started in April 2011 and was completed in October 2011. This project was selected to verify if the better pavement condition and newly installed pavement markings/markers had an impact on driver behavior. During this study, the research team only used data for continuous freeway segments between interchanges (Figure 1). To eliminate the impacts of ramps and auxiliary lanes, SHRP 2 data from interchanges were not used.

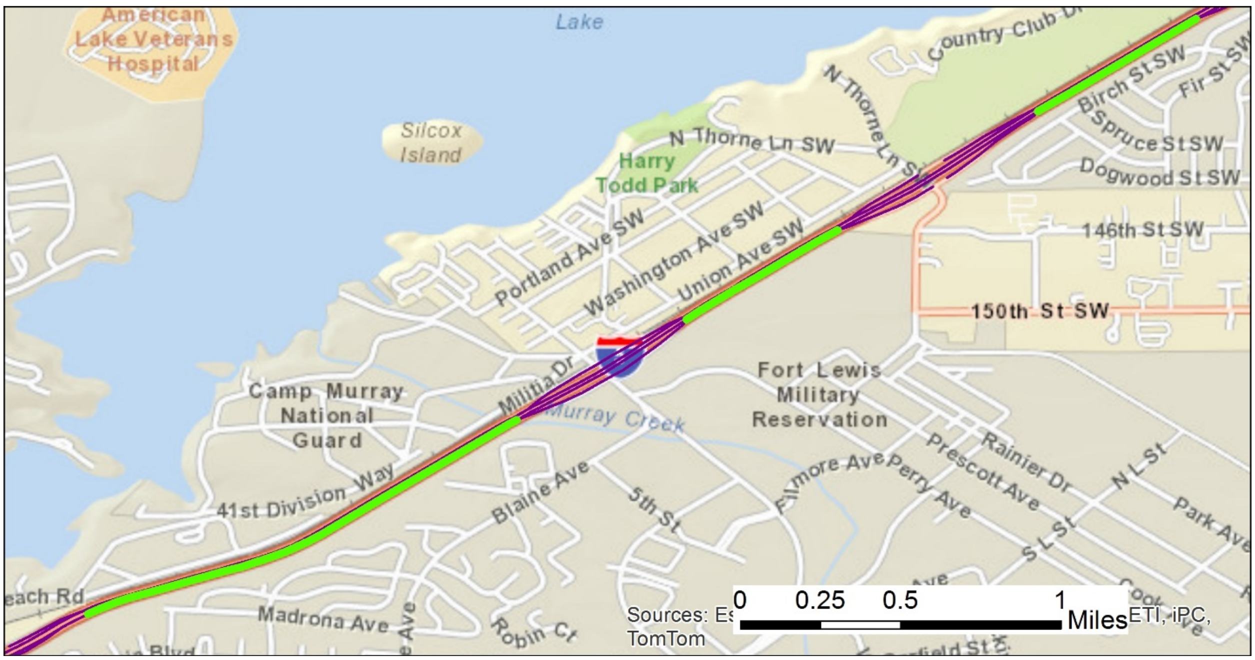


Figure 13. Map. Pavement overlay project section on I-5.

- Case study #2: A concrete median barrier replacement project on a segment of I-5 near DuPont, Washington, from Mounts Road to Thorn Lane. This project took place approximately between May and October 2012. The project was categorized as a safety project to improve safety by replacing damaged concrete barriers along the roadway segment. The I-5 roadway segment was approximately 5-miles long (Figure 14). This section of roadway closely resembles typical urban freeway settings where both directions of traffic are separated by concrete median barriers with a narrow left shoulder on each side (Figure 15).

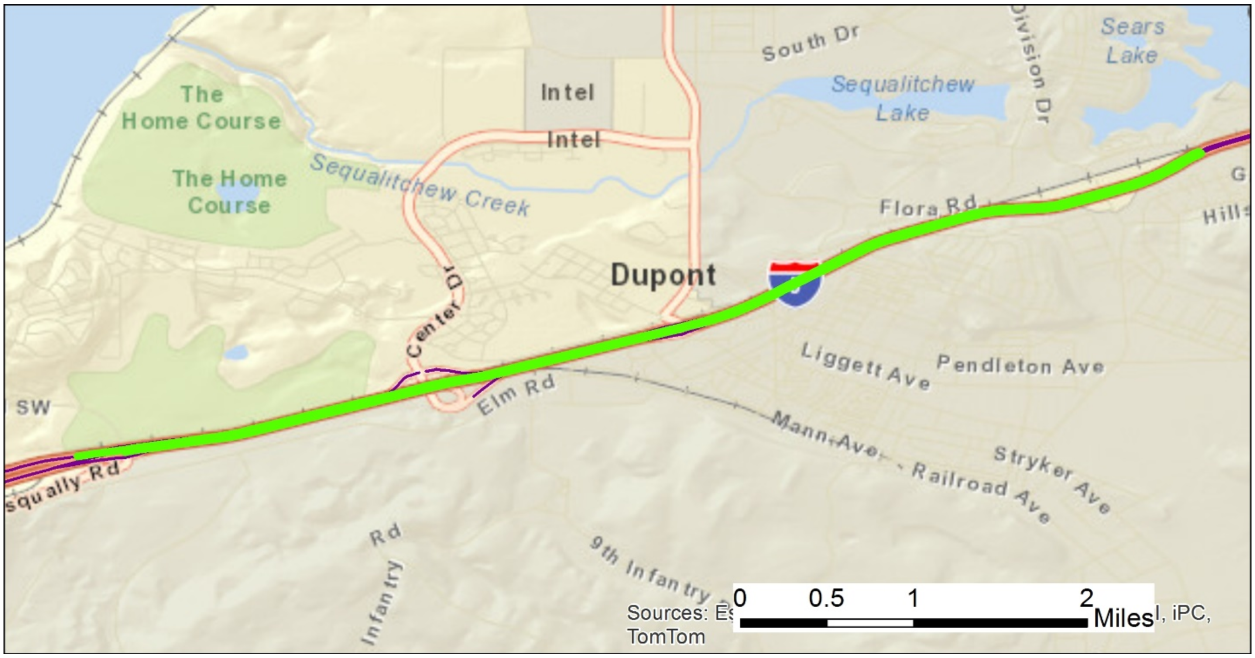


Figure 14. Map. Median barrier replacement project section on I-5.

Figure 15. Photo. I-5 cross-section configuration and median barriers after replacement.

SAFETY SURROGATES AND STATISTICAL METHODOLOGY

The research team focused on the analysis of NDS time series data for the case studies. Initially, the research team planned to use NDS event data and RID crash data for the case studies as well. However, the research team did not identify any NDS crashes or near-crashes for the roadway sections where the selected projects took place. The RID database included data of actual crashes from the WSDOT crash database. Similarly, due to the limited scope of this phase, the research team only identified a handful of crashes to study, which was not statistically sufficient for meaningful analysis.

Consequently, the time series data analysis was based on a number of safety surrogates in an effort to understand crash risks systematically and statistically. The researchers identified the safety surrogates based on a comprehensive literature review, relevant research experience in previous safety studies, and time series data availability.

To date, significant research has been conducted to identify safety-related surrogate measures and to quantify their association with crash risks and events. Depending on the areas of interest defined by crash type (e.g., rear-end versus head-on) and location (e.g., roadway segment versus intersections), a variety of safety surrogates have been used in the absence of actual crash data during safety-related studies. The following is a list of surrogate measures that were used in this study:

- Speed. Speed is commonly considered a major contributing factor to crashes and crash severity.(9- 15) Studies have suggested that overall crash involvement as a function of travel speed generally follows a U-shaped curve with crash likelihood increasing quadratically with the increase of absolute difference between one's travel speed and the predominant speed on the roadways.(16)

- Longitudinal acceleration rate, which is a measure of speed change during a certain period of time. The measure was used in this study to understand the magnitude and frequency of speed changes as a function of independent variables such as light level during the nighttime. Studies have found that crash-involved drivers frequently engage in abrupt deceleration behavior.(14) Longitudinal acceleration was also used as a major indicator of crashes and near-crashes during the SHRP 2 NDS study.(17)

- Lane-keeping measures including lane position offset (i.e., distance of the vehicle to the center of the lane) and lateral acceleration rate. Lane position offset has been widely used as a surrogate measure for lane departure crashes.(9) Deviations from a travel lane have been associated with an increase in the likelihood of a vehicle being involved in fixed-object and multiple-vehicle collisions. Lateral acceleration rate may provide information about a vehicle's lane-keeping behavior and evasive maneuvers that are closely related to crash risks. Lateral acceleration was also used as an indicator of near-crashes and crashes during the SHRP 2 NDS study.(17)

- TTC, which measures the time difference between two successive vehicles with the assumption that a collision occurs if none of the involved parties change the current speed or deviate from the travel path. TTC is statistically related to crash likelihood and has been used as a safety surrogate in studies to indicate crash risks.(9, 15, 17, 18) Note that TTC measurements can be obtained at any point of time for any two objects of interest regardless of whether the two objects collide subsequently or not. Depending on travel speed, a threshold TTC value (e.g., 4 seconds)(17) may be obtained such that any value lower than the threshold represents a significant probability of a vehicle crash. During this study, the research team also analyzed two variables closely related to TTC: following distance and relative speed. The former is the distance between the vehicle and the proceeding vehicle, and the latter is the relative speed between the two vehicles.

In addition to indicating crash risks, the above surrogate measures also provide important information on safety-related driver behavior (e.g., speeding, lane keeping, and tailgating) and the overall safety of the traffic environment. During the analysis, the research team calculated and compared both the mean values (μ) and the standard deviations (σ) of the variables listed above.

The objective of the time series data analysis was to identify statistically significant differences of the safety surrogates between the traffic on the treated roadway segments and the untreated segments. During the comparison, the research team analyzed daytime data and nighttime data separately. However, due to the small sample size and because this is a feasibility study, the research team did not group the data further based on other variables such as weather condition, driver gender, and day of week.

For the I-5 median barrier replacement project, the research team obtained data collected both before and after the project took place. For the paving project, due to the limited data collected before the pavement project took place, the research team used a 2.5-mile control section located on the same freeway in close vicinity (Figure 16). Both roadway sections had very similar roadway configurations and traffic controls. Based on the WSDOT project information, the roadway section used for control purposes did not experience pavement improvement between 2011 and 2013.

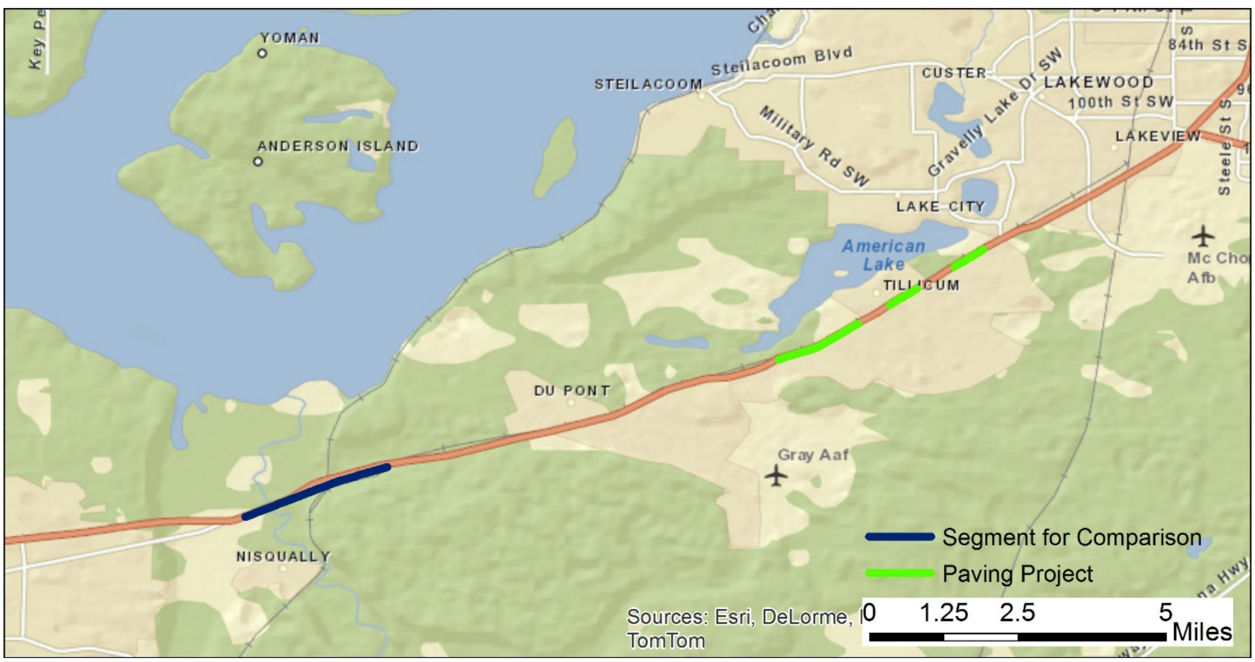


Figure 16. Map. Study and control sections on I-5 for the paving project case study.

SAS software and two-sample *t*-test for means statistics were used to evaluate the change in safety surrogates for the case studies. The two-sample *t*-test was developed to statistically compare two population means based on hypothesis tests. The *t*-statistic is defined as[(19)]

$$T = \frac{\overline{Y}_1 - \overline{Y}_2}{\sqrt{s_1^2 / N_1 + s_2^2 / N_2}},$$

where N_1 and N_2 are the sample sizes, $\overline{Y}_1$ and $\overline{Y}_2$ are the sample means, and s_1^2 and s_2^2 are the sample variances.

When the variances of the two samples are equal, the above formula is equivalent to

$$T = \frac{\overline{Y}_1 - \overline{Y}_2}{s_p \sqrt{1/N_1 + 1/N_2}},$$

where s_p is the pooled estimation of the standard deviation that can be obtained through the pooled variance defined as

$$s_p^2 = \frac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2}{N_1 + N_2 - 2}.$$

The degrees of freedom (*df*) for the statistic are

$$df = N_1 + N_2 - 2.$$

When the variances of the two samples differ significantly, the degrees of freedom are calculated through the effective number of degrees of freedom (*f*) as

$$f = \frac{(s_1^2 / N_1 + s_2^2 / N_2)^2}{\frac{(s_1^2 / N_1)^2}{N_1 - 1} + \frac{(s_2^2 / N_2)^2}{N_2 - 1}}.$$

A statistically significant difference was identified at the 0.05 level of significance during this study.

SHRP 2 DATA PROCESSING

For the purpose of the case studies, the research team requested 200 random NDS trips for three non-peak periods: 9:30 p.m. – 4:00 a.m. (nighttime), 10:00 a.m. – 11:00 a.m., and 2:30 p.m. – 3:30 p.m. To ensure all safety surrogates could be calculated, the research team requested all vehicle kinematic and lane-keeping variables available in the time series data. The data request actually resulted in 1,628,173 data points from 138 nighttime trips and 92 daytime trips.

After obtaining the data, the research team went through the following process to prepare the data for analysis:

- Extract trip portions on study roadway segments. The original data contained data points on additional roadway segments adjacent to the study segments. The research team used a spatial analysis procedure on the ArcGIS Desktop platform to extract the data points that only occurred on the study roadway segments.

- Separate trip segments by direction of travel. To increase accuracy, the researchers separated the SHRP 2 trips on the study roadway segments by direction of travel and analyzed trips in each direction separately. The direction of travel was identified based on the sequences of time stamps of consecutive data points.

- Calculate aggregated safety surrogate measures. Safety surrogate measures were calculated for each trip on each roadway segment by direction. For each surrogate measure, the research team calculated both mean values and variances.

CHAPTER 4. CASE STUDY RESULTS

CASE STUDY #1: I-5 PAVING PROJECT

Table 3 and Table 4 list the two-sample *t*-test results for the I-5 paving case study. In the tables, statistically significant results are highlighted using bold font.

Table 3. Two-sample *t*-test results for I-5 paving project – daytime comparison.

Variable		Mean		*Pr* > |*t*| for Variance Difference	*Pr* > |*t*| for Mean Difference	
		Newly paved	Control		Equal Variance	Unequal Variance
Speed (km/h)	σ	6.20	4.78	0.440	0.330	0.327
	μ	97.68	101.90	0.224	0.156	0.152
Longitudinal acceleration rate (m/s^2)	$\boldsymbol{\sigma}$	**0.02**	**0.03**	0.000	0.076	**0.070****
	μ	-0.01	0.00	0.809	0.282	0.283
Lateral acceleration (m/s^2)	$\boldsymbol{\sigma}$	**0.03**	**0.02**	0.007	<.0001	**<.0001**
	μ	0.02	0.01	0.934	0.457	0.457
Lane deviation from center (mm)	σ	26.14	25.86	0.934	0.928	0.928
	$\boldsymbol{\mu}$	**-9.93**	**-24.17**	0.569	**0.061****	0.060
TTC (s)	μ	N/A*	N/A*	0.006	0.614	0.618
Following distance (m)	σ	17.58	19.26	0.011	0.596	0.600
	μ	40.33	46.87	0.135	0.133	0.136
Relative speed (km/h)	$\boldsymbol{\sigma}$	**2.94**	**1.74**	0.080	0.035	**0.034**
	μ	-0.46	-0.23	0.884	0.551	0.551

*Mean TTCs for both before and after cases were negative, suggesting that the following vehicles were slower than the leading vehicles on average.
**Statistically significant at 0.1 level of significance.

Table 4. Two-sample *t*-test results for I-5 paving project – nighttime comparison.

Variable		Mean		*Pr* > |*t*| for Variance Difference	*Pr* > |*t*| for Mean Difference	
		Newly paved	Control		Equal Variance	Unequal Variance
Speed (km/h)	$\boldsymbol{\sigma}$	**3.06**	**4.06**	<.0001	0.019	**0.023**
	μ	106.60	107.10	0.233	0.682	0.684
Longitudinal acceleration rate (m/s^2)	$\boldsymbol{\sigma}$	**0.02**	**0.03**	0.698	**<.0001**	<.0001
	$\boldsymbol{\mu}$	**0.00**	**0.02**	0.611	**0.000**	0.000
Lateral acceleration (m/s^2)	$\boldsymbol{\sigma}$	**0.04**	**0.02**	0.063	**<.0001**	<.0001
	$\boldsymbol{\mu}$	**0.02**	**0.01**	0.619	**<.0001**	<.0001
Lane deviation from center (mm)	σ	14.57	15.91	0.962	0.561	0.561
	μ	-10.16	-12.53	0.632	0.330	0.329
TTC (s)	μ	N/A*	2.00	<.0001	0.206	0.173
Following distance (m)	σ	37.31	36.68	0.006	0.827	0.832
	μ	75.00	72.48	0.579	0.651	0.653
Relative speed (km/h)	$\boldsymbol{\sigma}$	**7.42**	**2.10**	<.0001	<.0001	**<.0001**
	$\boldsymbol{\mu}$	**-5.67**	**-2.70**	<.0001	0.035	**0.024**

*Mean TTC for the before case was negative, suggesting that the following vehicles were slower than the leading vehicles on average.

Daytime Comparison Results

The daytime results for the I-5 paving project (see Table 3) in terms of speed, longitudinal acceleration, lateral acceleration, lane deviation from center, and car following and TTC can be summarized as follows.

- Speed. The results suggest that during the daytime the roadway section with newly installed pavement and markings corresponded with higher speed variation among drivers but lower mean speed compared with the control section (Figure 17). However, the differences were not statistically significant.

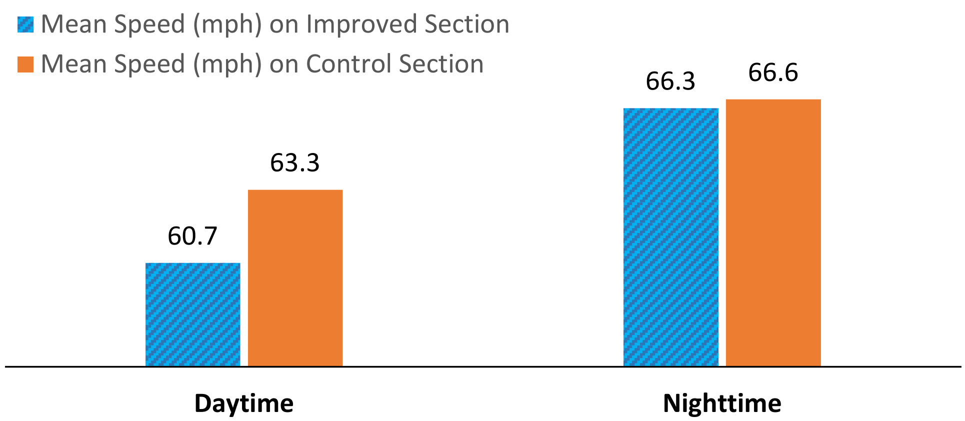


Figure 17. Diagram. Comparison of mean speed for pavement improvement case study.

- Longitudinal acceleration. The results suggest that the variation in acceleration was lower for the case study section in general, which was statistically significant at the 0.1 level of significance. In addition, the mean longitudinal acceleration was negative on the new pavement (see Figure 18 for the safety surrogate coordinate system), while those on the control section generally maintained their speeds. Note that the difference for mean speed was not statistically significant.

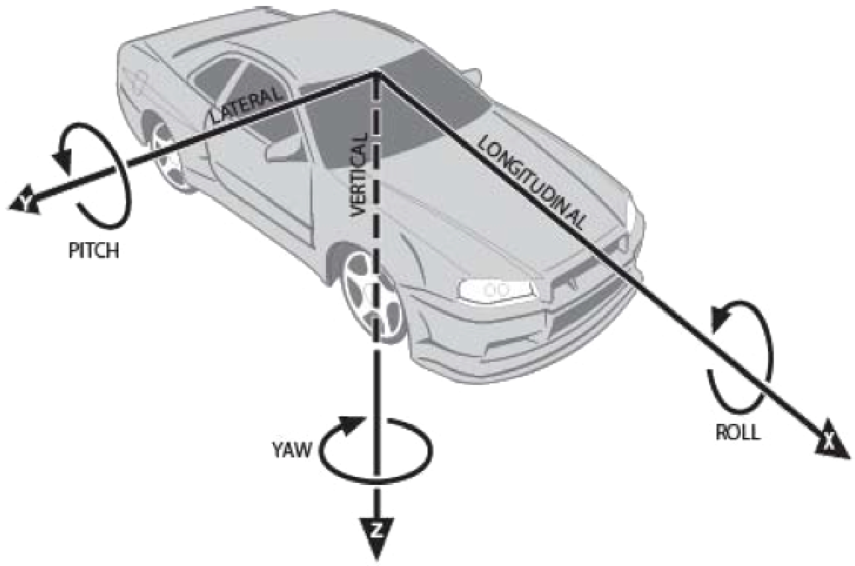


Figure 18. Diagram. Coordinate system for vehicle and roadway-related safety surrogates.[20]

- Lateral acceleration. Lateral acceleration rate can be an indicator of aggressive lane changing behavior. The results suggest that during the daytime the new pavement condition coincided with slightly higher lateral acceleration variance (statistically significant) and mean lateral acceleration rate (not statistically significant).

- Lane deviation from center. The results suggest that the travelers on the newly paved segment deviated much less than those on the control section in general. The difference was found to be statistically significant.

- Car following and TTC. On average, the results suggest that travelers on the newly paved segment followed other vehicles closer but reduced speeds more when they approached another vehicle. Note that the data used were for daytime non-peak hours, and therefore the following distances and TTCs were generally large. For this case, the calculation resulted in negative TTCs on average, suggesting slower speeds for the following vehicles.

Nighttime Comparison Results

The data analysis results (see Table 4) suggest that there are more significant differences in safety surrogates during the night. This observation is understandable since the newer pavement markings have much higher retroreflectivity. The nighttime results for the I-5 paving project in terms of speed, longitudinal acceleration, lateral acceleration, lane deviation from center, and car following and TTC can be summarized as follows.

- Speed. During nighttime, both lower speed variance (statistically significant) and mean speed (not statistically significant) were found for the newly paved freeway segment, which is a desired effect. Note that the mean speed for both sites exceeded the 60 mph (96 km/h) speed limit (Figure 17).

- Longitudinal acceleration. Both mean acceleration rate and acceleration variance were found to be statistically significantly lower on the newly paved freeway segment than on the control segment during nighttime. Combining these results with those for speed, the better pavement and the newly installed pavement markings seem to have resulted in safer driver behavior.

- Lateral acceleration. In terms of lateral acceleration during the nighttime, the results suggest statistically significantly higher mean lateral acceleration rates and variance. This finding indicates that with improved pavement conditions and better-marked travel lanes travelers tended to switch lanes more often and/or faster.

- Lane deviation from center. The results suggest that vehicles traveling on the newly paved segment during the nighttime generally had lower mean lane deviation distances and variance, but neither measure was statistically significant.

- Car following and TTCs. The results suggest that the vehicles traveling on the newly paved segment generally had larger mean following distances and larger variance for following distances, although neither difference was statistically significant. The results also suggest statistically significant lower relative speed compared to their preceding vehicles but with higher relative speed variance. The TTC difference for the data on the two roadway segments was not statistically significant.

CASE STUDY #2: I-5 MEDIAN BARRIER REPLACEMENT PROJECT

Table 5 and Table 6 show the statistical test results for the median barrier replacement case study. The tests compared mean values for several safety surrogates before and after the concrete barrier was replaced.

Table 5. Two-sample *t*-test results for median barrier project – daytime comparison.

Variable		Mean		***Pr* > |*t*| for Variance Difference**	***Pr* > |*t*| for Mean Difference**	
		Before	After		Equal Variance	Unequal Variance
Speed (km/h)	***σ***	**6.36**	**4.39**	0.000	0.093	**0.070****
	μ	**95.55**	**103.8**	<.0001	0.014	**0.007**
Longitudinal acceleration rate (m/s²)	*σ*	0.03	0.03	0.248	0.373	0.360
	μ	-0.01	-0.01	<.0001	0.829	0.847
Lateral acceleration (m/s²)	*σ*	0.03	0.03	0.002	0.178	0.210
	μ	**0.01**	**0.02**	0.494	**0.001**	0.001
Lane deviation from center (mm)	*σ*	32.78	27.64	0.000	0.116	0.150
	μ	**-2.57**	**-23.35**	0.032	<.0001	**0.000**
TTC (s)	*μ*	Invalid*	Invalid*	0.001	0.702	0.732
Following distance (m)	*σ*	21.96	18.3	0.078	0.181	0.210
	μ	42.65	40.55	0.050	0.584	0.610
Relative speed (km/h)	*σ*	3.21	2.79	0.007	0.636	0.666
	μ	**-0.34**	**-0.73**	0.005	0.092	**0.064****

*Mean TTCs for both before and after cases were negative, suggesting that the following vehicles were slower than the leading vehicles on average.
**Statistically significant at 0.1 level of significance.

Table 6. Two-sample *t*-test results for median barrier project – nighttime comparison.

Variable		Mean Before	Mean After	*Pr* > |*t*| for Variance Difference	*Pr* > |*t*| for Mean Difference: Equal Variance	*Pr* > |*t*| for Mean Difference: Unequal Variance
Speed (km/h)	σ	4.46	3.89	<.0001	0.295	0.367
	$\boldsymbol{\mu}$	**102.7**	**108.1**	0.783	**<.0001**	0.000
Longitudinal acceleration rate (m/s^2)	σ	0.03	0.03	0.325	0.205	0.221
	μ	0	0.01	0.002	0.185	0.140
Lateral acceleration (m/s^2)	$\boldsymbol{\sigma}$	**0.029**	**0.034**	0.003	<.0001	**<.0001**
	μ	0.02	0.02	0.771	0.130	0.135
Lane deviation from center (mm)	$\boldsymbol{\sigma}$	**28.88**	**14.85**	0.002	<.0001	**<.0001**
	μ	-15.33	-16.61	0.127	0.713	0.698
TTC (s)	μ	38	55	<.0001	0.131	0.184
Following distance (m)	$\boldsymbol{\sigma}$	**33.54**	**39.93**	0.600	**0.061***	0.058
	μ	66.31	69.38	0.279	0.542	0.530
Relative speed (km/h)	σ	4.72	4.64	0.882	0.930	0.930
	$\boldsymbol{\mu}$	**-1.04**	**-4.85**	<.0001	0.036	**0.014**

*Statistically significant at 0.1 level of significance.

Daytime Results

Changes in travel behavior during the daytime (Table 5) in terms of speed and longitudinal acceleration, lateral acceleration, lane deviation from the center, and car following and TTC were as follows:

- Speed and longitudinal acceleration. The results show that the mean daytime speed was statistically significantly higher after the old median barriers were replaced (Figure 19). However, the standard deviation for speed was significantly (at 0.1 level of significance) lower after the barriers were replaced, suggesting more uniform speed among travelers. The results did not show significant differences in terms of longitudinal acceleration before and after the improvement.

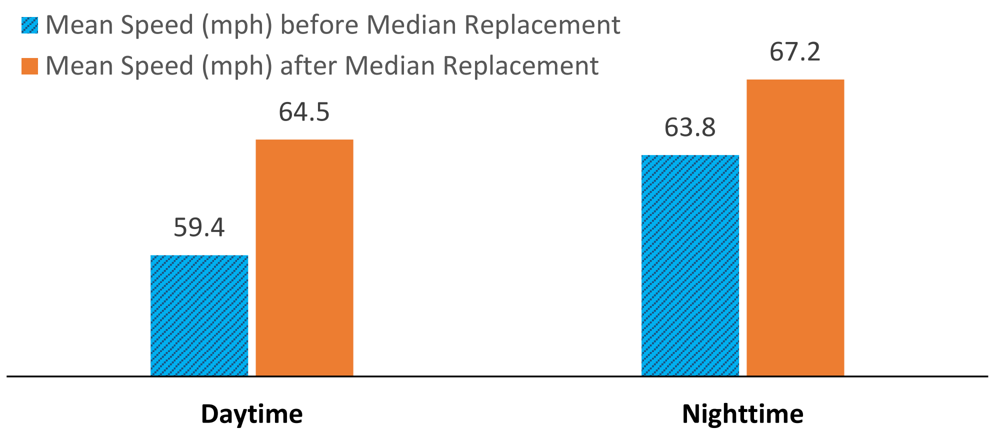


Figure 19. Diagram. Comparison of mean speed for median barrier case study.

- Lateral acceleration. The results show that the mean lateral acceleration rate for traffic after the improvement was significantly higher than before the improvement. This observation suggests that drivers conducted more and/or faster lane changes when traveling on the roadway with better median barriers.

- Lane deviation from center. The results show that travelers tended to deviate from the lane center more to the left after the median barrier improvement (i.e., 23 cm from lane center to left after improvement compared to 3 cm), which arguably suggests that drivers drove with more ease with improved median barriers.

- Car following and TTC. No statistically significant differences were found in terms of TTC.

Nighttime Results

Changes in travel behavior during the nighttime (Table 6) in terms of speed and longitudinal acceleration, lateral acceleration, lane deviation from the center, and car following and TTC were as follows:

- Speed and longitudinal acceleration. The results show higher mean speeds after the median improvement, along with lower speed variance (not statistically significant) (Figure 19). The results do not show significant differences in terms of longitudinal acceleration rate.

- Lateral acceleration and lane deviation. The results show higher lateral acceleration variance after the median barrier improvement (statistically significant). In addition, significantly lower lane deviation variance was found for nighttime traffic after the median barrier improvement.

- Car following and TTC. The tests unveiled statistically significant higher variance for following distances after the improvement. In addition, the results show slower relative speeds (following vehicle speed relative to proceeding vehicle) after the median improvement. Although not statistically significant, the results show higher mean TTC for traffic after the median barrier improvement.

CASE STUDY CONCLUSION

The findings of the two case studies include the following:

- New pavement with newly installed markings had an impact on driver behavior relevant to safety. Based on the limited sample data, better pavement conditions and pavement markings coincided with statistically significant differences in more behavioral variables during nighttime than during daytime. In addition, the newly rehabilitated section in general had slower speeds, more speed uniformity, and less longitudinal acceleration, but more and/or faster lane changes. In addition, the results indicated that the lane-keeping metrics, particularly during nighttime, for the freeway segment with improved pavement and markings were better. Because the data analyzed for this case study were for non-peak hours, the researchers did not identify significant findings in terms of car-following metrics.

- The median barrier replacement also had some impact on driver behavior. The replacement of the median barrier seemed to result in higher mean speeds during both daytime and nighttime, which suggests a perceived improvement in driving conditions by users, although not necessarily a desired safety outcome. The median improvement also resulted in a higher mean lateral acceleration rate during the daytime and a higher lateral acceleration variance during the nighttime, which seems to indicate more and/or faster lane changes. The results also suggest higher lane deviation to the left side but lower lane deviation variance during both daytime and nighttime. Similar to the results from the pavement project, the research team did not find meaningful differences in terms of car-following behavior due to the low non-peak-hour traffic.

- The two case studies illustrate two different methods for studying the effectiveness of safety improvements. The paving project case study compared safety surrogates between the data collected at the project site after the roadway improvement and at an adjacent site with similar roadway conditions but without the pavement improvement. The median barrier project case study compared data before and after the roadway improvement on the same segment. The two different methods illustrate the flexibility available with SHRP 2 safety data to accommodate different project timeframes.

- Additional data sources are required for evaluating the effectiveness of safety improvements. The SHRP 2 safety data contain detailed vehicle kinematic and driver behavioral information that enable the calculation of a variety of safety surrogates. To obtain detailed roadway information, including transportation project information, it is necessary to rely on additional data sources such as state transportation agencies. The RID includes some roadway and traffic information but lacks details regarding roadway projects.

CHAPTER 5. CONCLUSIONS

Traffic safety continues to be a major concern for the traveling public, government agencies, and transportation professionals. The SHRP 2 safety data, including the RID data, have enabled a large variety of safety and traffic-related analyses that differ from traditional crash-based analyses. This study was a feasibility assessment of using SHRP 2 NDS data to evaluate the safety effects of roadway improvement projects. The assumption was that researchers could use data collected in a naturalistic driving environment to better understand the impacts of roadway improvement projects on driver safety behavior and crash risks. If feasible, such analyses have the potential to provide unique insights into the safety effectiveness of roadway projects, especially when there is a lack of sufficient before and after crash data.

During this project, the research team conducted two case studies based on NDS data from 200 trips. The two case studies included a paving project and a median barrier replacement project. The paving project was evaluated for the safety effects of newly installed pavement and markings. The median barrier replacement project was evaluated for the safety effects of the newly installed and restored concrete median barriers. The availability and suitability of SHRP 2 data for evaluating safety improvement projects were also assessed. During the case studies, a number of safety surrogate measures were used to develop a comprehensive understanding of how driver behavior changed with and without the safety treatment. The surrogate measures included speed, acceleration, lane-keeping, and car-following variables.

SUMMARY OF CASE STUDY FINDINGS

To assess the feasibility of using SHRP 2 safety data for effective evaluation of the safety impacts of roadway improvement projects, the research team conducted the following two case studies:

- **Case study #1 – Paving project**. This project involved pavement overlay on an approximately 3-mile long segment of northbound I-5. The project underwent construction in 2011. The purpose of this case study was to assess the safety impact of newly constructed pavement and pavement markings on daytime and nighttime driver behavior. Due to the limited before-construction data available in the SHRP 2 safety database, the research team compared safety data for the case study segment with data of a comparable freeway segment that did not receive pavement rehabilitation.

  The case study results suggest that the new pavement with newly installed markings had an impact on driver safety behavior. Better pavement conditions and pavement markings coincided with significant differences in more driver behavior measures during the nighttime than during the daytime. In addition, the newly rehabilitated section in general had slower speeds, more speed uniformity, and longitudinal acceleration, but more and/or faster lane changes. In addition, the results indicate that the lane-keeping metrics, particularly during nighttime, were better for the freeway segment with improved pavement and markings.

- **Case study #2– Concrete median barrier replacement project.** The project's objective was to improve safety by installing better-designed concrete barriers and replacing previously damaged concrete barriers along the roadway segment. This section of roadway closely resembles typical urban freeway settings where both directions of traffic are separated by concrete median barriers with a narrow left shoulder on each side. The research team compared driver behavior before and after the improvement.

The results suggest that the barrier replacement also had some impact on driver behavior. The replacement of the median barrier seemed to result in higher mean speeds during both daytime and nighttime, which suggests a perceived improvement in driving conditions and safety by users. The median improvement also resulted in a higher mean lateral acceleration rate during daytime and a higher lateral acceleration variance during nighttime, which seems to indicate more and/or faster lane changes. The results also suggest higher lane deviation to the left side but lower lane deviation variance during both daytime and nighttime.

The two case studies illustrate two different methods for studying the effectiveness of safety improvements. The paving project case study compared safety surrogates between the data collected at the project site after the roadway improvement and at an adjacent site with similar roadway conditions but without the pavement improvement. The median barrier project case study compared data before and after the roadway improvement on the same segment. The two different methods illustrate the flexibility available with SHRP 2 safety data to accommodate roadway projects of different timeframes.

Note that both case studies were based on limited sample data. The findings of the impact on driver behavior may change when a full dataset is used.

DATA AVAILABILITY AND SUITABILITY FOR FULL ANALYSIS

The following points address the availability and suitability of SHRP 2 data for evaluating the safety impact of roadway improvements based on this feasibility project.

- SHRP 2 time series data. This project showed that the SHRP 2 time series data contain rich information depicting vehicle kinematics and driver behavior. In particular, the database contains accurate and high-frequency data on speeds, longitudinal and lateral accelerations, and to a lesser extent, lane offsets. Such data are the basis for several common safety surrogate measures that previous research has found to be closely related to crash frequency and severity.

- SHRP 2 events data can provide valuable information on how drivers act in relation to the same types of roadway improvements during crashes or near-crashes. However, due to the relatively rare nature of such events, the SHRP 2 database contains a limited number of crashes and near-crashes for certain roadway locations. To conduct meaningful research based on SHRP 2 events, a sufficiently large mileage of roadway should be used. This fact limits the study of roadway improvements to those that were applied to a very long section of road or to a large number of sections. The two case studies in this research collectively involved data for approximately 8 miles of roadway. The research team could not identify a sufficient number of crashes and near-crashes for analysis.

- The RID information should be complemented by data directly from states in some cases. Particularly for this study, the RID contained limited information about roadway projects and was not sufficient for the two cases studies. The research team had to collect additional information on the projects directly from state data sources.

- The RID crash data can be used for suitable studies that involve a large mileage of roadways. The SHRP 2 RID database contains crash data for 3 years (e.g., 2011–2013). When analyzing roadway sections of significant length, either individually or collectively, the crash data can provide valuable information on the safety impacts of improvements. During the two case studies, however, the research team did not identify a sufficient number of crashes on the studied roadways.

REFERENCES

1. National Highway Traffic Safety Administration. (2015). *Fatality Analysis Reporting System (FARS)* [database]. Retrieved from http://www.nhtsa.gov/FARS

2. Federal Highway Administration. (2015). Safety - Facts and statistics. Retrieved from http://safety.fhwa.dot.gov/facts_stats/

3. Transportation Research Board of the National Academies. (2014). The SHRP 2 Naturalistic Driving Study (NDS). Retrieved from http://www.trb.org/StrategicHighwayResearch Program2SHRP2/Pages/The-SHRP-2-Naturalistic-Driving-Study-472.aspx

4. McLaughlin, S., & Hankey, J. (2015). *Naturalistic Driving Study: Linking the study data to the Roadway Information Database* (SHRP 2 Report S2-S31-RW-3). Blacksburg, VA: Virginia Tech Transportation Institute.

5. Campbell, K. (2012, September–October). The SHRP 2 Naturalistic Driving Study: Addressing driver performance and behavior in traffic safety. *TR News*, *282*, 30-35. Retrieved from https://insight-forums.shrp2nds.us/uploads/FileUpload/80/ 9cb98204a5cf10632df695a674b4c9.pdf

6. Virginia Tech Transportation Institute. (2014). SHRP 2 NDS InSight – Data. Retrieved from https://insight.shrp2nds.us/home/index

7. Virginia Tech Transportation Institute. (2014). International Center for Naturalistic Driving Data Analysis at Virginia Tech. Retrieved from https://www.vtti.vt.edu/facilities/data-services.html

8. Washington State Department of Transportation. (2014). Project search. Retrieved from http://www.wsdot.wa.gov/ projects/search/

9. Hallmark, S., Hsu, Y., Boyle, L., Carriquiry, A., Tian, Y., & Mudgal, A. (2011). *Evaluation of data needs, crash surrogates, and analysis methods to address lane departure research questions using Naturalistic Driving Study Data* (SHRP 2 Report S2-S01E-RW-1). Washington, DC: Transportation Research Board of the National Academies.

10. Shankar, V., Jovanis, P., Aguero-Valverde, J., & Gross, F. (2008). Analysis of naturalistic driving data: Prospective view on methodological paradigms. *Transportation Research Record 1908*, 1-8.

11. Li, Y. & Bai, Y. (2009, October). Highway work zone risk factors and their impact on crash severity. *Journal of Construction Engineering, 135*(10), 694-701.

12. Forbes, G., Eng, M., & Eng, P. (2003, March). *Synthesis of safety for traffic operations* (Report TP 14224 E). Ontario, Canada: Intus Road Safety Engineering Inc.

13. Campbell, B., Smith, J., & Najm, W. (2003, October). *Examination of crash contributing factors using national crash databases* (Report DOT- VNTSC-NHTSA-02-07). Cambridge, MA: John A. Volpe National Transportation Systems Center, U.S. Department of Transportation.

14. Jun, J., Ogle, J., & Guensler, R. (2007). Relationships between crash involvement and temporal-spatial driving behavior activity patterns: Use of data for vehicles with Global Positioning Systems. *Transportation Research Record, No. 2019*, 246-255.

15. Gettman, D. & Head, L. (2013). *Surrogate safety measures from traffic simulation models* (Final Report FHWA-RD-03-050). Tucson, AZ: Siemens Gardner Transportation Systems.

16. Ferguson, S. (2015, June 15). *Relation of speed and speed limits to crashes*. National Forum on Speeding, Washington, DC.

17. Dingus, T., S. Klauer, V. Neale, A. Petersen, S. Lee, J., Sudweeks, . . . Knipling, R.. (2006, April). *The 100-Car Naturalistic Driving Study, Phase II – Results of the 100-Car field experiment*. Blacksburg, VA: Virginia Tech Transportation Institute.

18. St-Aubin, P. & Saunier, N. (2015, January). *Comparison of various objectively-defined time-to-collision prediction and aggregation methods for surrogate safety analysis*. Transportation Research Board 94th Annual Meeting, Washington, DC.

19. SAS. (2015). The TTEST Procedure. *SAS/STAT(R) 9.2 User's Guide, Second Edition*. Retrieved from http://support.sas.com/documentation/cdl/en/statug/63033/HTML/default/viewer.htm#ttest_toc.htm.

20. Virginia Tech Transportation Institute. (2016). InSight data access website: SHRP2 Naturalistic Driving Study. Retrieved from https://insight.shrp2nds.us/info/ printable/23?type = dataset