REPORT S2-S03-RW-1

Roadway Measurement System Evaluation

SHRP 2 SAFETY RESEARCH

SHRP 2

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The Second

STRATEGIC HIGHWAY RESEARCH PROGRAM

SHRP 2 Report S2-S03-RW-01

Roadway Measurement System Evaluation

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TRANSPORTATION RESEARCH BOARD

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SHRP 2 was authorized in August 2005 as part of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). The program is managed by the Transportation Research Board (TRB) on behalf of the National Research Council (NRC). SHRP 2 is conducted under a memorandum of understanding among the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), and the National Academy of Sciences, parent organization of TRB and NRC. The program provides for competitive, merit-based selection of research contractors; independent research project oversight; and dissemination of research results.

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The principal investigators for this effort were John E. Hunt, PE, of Applied Research Associates, Inc., and Anita P. Vandervalk, PE, of Cambridge Systematics, Inc. The researchers would like to thank Mr. Robert Wilson of the Virginia Department of Transportation for his assistance in identifying candidate test sites in Northern Virginia. We also thank all the data collection vendors who took part in the equipment rodeo.

FOREWORD

Charles Fay, *SHRP 2 Senior Program Officer, Safety*

This report for SHRP 2 Safety Project S03 documents the evaluation of automated/mobile data-collection services to provide data on roadway features and characteristics considered important for safety analysis, especially analysis of data from the SHRP 2 Naturalistic Driving Study (NDS). To obtain these roadway data, SHRP 2 set out to procure the services of a vendor to collect data at highway speed. However, at the time, no validation of vendors' capabilities to collect these data was publicly available. As a result, SHRP 2 conducted its own evaluation—the rodeo. The objectives of the rodeo were to determine the capabilities of the industry (as represented by 10 participating vendors) and to prequalify a list of vendors to bid on the project that would collect new roadway data in the six NDS sites throughout the United States.

The design of the rodeo focused on replicating real-world data-collection environments likely to be encountered in the six sites. Two data-collection routes—one rural and one urban—totaled approximately 43 centerline miles. These routes included a variety of roadway types, terrain, and vegetation cover. Within the two routes were six 2,500-ft test sections that contained 113 data elements of interest. These six test sections were manually surveyed and certified by a professional land surveyor. The surveyor's measurements were used as reference data for the evaluation. Vendors were evaluated for coverage, consistency, completeness, and accuracy.

Vendors provided data from three separate data-collection passes totaling approximately 8.5 survey miles for the six test sections. In addition to the data collected from the test sections, vendors provided GPS data on 258 survey miles covering the entire rodeo route.

For the GPS data, most of the vendors achieved a consistency of sub 30 cm over the entire rodeo route. This represents the capability of the vendors to geo-reference their vehicles while the vehicles are traveling at highway speed. In general, the vendors' ability to locate roadside features diminishes the farther the features are from the vehicle, especially if these features are beyond the paved shoulder. With sufficient quality control/quality assurance (QC/QA), features up to the paved shoulder can be located consistently to an accuracy of sub meter, although this is not true without adequate QC/QA processes.

Numerous issues were encountered that made it difficult for the Project S03 contracting team to achieve the objective of prequalifying a short list of vendors. Vendors were inconsistent in adhering to the data-collection procedures and data-processing requirements outlined in the rodeo instructions. No vendor reported all 113 data elements. The data were often incomplete, making it difficult to link the data to the reference data set. Almost all the vendors failed to provide any geometric data (e.g., horizontal radius of curvature)—a data category of high importance to the SHRP 2 Safety program for analyzing run-off-road crashes.

This lack of reporting resulted in the need for SHRP 2 to conduct a follow-up evaluation that was managed under another project (Safety Project S04A, Roadway Information Data-

Table F.1. Comparison of Rodeo Target Accuracy and Project S04B Specifications

Data Type	Rodeo Target Accuracy	Project S04B Specification
Curvature length	2 ft	50 ft
Curvature radius	25 ft	50 ft
Point of curvature	3 ft	25 ft
Point of tangency	3 ft	25 ft
Grade	0.50%	0.50%
Cross slope	0.10%	1.00%
Lane width	1 ft	1 ft
Paved shoulder width	1 ft	1 ft
Inventory feature location	3 ft	7 ft

base Development and Technical Coordination and Quality Assurance of the Mobile Data Collection Project). Seven out of the original 10 rodeo vendors participated in the follow-up evaluation; three of the seven were prequalified to bid on the mobile data collection project (Safety Project S04B, Mobile Data Collection). Results of the follow-up evaluation were considered when developing the specifications for Project S04B. These specifications are provided in Table F.1.

There were several things that SHRP 2 learned from Project S03 that are being addressed as Safety projects move forward with roadway data collection. To clarify parameters and specifications for data collection, a Data Dictionary and Field Data Collection Manual are being developed by the Project S04A contractor. The S04A contractor is responsible for providing quality assurance (QA) for new data collected under Project S04B, and the S04A materials will be provided to the vendor chosen for Project S04B. Calibration sites will be established in each of the six NDS sites by the S04A contractor; the S04B contractor will be required to run these calibration sites at specific times during the data-collection process. In addition, the S04A contractor will develop QA processes to ensure that the data collected by the S04B contractor meets project specifications.

In hindsight, 113 data elements were too many; a subset of data elements would have sufficed. SHRP 2 used such a subset in the follow-up evaluation conducted under Project S04A. In addition, the rodeo target accuracies were too stringent. Table F.1 compares the rodeo target accuracies with the specifications for Project S04B.

The information in this report provides an overview of the rodeo that evaluated the capabilities of automated/mobile data-collection services to collect data on roadway features and characteristics considered important for safety analysis. Although not a complete guide, it will provide highway agencies with valuable information before they conduct their own evaluation or procure automated/mobile data-collection services.

CONTENTS

Executive Summary

The SHRP 2 safety research plan includes two tracks: a field study of driving behavior using volunteer drivers and a sophisticated instrumentation package installed in the volunteers' vehicles (in-vehicle study), and a video system to record movements of all vehicles at specific road sites such as intersections (site-based study). The in-vehicle study consists of three areas: (1) study design and field data collection, (2) roadway data, and (3) analysis. Safety Project S03, Roadway Measurement System Evaluation, fits under the roadway data area of the in-vehicle study.

The goals of the Safety Project S03 research were to

- Prequalify commercial data collection vendors for bidding on Safety Project S04B, Mobile Data Collection;
- Evaluate the precision and accuracy of the mobile roadway and pavement inventory data collection services as they relate to selected roadway safety data elements collected at highway speeds; and
- Produce a recommended list of roadway data elements and associated specifications to be collected under the S04B project.

On December 19, 2007, SHRP 2 awarded Safety Project S03 to the research team of Applied Research Associates, Inc. (ARA), Cambridge Systematics, Inc. (CS), and KCI Technologies, Inc. (KCI).

The work for this assignment was completed under the following tasks:

- Finalizing the work plan and the Quality Assurance/Quality Control Plan;
- Determining the prioritization of data elements;
- Developing the test site selection criteria;
- Formulating the test site evaluation and recommendations;
- Conducting the test site mapping and surveying;
- Organizing and completing the field data collection;
- Evaluating the data collected; and
- Producing the final report.

The core research was accomplished through the development, organization, and conduct of a roadway measurement system evaluation (rodeo). Ten commercial data collection vendors and the Federal Highway Administration (FHWA) participated in the rodeo evaluation and provided the research team with preliminary data. Two types of data sets were provided to the research team: initial data set and final data set. The purpose of the initial data sets was to provide insight into the participants' ability to collect data consistently under real-world survey conditions likely to be encountered during S04B. The purpose of the final data sets was to evaluate the participants' ability to collect the specific roadway assets and features of interest to the roadway safety research community. Each participant was to provide the research team with three repetitions of data collection for each data set. The initial data sets covered a total of 258 lane miles of rodeo survey routes and included digital images, Global Positioning System (GPS) coordinates, and roadway profile and geometrics data. These were delivered by the participants before leaving the rodeo site. The final data sets covered a total of 8.5 lane miles on the six specific rodeo test sites and included the roadway data elements from the data elements list. The participants postprocessed these data and delivered them after the conclusion of the rodeo. The research team evaluated the initial and final data sets provided by participants based on the data quality attributes of coverage, consistency, completeness, and accuracy.

The evaluation of the initial data sets indicated that consistency of GPS data was very good for all sites, including various land use and cover conditions such as urban, rural, canopy, and highway locations. Five of the six data collection teams reporting GPS data achieved a consistency rating of sub-30 cm (1 ft).

Three of the 10 commercial vendors—Teams 06, 08, and 10—were eliminated from further consideration upon evaluation of the final data sets because of their lack of coverage or data format issues. Of the remaining seven teams, none provided all of the requested data elements. Some vendors focused on providing only a few data elements that were complete; others provided more data elements but may have sacrificed accuracy and precision in doing so. Because the results of the rodeo were inconclusive, SHRP 2 decided to prequalify all the participants. Team 10 decided not to continue in the pursuit of Safety Project S04B.

Overall, it was concluded that most of the desired data elements can be collected, although the desired target accuracy, as used in the rodeo, may not be achieved. However, it was observed that vendors were largely inconsistent in adhering to the data collection procedures and data processing requirements outlined in the rodeo data collection plan and data elements list.

There appeared to be general confusion regarding engineering terminology, such as *Manual on Uniform Traffic Control Devices* (MUTCD) code, gore area, and number of approaches at an intersection. This resulted in poor accuracy results for some asset types, including special pavement markings, roadside obstacles, rumble strips, sidewalks, intersections, lanes, and ramps. Other data elements were not collected at all, including pavement marking retroreflectivity, pavement edge drop-off, vertical curvature, sight distance, clear zone width, clear zone slope, superelevation, horizontal point of tangency, and location of traffic signal head. The research team provided some insight in the conclusions section of this report regarding why these data elements were not collected.

On the basis of these observations, it is recommended that before commencing the data collection of the Safety Project S04B contract, the parameters and specifications should be clearly defined. As part of this effort, it is recommended that a Safety Data Dictionary and a detailed Field Data Collection Manual be developed to provide even more in-depth descriptions of data elements and to establish clear guidelines regarding where to reference the data elements, where to measure the data elements, how to process measured data into the desired format for future SHRP 2 work, and how to report parameters, including proper units. The manual should include photographs, diagrams, formulas, and any other guidance necessary to ensure that SHRP 2 receives the required data for Safety Project S04B.

As part of the quality assurance process for S04B, it is recommended that short verification sites be established in each region to accommodate verification of the distance measuring instrument (DMI), GPS, image interval and quality, cross-slope, grade, and data take-off process from the images collected. The selected data collection contractor should be required to survey the verification site prior to starting work in that region, as well as periodically throughout the regional data collection effort. It is recommended that SHRP 2 work closely with the selected team to ensure that it receives the data required to support the Safety Project S04, Acquisition of Roadway Information.

The primary challenge faced during the S03 project occurred during the processing and evaluation of the data received from the participants. The challenges encountered with the participants' data included the following:

- None of the participants reported all 113 data elements requested.
- The data provided were incomplete, and one team did not provide any final data.
- Incomplete final data made it more difficult to link the data provided to the reference data set.
- Very few teams provided geometric data. Some geometric data related to grade, cross-slope, horizontal point of curvature, length of curve, and radius of curvature were received; however, only two teams provided final geometric data in a usable format.

These issues required more discussion with the participants to obtain additional data. Five of the 10 participating commercial firms were contacted to provide data to address these concerns. Two of these five firms stated that they would not provide any additional data (Teams 08 and 10). The other three firms (Teams 03, 06, and 09) provided additional data. However, the additional data were either in worse condition than the original (Team 06) or still incomplete (Teams 03 and 09). The research team spent additional resources cleaning the participants' data files and linking the provided data back to their reference data sets.

Because of the lack of geometric data received from the participants, SHRP 2 requested that participating firms reprocess their data to provide additional basic geometric and road inventory data. These basic geometric data included grade, cross-slope, horizontal point of curvature, length of curve, and radius of curve. The additional roadway inventory data requested included lane width, shoulder width (paved), and sign data (GPS coordinates and MUTCD code). These additional data are to be submitted to SHRP 2 along with the participants' responses to the S04B request for quotations and proposals (RFQ/P) to be released in 2010.

Despite the challenges with this project, S03 resulted in the following significant contributions to SHRP 2.

- Research revealed several potential challenges and opportunities related to integrating roadway element data and in-vehicle data to be collected in S07, In-Vehicle Driving Behavior Field Study. These were documented in a white paper, dated October 10, 2008, and resulted in splitting the S04 project into two components (S04A, Roadway Information Database Development and Technical Coordination and Quality Assurance of the Mobile Data Collection Project; and S04B, Mobile Data Collection).
- In-depth insight and experience were gained regarding the practicality of collecting roadway safety elements. This resulted in the development of detailed recommendations for data collection practices to be used in S04B.
- A list of data elements and associated specifications for collection during Safety Project S04B was generated.

CHAPTER 1

Introduction: The Research Approach

The work for this assignment was completed under the following tasks, as described.

Task 1: Finalizing Work Plan and QA/QC Plan

Task 1 involved reviewing the original Work Plan and Quality Assurance/Quality Control (QA/QC) Plan provided to SHRP 2 as part of the S03 proposal package, updating these plans as necessary.

Task 2: Determining Prioritization of Data Elements

During Task 2, the research team developed a prioritized list of roadway safety data elements to be used in evaluating the performance of the S03 participants. This list was developed to reflect the importance of the roadway safety data elements in crash analysis and input from the Safety Technical Coordinating Committee and other SHRP 2 safety contractors. The list of data elements was developed for use in the Roadway Measurement System Evaluation Rodeo to evaluate automated data collection firms. The data elements list and prioritization methodology were provided to SHRP 2, FHWA, and other safety research stakeholders for review and comment in April 2008. The data elements report was provided to SHRP 2 for review and comment on May 6, 2008. Comments received were incorporated or addressed, and the revised data elements list with definitions and target accuracies were provided to the rodeo participants for review and comment in August 2008. Comments received were addressed or incorporated, and the final data elements list was provided to the rodeo participants on September 15, 2008.

Task 3: Developing the Test Site Selection Criteria

Under Task 3, the S03 research team developed test site selection criteria, combining the prioritized data elements list with physical roadway characteristics and logistical considerations. These criteria were used in selecting challenging test sections for evaluating the participating vendors under conditions similar to those that may be encountered during the S04B project.

Task 4: Test Site Evaluation and Recommendation

In Task 4, the S03 research team used the criteria developed in Task 3 to evaluate three general locations around the country to host the Roadway Measurement System Evaluation Rodeo. Roadways in Northern Virginia were selected, and the same criteria were then used to select 10 possible test locations for detailed evaluation of the rodeo participants. From the 10 possible test site locations, four locations were selected, with Virginia Department of Transportation input, for use during the rodeo, as shown in Figures 1.1 through 1.4. The selected locations resulted in the following six test sites:

- Site 1: SR 120, WB—Arlington, Virginia;
- Site 6N: SR 287—Lovettsville, Virginia;
- Site 6S: SR 287—Lovettsville, Virginia;
- Site 7N: SR 15—Lucketts, Virginia;
- Site 7S: SR 15—Lucketts, Virginia; and
- Site 10: SR 15 SB—Leesburg, Virginia.

These six test sites were contained within two rodeo survey routes (eastern and western) covering approximately 43 centerline miles and were used to evaluate the consistency of the participants' data collection activities under a variety of real-world conditions. Each route was surveyed three times in both directions, for a total of 258 survey miles.

The six test sites were blind tests and not marked in the field. Each was 2,500 ft long and included most of the roadway asset types contained in the Data Elements List. The test sites covered 8.5 lane miles of roadway (2,500 ft/site × 6 sites × 3 repetitions) and included a variety of land use, cover types, and roadway types.

Figure 1.1. Site 1: SR 120 westbound, Arlington, Virginia.

Figure 1.2. Site 6: SR 287 northbound and southbound, Lovettsville, Virginia.

Task 5: Test Site Mapping and Surveying

In Task 5, the team used KCI Surveys, a professional land surveyor (PLS), to collect highly accurate positional information and asset attribute data for the data elements located

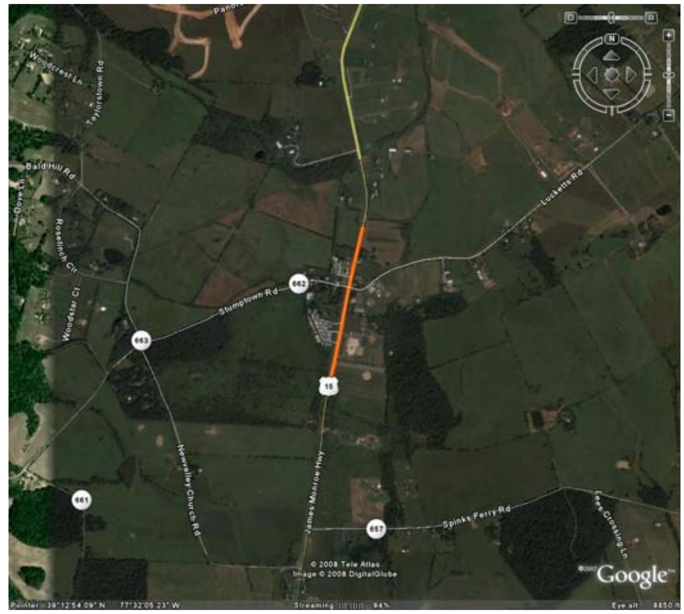

Figure 1.3. Site 7: SR 15 northbound and southbound, Lucketts, Virginia.

Figure 1.4. Site 10: SR 15 southbound, Leesburg, Virginia.

along the six test site locations. The data thus collected were then used as the basis of the reference data sets for the evaluation of the rodeo participants. The following list specifies the equipment and the order of deployment used in Task 5, as well as the primary data collection devices KCI Surveys used to obtain the highest degree of accuracy and mitigate the effects of the environmental positional degradation.

1. Global Navigation Satellite System (GNSS) instruments were used to provide primary control for each area. The project team followed the Federal Geodetic Control Subcommittee guidelines and the National Geodetic Survey draft report using real-time GNSS procedures meeting a positional tolerance of 1.5 cm at 20 PPM. The GNSS was used to compute the trajectories along the roadways so that satellite availability could be validated.
2. Conventional differential level techniques were used to establish the height difference between the control stations.
3. Robotic total station (RTS) was used to capture the asset information referenced to the control stations.

The six selected rodeo test sections were surveyed between August 8, 2008, and September 11, 2008. The 1 sigma or 95% confidence of error for the primary control at each site was less than 2 cm horizontal and 1 cm vertical. For each site, RTSs were used to capture the asset information relative to the control stations. These instruments produced a positional accuracy at the 1-sigma level of less than 1 cm. KCI provided Applied Research Associates, Inc., (ARA) with the PLS certification on January 29, 2009. The electronic data files, including DNG and DWG files, and geo-databases, were provided on February 28, 2009. ARA's review of the delivered geodatabases revealed that some of the attribute data for some of the assets were missing. ARA used the CAD files and the digital images collected by ARA to fill the attribute gaps and create the asset attribute data for the reference data set.

Task 6: Organizing and Conducting the Rodeo

During Task 6, the S03 research team planned, organized, and executed the Roadway Measurement System Rodeo in Northern Virginia to prequalify the automated data collection vendors for participation in the follow-on Safety Project S04B. The rodeo participants were provided with the list of data elements with the desired target accuracies developed in Task 2. The Roadway Measurement System Evaluation Rodeo was held from September 14 to 20, 2008, in Fairfax, Virginia, and included the following 11 firms or agencies:

- Data Transfer Solutions (DTS);
- eRoadInfo;
- FHWA;
- Fugro/Roadware, Inc.;
- GeoSpan;
- Mandli Communications, Inc.;
- Michael Baker, Jr., Inc.;
- Pathway Services, Inc.;
- Sanborn;
- Tele Atlas; and
- Yotta.

Task 7: Evaluating Rodeo Data

In Task 7, the research team compared the data provided by the nine commercial rodeo participants with the reference data set for the six rodeo test sites (Team 10 did not provide any final data for the six test sections). The goal was to determine how well the participants were able to capture the various priority safety data elements of interest to the highway safety research community as determined in Task 2. The participants were evaluated for completeness of coverage, positional accuracy and precision, and attribute accuracy and precision.

Task 8: Producing the Final Report

This task involved the creation of this final project report.

CHAPTER 2

Roadway Measurement System Evaluation Rodeo

Challenges and Issues

Overall, the rodeo itself went quite well, with very good feedback from the participants and SHRP 2. However, when the data results were delivered by the teams, it became apparent that there were some issues with respect to consistency and quality of the data. The largest challenge encountered was obtaining the desired data in the correct format from each of the participants.

Before the rodeo, the rodeo data collection plan, data elements list, and data delivery templates appeared to be sufficient for the participants to perform the data reduction and provide the research team with the desired data. The participants were provided with 1 month to review the data elements list, and they did not raise any questions prior to the rodeo.

It subsequently became apparent that the participants did not understand how to fill out the data templates properly and provide the research team with the data in the proper requested format. Some of the data format issues were readily corrected by the research team, while others resulted in requests for clarification from the participants. Unfortunately, even after the study team requested clarification from one of the teams, its data could not be matched with the reference data within a reasonable level of effort. Therefore, its data was not included in the final data analysis. In addition, three of the teams did not provide the requested three repetitions of each rodeo site; only subsequently did two of these teams provide the requisite data.

All of the teams provided copies of their digital image files. Only six teams provided their GPS traces, and only four provided road profile and geometrics data.

Analysis of the final data elements provided by the teams revealed that none of the teams provided all the requested data elements. This is summarized by overall data type in Table 2.1. For the reasons cited, Teams 06, 08, and 10 were not evaluated. Teams 08 and 10 did not provide sufficient data to evaluate; the data from Team 06 could not be matched to the reference data.

The participants also seemed to have difficulty using the provided georeference coordinates for the “0” reference locations to reference their data for reporting some of the data elements, such as International Roughness Index (IRI) and cross-slope.

This resulted in greater effort by the research team to obtain complete data from several of the participants and then to rework some of the data to make them usable in the S03 analysis.

As more in-depth analysis of the final data set proceeded, it was observed that the participants may not have fully understood the data reduction and processing descriptions in the rodeo data collection plan and data elements list. The provision of more in-depth descriptions of the data elements, including the following, may have improved the teams’ understanding of the data requirements:

- Descriptions of the data elements;
- Instructions regarding where to reference the data elements;
- Details regarding where to measure the data elements;
- How to measure the data elements;
- How the data elements are reported, including units; and
- Methodologies for processing directly measured data into desired final data, for example, instructions related to how to take the sliding grade measurements from the vehicles and use them to develop vertical curvature data.

The above data collection and reporting issues should be addressed through the development of a detailed data collection manual focused on the needs of the SHRP 2 Safety Program.

Data Elements

Several of the data elements in the rodeo data elements list are desired data for roadway safety research but not routinely collected by typical roadway inventory data collection firms, such as those that participated in the rodeo. However, with the advent of the newer data collection technologies, such as LIDAR systems and scanning laser systems, these desired data elements were included to determine if the participants could

Table 2.1. Summary of Final Data Sets Received

Items Collected	Team 01	Team 02	Team 03	Team 04	Team 05	Team 06	Team 07	Team 08	Team 09	Team 10
Right-of-Way Inventory (Assets)										
Barrier Systems	Partial	x	—	—	x	No Match	Partial	1 rep	Partial	—
On-Street Parking	x	x	x	x	x	No Match	x	1 rep	x	—
Pavement Markings	Partial	x	Partial	Partial	x	No Match	Partial	1 rep	Partial	—
Roadside Obstacles	Partial	Partial	—	x	—	No Match	Partial	1 rep	Partial	—
Rumble Strips	x	—	—	—	x	No Match	—	1 rep	x	—
Sidewalks	x	x	x	x	Partial	No Match	x	1 rep	x	—
Signs	x	Partial	x	Partial	x	No Match	x	1 rep	Partial	—
Street Lighting	x	x	x	x	x	No Match	x	1 rep	x	—
Intersections										
Configuration & Dimensions	x	x	Partial	x	x	No Match	Partial	1 rep	Partial	—
Traffic Control	x	x	x	x	x	No Match	x	1 rep	x	—
Signalized Intersections	x	—	Partial	x	x	No Match	x	1 rep	Partial	—
Stop-Controlled Intersections	x	x	x	x	x	No Match	x	1 rep	—	—
Driveways	x	x	x	x	x	No Match	x	1 rep	Partial	—
Lanes	Partial	Partial	Partial	—	Partial	No Match	Partial	1 rep	Partial	—
Median	x	x	x	x	—	No Match	Partial	1 rep	Partial	—
Ramps	x	—	x	x	—	No Match	x	1 rep	Partial	
Shoulder	x	x	x	—	x	No Match	—	1 rep	Partial	
Geometrics										
Grade	x	—	No Match	—	No Match	No Match	x	—	—	—
Roadway Cross-Slope	x	—	No Match	—	No Match	No Match	x	—	—	—
Clear Zone Cross-Slope & Width	—	—	—	—	—	—	—	—	—	—
Horizontal Curvature	Partial	—	—	—	No Match	No Match	Partial	—	—	—
Sight Distance	—	—	—	—	—	—	—	—	—	—
Vertical Curvature	—	—	—	—	—	—	—	—	—	—
Road Profile	—	—	x	—	x	x	x	—	—	—
Pavement Texture	—	—	—	—	—	No Match	x	—	—	—
Pavement Edge Drop-off	—	—	—	—	—	—	—	—	—	—
Pavement Marking Reflectivity or Retroreflectivity	—	—	—	—	—	—	—	—	—	—

Note: x = the team reported data for all data elements of this data type; — = the team did not report any of the data elements for the data type; Partial = the team reported some of the data elements for the particular data type.

indeed collect them. Therefore, the following data types and elements were included:

- Pavement marking retroreflectivity;
- Pavement edge drop-off;
- Horizontal curvature;
- Sight distance;
- Vertical curvature; and
- Clear zone width and slope.

Three participants provided some data on horizontal curvature. However, these data did not meet the accuracy requirements for the rodeo. The rest of these data types and elements were not provided by any of the teams evaluated in the analysis of the final data set.

The following discussion regarding data elements that were not provided by any of the participants offers some insight into why they were not offered by the participants.

- **Pavement Marking Retroreflectivity.** While this is an important data element from the standpoint of determining the visibility of pavement markings, it can only be measured directly through use of a retroreflectometer. When asked at the rodeo kick-off meeting, none of the participants claimed to be able to collect this data. The automated data collection vendors that used a scanning laser or LIDAR system could, theoretically, have measured the reflectance of the pavement markings. The reflectance would then have to be correlated back to measurements of retroreflectivity measured with a retroreflectometer.
- **Pavement Edge Drop-off.** Edge drop-off can be an important parameter in rural, run-off-road accidents. However, this cannot be measured from right-of-way images as part of a roadway evaluation because of the location in the images and the small size of the measurements (typically less than 2 in.). It is theoretically possible to measure edge drop-off with a scanning laser; however, this has not yet been proven in the industry.
- **Vertical Curvature.** This item is not directly measured from the automated data collection equipment, and is not a standard item reported as part of a roadway inventory project. With the automated equipment measuring to the 0.001% of grade and with reporting grade as a sliding value over the wheelbase of the vehicle collecting the data, identifying a vertical curve can require significant analysis, including determining how much change in grade represents a vertical curve.
- **Sight Distance.** Sight distance is similar to vertical curvature because it is not directly measured, nor is it a standard item reported as part of a roadway inventory project. Determining sight distance requires engineering analysis of the horizontal and vertical alignment data for the roadway.
- **Clear Zone Width.** This measurement could be made from right-of-way cameras by measuring the distance from the edge of the lane to the first obstacle encountered, assuming that the obstacle is also captured in the same image as the edge of the lane. In theory this could be measured using a scanning laser or LIDAR system; however, this has not been proven and would require significant programming and data analysis.
- **Clear Zone Slope.** This cannot be measured by the vehicle-mounted systems in use today, such as the Applanix POS LV, because these systems measure slope as it relates to the attitude of the data collection vehicle. In theory, these systems could be used in conjunction with a scanning laser or LIDAR system to produce this information within the measurement limitation of the system. This technology, however, also has not been proven.
- **Superelevation.** The automated data collection equipment measures superelevation as part of cross-slope. For this to be reported separately, an acceptable range of cross-slope values would need to be established, and anything outside of this range would be reported as superelevation.
- **Horizontal Point of Tangency (PT).** This item is not routinely reported from automated data collection systems. Typically, the radius of curvature is very large (thousands of feet), indicating a relatively tangent section, unless a vendor processes the data to filter out locations where the radius of curvature is too large. To determine the PT for a curve, it is necessary to establish the maximum radius of curvature before the roadway is considered "straight" and to use the DMI or GPS location of this point as the PT.
- **Location of Traffic Signal.** Participants did not appear to know where to measure the location of the traffic signal head.

An important data type for analysis of rural, run-off-road accidents is roadway geometrics. This data type includes grade, roadway cross-slope, and curvature. The teams participating in the rodeo seemed to have difficulty providing these types of data. Eight out of 10 teams claimed before the rodeo that they could collect common roadway geometric data; however, only five teams provided any geometric data as part of their final data set. Three out of the five teams that provided geometric data did not provide their data in a format that would allow the data to be readily matched to the individual test sites and the reference data. The two teams that did provide geometric data did not provide it in the requested format; however, they included GPS coordinates with their data so the research team was able to link it back to the rodeo test sites. The two teams that provided data that could be evaluated provided grade, roadway cross-slope, point of curvature, radius of curvature, and length of curve.

The lack of geometric data provided by the participants was of concern to the project Expert Task Group. Therefore, on September 4, 2009, SHRP 2 issued a request to the 10 teams to reprocess selected data elements on Sites 6 and 7 to be delivered by October 16, 2009. This request was followed by a conference call on September 14, 2009, between SHRP 2, the rodeo participants, and the S03 research team to discuss the data to be collected and offer the participants an open forum to ask questions. Subsequently, SHRP 2 decided to prequalify all rodeo participants and asked them to submit the requested geometric data with their submission for the S04B RFQ/P to be released in 2010. The selected data elements to be reprocessed by each participant include the following:

- General information on experience collecting geometric data: grade, cross-slope, horizontal and vertical curvature;
- Geometric calibration and verification procedures;
- Typical accuracies obtained for geometric data;
- Site 6—Horizontal curvature data (radius of curvature, length of curve, and point of curvature); and
- Site 7—Cross-slope, grade, length of pavement for grade measurement, lane width, shoulder width (paved width), and signs (GPS coordinates and MUTCD code).

Lessons Learned

The lessons learned during the rodeo and the subsequent data analysis can be summarized as follows:

- Most automated data collection firms required that data collection requirements be very clearly specified.
- Data delivery templates are not sufficient to ensure correct delivery of data. They should be populated with at least one row of "dummy" data for each data element to be collected.
- The participating data collection firms appeared to have difficulty using GPS coordinates to reset their zero-reference location.
- The apparent inability of many of the teams to provide the requested data in the desired format is likely indicative of their reluctance to spend a large amount of resources for a demonstration project for which they did not receive any compensation.

CHAPTER 3

Results

Data Evaluation Results

Following the rodeo data analysis, the research team evaluated the rodeo data elements list in relation to these four items:

- Data elements reported by the participants;
- Rodeo target accuracies for each data element;
- Desired data element accuracies to research the causes of rural, run-off-road, single vehicle accidents as addressed in SHRP 2's forthcoming S01E report (*1*); and
- Best accuracy achieved by the participants during the rodeo for each data element reported.

Data elements on which none of the participants reported were removed. The remaining data elements were reviewed to determine the accuracies to be sought during the S04B data collection effort. This resulted in the data elements list shown in Table 3.1.

The research team also reviewed the reduced data elements list to determine those data elements necessary to answer questions related to rural, run-off-road accidents. This further-reduced data elements list is shown in Table 4.1.

The research team analyzed the rodeo results during the Task 7 data analysis to determine which teams could most likely provide SHRP 2 with the desired data elements to be collected under the S04B project. A two-tiered analysis was used covering the following:

- Combined precision and accuracy of each team in reporting each data element; and
- Combined precision and accuracy of data element reporting completeness for each team.

For example, an analysis of the combined precision and accuracy for the data element "Barrier Type" results in Team 01 having a combined precision and accuracy of 164%, which results in a Team Order of 1, as shown in Table 3.2.

The analysis of the team precision and accuracy for completeness in data element reporting looks at the overall completeness for each team. Team precision and accuracy for completeness are defined as follows:

- Completeness precision is the average percent of the data elements included in three repetitions reported by a particular team; and
- Completeness accuracy is the average percent of the data elements reported in any repetition by a particular team, as compared to the number of reference data elements.

Team completeness analysis resulted with Team 01 having the best completeness, followed by Team 07, Team 09, and Team 04. The teams were ranked using each of the above analysis criteria. This resulted in Team 01, Team 04, and Team 07 being at the top of the list for each criterion. Team 04 did not provide any geometric data during the rodeo; therefore, if they are to be used for data collection under the S04B project, they will need to add, and prove, this capability.

Assessment of State of the Practice

The current state-of-the-art in automated data collection technology permits the collection of the data elements contained in the S04B Data Elements for Collection list (Table 3.1). The majority of the data elements will achieve the target accuracies contained in the original rodeo data elements list, but not all. These data elements are discussed here.

Georeference of Vehicle, Images, and Roadway Features

These data are readily available at the sub-1 m level of accuracy for mobile applications. With the correct antennas and real-time differential correction signal, mobile systems can attain accuracies of sub-15 cm or sub-10 cm for the location of the vehicle and images, with slightly lower accuracies for the roadway features extracted from the images. The georeference data for roadway features extracted from

Table 3.1. Data Elements for Collection in SHRP 2 Safety Project S04B

Feature	Data Element	Definition	Rodeo Target Accuracy	CTRE Desired Accuracy	Best Achieved Accuracy	Recommended Accuracy
		Assets				
Barrier Systems	Barrier type	Cable, W beam, tri-beam, box beam, concrete barrier, other	100%	100%	64%	100%
	Location	Roadside or median	100%	100%	73%	100%
	Barrier beginning location	GPS coordinates of the beginning of entire barrier system	±3 ft	±3 ft	±3 ft	sub-1 m
	Barrier ending location	GPS coordinates of the end of entire barrier system	±3 ft	±3 ft	±3 ft	sub-1 m
	Barrier offset—beginning	From edge of lane to face of barrier (in.)	±0.25 ft	±0.25 ft	-4.03 ft	±3 in.
	Barrier offset—ending	From edge of lane to face of barrier (in.)	±0.25 ft	±0.25 ft	-2.96 ft	±3 in.
	Barrier height	From ground surface to top of barrier (in.)	±1 in.	±1 in.	1.23 in.	±1 in.
	Post type	Strong post (metal [6-in. I beam]), weak post (metal [C channel, box post, 3-in I-beam]), wooden post, N/A, other	100%	100%	42%	100%
	End treatment type—beginning	Impact attenuator, buried end, terminal end, fist, bridge connection, none, other	100%	100%	18%	100%
	End treatment type—end	Impact attenuator, buried end, terminal end, fist, bridge connection, none, other	100%	100%	15%	100%
On-Street parking	Beginning of on-street parking	GPS coordinates of the start of on-street parking	±3 ft	±3 ft	±3 ft	sub-1 m
	Ending of on-street parking	GPS coordinates of the end of on-street parking	±3 ft	±3 ft	±3 ft	sub-1 m
	Side of street with on-street parking	Left, right, both	100%	100%	79%	100%
Pavement Markings	Location of marking—begin	GPS coordinates of start of pavement marking	±3 ft	±3 ft	±3 ft	sub-1 m
	Location of marking—end	GPS coordinates of end of pavement marking	±3 ft	±3 ft	±3 ft	sub-1 m
	Marking type	Centerline; lane lines (skips); edge/fog line	100%	100%	99%	100%
	Marking offset	Offset of each type of line (center, lane and edge) from right edge of pavement. Measured to the nearest edge of marking from the right edge of pavement.	±1 in.	±1 in.	1.49 in.	±1 in.
	Centerline marking type	Broken yellow, broken/solid yellow, double yellow, etc.	100%	100%	100%	100%
	Special pavement marking location	GPS coordinates of edge of marking nearest to the data collection vehicle.	±3 ft	±3 ft	±3 ft	sub-1 m

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Table 3.1. Data Elements for Collection in SHRP 2 Safety Project S04B (continued)

Feature	Data Element	Definition	Rodeo Target Accuracy	CTRE Desired Accuracy	Best Achieved Accuracy	Recommended Accuracy
		Assets				
Pavement Markings (continued)	Special pavement marking description	RXR, SCHOOL, arrows, stop bar, etc.	100%	100%	24%	100%
	Raised pavement markers present	Yes/no	100%	100%	74%	100%
	Location of raised pavement markers	Centerline; lane lines; edge/fog line; center and edge lines; center, lane & edge lines	100%	100%	73%	100%
Roadside Obstacles	Type of roadside obstacles	Tree, shrub, building, mailbox, pole, fence, stone, etc.	100%	100%	39%	100%
	Offset of roadside obstacle	From edge of lane to nearest point on obstacle	±0.25 ft	±0.25 ft	7.72 ft	±3 in.
	Location of road-side obstacle	GPS coordinates of each obstacle	±3 ft	±3 ft	±3 ft	sub-1 m
Rumble Strips	Rumble strip lateral location	Centerline or shoulder	100%	100%	100%	100%
	Location of rumble strip—begin	GPS coordinates of start of rumble strips	±3 ft	±3 ft	±3 ft	sub-1 m
	Location of rumble strip—end	GPS coordinates of end of rumble strips	±3 ft	±3 ft	±3 ft	sub-1 m
	Rumble strip offset	From edge of lane to point on rumble strip nearest to the lane	±1 in.	±1 in.	0.08 in.	±1 in.
Sidewalk	Location of sidewalk—begin	GPS coordinates of start of sidewalk segment	±3 ft	±3 ft	±3 ft	sub-1 m
	Location of sidewalk—end	GPS coordinates of end of sidewalk segment	±3 ft	±3 ft	±3 ft	sub-1 m
	Sidewalk is separated from edge of road	Yes/no	100%	100%	30%	100%
Signs	Support type	Post, pole, sign structure, bridge, other	100%	100%	74%	100%
	Support location	GPS coordinates of the location where the nearest post/pole of the support enters the ground. For an overhead sign, the post/pole on the right side of the road will be used. If the overhead sign is mounted on a bridge, the location where the right-hand side of the sign is mounted.	±3 ft	sub-2m	±3 ft	sub-2m
	Multisign	Yes/no	100%	100%	78%	100%
	Sign type(s)	Record the MUTCD code for each sign. If not a standard sign, record sign legend.	100%	100%	36%	100%
Street Lighting	Location of street lighting	GPS coordinates of light pole	±3 ft	±3 ft	±3 ft	sub-1 m

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Table 3.1. Data Elements for Collection in SHRP 2 Safety Project S04B (continued)

Feature	Data Element	Definition	Rodeo Target Accuracy	CTRE Desired Accuracy	Best Achieved Accuracy	Recommended Accuracy
Intersection						
Configuration and Dimensions	Type of intersection	X intersection, T intersection, Y intersection, More than 4 legs, roundabout, other	100%	100%	77%	100%
	Number of approaches	3, 4, ... approaches	100%	100%	70%	100%
	Intersection location	GPS coordinates of center of intersection.	±3 ft	±3 ft	sub-2m	sub-1 m
	Number of through lanes on approach		100%	100%	77%	100%
	Channelization exists on approach	Yes/no	100%	100%	77%	100%
	Number of exclusive left-turn lanes		100%	100%	67%	100%
	Length of exclusive left-turn lane	Identify storage length of left-turn bay. If more than one left-turn lane exists, report the length of the longest one.	±2 ft	±2 ft	5 ft	±2 ft
	Number of exclusive right-turn lanes		100%	100%	67%	100%
	Length of exclusive right-turn lane	Identify storage length of right turn bay. If more than one right-turn lane exists, report the length of the longest one.	±2 ft	±2 ft	-108.76 ft	±2 ft
	Intersection has marked crosswalks	Yes/no	100%	100%	30%	100%
	Intersection is illuminated	Yes/no	100%	100%	77%	100%
Traffic Control	Type of traffic control	None, signalized, stop, yield	100%	100%	77%	100%
Signalized Intersection	Type of signalized intersection	Standard, protected left-turn, permitted turn	100%	100%	57%	100%
	Intersection has pedestrian signal head	Yes/no	100%	100%	50%	100%
	Location of traffic signal	GPS coordinates of signal head	±3 ft	±3 ft	N/A	sub-1 m
Stop-Controlled Intersection	Type of stop-controlled intersection	Two-way, three-way, all-way stop control	100%	100%	77%	100%
	Flashing beacon present	Yes/no (Flashing yellow/red beacon)	100%	100%	70%	100%

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Table 3.1. Data Elements for Collection in SHRP 2 Safety Project S04B (continued)

Feature	Data Element	Definition	Rodeo Target Accuracy	CTRE Desired Accuracy	Best Achieved Accuracy	Recommended Accuracy
		Roadway Inventory				
Bridges Approaches	Bridge begin location	GPS coordinates of where the bridge parapet or rail begins.	±3 ft	±3 ft	N/A	sub-1 m
	Bridge end location	GPS coordinates of where the bridge parapet or rail ends	±3 ft	±3 ft	N/A	sub-1 m
	Bridge rail exists	Yes/no	100%	100%	N/A	100%
	Offset of bridge rail	From edge of lane to nearest face of rail/parapet (ft)	±2 ft	±2 ft	N/A	±2 ft
Driveways	Driveway location	GPS coordinates of near side of driveway	±3 ft	±3 ft	±3 ft	sub-1 m
	Driveway type	Residential, farm, retail/ commercial, industrial	100%	100%	70%	100%
Lanes	Number of lanes	Number of full width lanes at a location	100%	100%	33%	100%
	Lane widths	Report lane width to the nearest whole foot.	±6 in.	±0.328 ft (0.1 m)	-0.02 ft	±0.328 ft (0.1 m)
	Location of measurement	GPS coordinates of reported data. Reported when the number of lanes changes, or lane width changes more than 1 foot, but not in transition reas.	±3 ft	±3 ft	±3 ft	sub-1 m
	Lane add point	GPS coordinates of start of a full lane width.	±3 ft	±3 ft	N/A	sub-1 m
	Lane drop point	GPS coordinates of end of a full lane width.	±3 ft	±3 ft	N/A	sub-1 m
	Special lane function type	Two-way left-turn lane, HOV lane, bicycle lane, reversible lane, bus bay, etc.	100%	100%	11%	100%
Median	Median type	Soil, paved (striped), paved (barrier), raised curb, None, other	100%	100%	80%	100%
	Location of measurement	GPS coordinates or reference post of reported data. Reported when the type changes, or the width changes more than 1 foot, but not in transition areas.	±3 ft	±3 ft	±3 ft	sub-1 m
	Median width		±0.5 ft	±0.5 ft (0.15 m)	-0.13 ft	±0.5 ft (0.15 m)
Rail Crossings	At-grade railroad crossing location	GPS coordinates of first rail of first track	±3 ft	±3 ft	N/A	sub-1 m
	Number of tracks		100%	100%	N/A	100%
	Railroad crossing control type	Crossbucks, gates, flashing lights, signal	100%	100%	N/A	100%

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Table 3.1. Data Elements for Collection in SHRP 2 Safety Project S04B (continued)

Feature	Data Element	Definition	Rodeo Target Accuracy	CTRE Desired Accuracy	Best Achieved Accuracy	Recommended Accuracy
Roadway Inventory						
Rail Crossings (continued)	Grade of approach side of crossing	Direction ("+" uphill in direction of travel, or "-" downhill in direction of travel) and Percent of Slope	±0.5%	±0.5%	N/A	±0.5%
	Grade of leave side of crossing	Direction ("+" uphill in direction of travel, or "-" downhill in direction of travel) and Percent of Slope	±0.5%	±0.5%	N/A	±0.5%
Ramps	Ramp location	GPS coordinates of point of ramp gore area	±3 ft	±3 ft	> 4 m	sub-1 m
	Type of ramp terminal	Entry or exit (for roadway on which the vehicle is traveling)	100%	100%	100%	100%
	Type of section	Acceleration lane, decceleration lane, weaving section	100%	100%	100%	100%
Shoulder	Shoulder type	Paved, unpaved, composite (part paved, part unpaved) and curb	100%	N/A	100%	100%
	Shoulder paved width	Width of paved portion of shoulder. Reported from edge line to edge of paved surface to the nearest foot.	±0.5 ft	±0.5 ft (0.15 m)	-0.03 ft	±0.5 ft (0.15 m)
	Shoulder total width	Total width of shoulder (composite only), including paved and unpaved parts. Measured to the first obstacle, or the break in slope.	±0.5 ft	±0.5 ft (0.15 m)	-0.29 ft	±0.5 ft (0.15 m)
	Location of measurement	GPS coordinates of reported data. Reported when the shoulder type changes, or the width changes more than 1 foot, but not in transition areas.	±3 ft	±3 ft	±3 ft	sub-1 m
Geometric Features						
Grade	Grade in direction of travel	Direction ("+" uphill in direction of travel, or "-" downhill in direction of travel) and percent of slope	±0.5%	±0.5%	-0.164%	±0.5%
	Location of measurement	GPS coordinates of reported data	±3 ft	±3 ft	N/A	sub-1 m
Cross Slope	Location of measurement	GPS coordinates of reported data	±3 ft	±3 ft	N/A	sub-1 m
	Roadway cross-slope	Cross-slope of lane being driven. Direction ("+" slopes toward side of road or "-" slopes towards center of road) and percent of slope.	±0.01%	±0.10%	-0.2045%	±0.2%
Curvature	Horizontal curve PC (point of curvature)	GPS coordinates where curve begins	±3 ft	±3 ft	-154.97 ft	sub-1 m
	Horizontal curve-length		±2 ft	±25 ft (7.62 m)	-17.5 ft	±25 ft (7.62 m)
	Horizontal curve-radius		±25 ft	±25 ft (7.62 m)	128.48 ft	±25 ft (7.62 m)

Table 3.2. Barrier Type: Accuracy and Precision

	Team 01		Team 02		Team 03	Team 04	Team 05		Team 07		Team 09	
	Accuracy	Precision	Accuracy	Precision			Accuracy	Precision	Accuracy	Precision	Accuracy	Precision
Barrier Type	64%	100%	21%	78%	N/A	N/A	24%	89%	61%	95%	0%	92%
Combined Precision & Accuracy		164%		99%	N/A	N/A		113%		156%		92%
Team Order		1		4	N/A	N/A		3		2		5

digital images can be lower than the georeference of the images from which they are extracted. The difference in accuracy between image georeference and the extracted feature georeference varies depending upon the placement of the feature within the digital image, as well as the care taken in calibrating the cameras on the data-collection vehicle.

Roadway Assets and Features

Data on roadway assets and features are readily extracted from the georeferenced digital images collected using semiautomated methods. Any asset that is captured in the images can be recorded and georeferenced. This includes bridges, signs, streetlights, barrier systems, trees, buildings, pavement markings, and rumble strips. The quality of these data depends upon the resolution and spacing of the images, the accuracy of the GPS coordinates, the software used, the system calibration, and a rigorous QA/QC program. There have been several attempts to develop a system to perform automated image processing to extract traffic signs from digital images. These systems have had mixed results. No system is currently capable of extracting all of the roadway assets and features.

Intersections

The intersection attributes contained in the data elements list (Table 3.1) can be obtained from the digital right-of-way images using semiautomated data analysis methods similar to those used for recording the roadway assets and features discussed. Accuracies will depend upon the GPS resolution of the mobile data-collection systems, care exercised in calibrating and configuring the mobile data-collection systems, care in recording the data elements, the firm's quality control procedures, and the client's quality assurance procedures.

Geometrics

The roadway geometric data elements contained in Table 3.1 are directly measured or reported by the automated data collection systems, as follows:

- **Grade** is measured as the sliding grade representing the grade over the length of the data collection vehicle. This measurement can provide accuracies within ±0.5%, compared with manual measurements over the same length.
- **Roadway Cross-slope** is typically measured between the wheel paths when using automated equipment. This equipment does not typically meet the 0.10% accuracy desired in the data elements list. However, using an Applanix POS LV 320 or 420 system with laser reference sensors, it is possible to achieve an average absolute error of 0.13% over 200–300 readings, compared with manual measurements, with a standard deviation of 0.03%.
- **Horizontal Curvature** data are determined from analysis of the heading data collected by the onboard inertial navigation system. The data collected from these systems, while generally acceptable for network-level evaluation or for Highway Performance Monitoring System (HPMS) reporting, may not have the resolution necessary for research work. The point of curvature typically varies from the reference by ±20%, the length of curve varies by ±10%, and the radius of curvature varies by ±55%, when using all the curves that matched the reference data set. If the curve for each participant that varied the most from the reference is removed from the analysis, the resulting radius of curvature varies by ±5% from the reference. While the variances may be higher than desired for research work, the systems are very repeatable, with precisions of 99%, 98%, and 91%, respectively.

Many of the other data elements from the original list can also be collected, some with existing technology, some with emerging technologies, and others through new data processing methods.

Existing technologies can be used to collect pavement roughness, which is routinely collected by state DOTs for reporting to FHWA. These same road profiling systems can be used to record pavement macrotexture. The pavement macrotexture can be measured as estimated mean texture depth (EMTD, ASTM E-965, or E-1845). If the profiling system uses 32 kHz or 64 kHz (preferred) laser profiling sensors, then the system can also collect EMTD. The macrotexture data is typically collected in one of the wheelpaths. Emerging technologies could be used to collect such data as pavement edge drop-off and pavement marking reflectivity, as follows.

Pavement Edge Drop-off

Currently there are three systems that could be used to measure edge drop-off:

1. INO LRMS system that projects a line laser onto the pavement's surface about 15 ft long and takes a digital image of it, which is later analyzed to determine transverse profile and rutting. If this line overlaps the edge of pavement where the drop-off occurs, it can be used to calculate edge drop-off.
2. Scanning laser system that captures a slice of the pavement's surface with each scan line. These scan lines can be analyzed for edge drop-off.
3. LIDAR point cloud laser system that uses lasers to obtain a 3-D model of the roadway near the data collection vehicle. None of these systems has been proven for measuring edge drop-off.

Pavement Marking Reflectivity

The emerging LIDAR and scanning laser systems have the potential to record the varying reflectance of pavement markings. Research could be performed to develop a correlation between pavement marking reflectance measured with LIDAR or a scanning laser and the pavement marking retroreflectivity measured with a pavement marking retroreflectometer, such as the Delta LTL-X.

Data elements such as those dealing with horizontal and vertical curvature and sight distance can be determined using a combination of collected sensor geometric data, GPS, and images. However, an industry standard methodology to make this determination is not available currently.

Reference

1. Hallmark, S., Y.-Y. Hsu, L. Boyle, A. Carriquiry, Y. Tian, and A. Mudgal. *SHRP 2 Report S2-S01E-RW-1: Evaluation of Data Needs, Crash Surrogates, and Analysis Methods to Address Lane Departure Research Questions Using Naturalistic Driving Study Data.* Transportation Research Board of the National Academies, Washington, D.C., forthcoming.

CHAPTER 4

Conclusions and Recommendations

The original goals of the S03 research were to prequalify commercial data collection vendors for bidding on the Safety Project S04B, Mobile Data Collection; to evaluate the precision and accuracy of the mobile roadway and pavement inventory data collection services as they relate to selected roadway safety data elements collected at highway speeds; and to produce a recommended list of roadway data elements and associated specifications to be collected under S04B. The following sections highlight the conclusions and recommendations related to each of these goals.

Prequalification of Vendors for SHRP 2 Safety Project S04B

The evaluation of the final data sets eliminated three of the 10 commercial vendors—Teams 06, 08, and 10—from further consideration because of lack of coverage or data format issues. Of the remaining seven teams, none provided all of the requested data elements. Some vendors focused on providing only a few data elements and performed very well, while others focused on providing more data elements but apparently sacrificed accuracy and precision in doing so. Because the results of the rodeo were inconclusive, SHRP 2 decided to prequalify all of the participants. Team 10 decided not to continue in the pursuit of Project S04B.

Before commencing data collection under the S04B contract, it is recommended that the ground rules for the data collection effort be described very clearly. As part of this effort, a SHRP 2 Safety Data Collection Manual should be developed to define each data element, how it is to be measured and reported, including the units to use, and any other necessary information. The manual should include photographs, diagrams, formulas, and any other items necessary to ensure SHRP 2 receives the required data. This will likely be an iterative process between the S04B contractor and the developer of the manual during the first few months of the contract.

As part of the quality assurance for the S04B project, it is recommended that SHRP 2 establish validation sites in each region. These sites would typically be 0.2-mi or 0.3-mi long and be laid out to verify the following: DMI, GPS, image interval and quality, cross-slope, grade, and the contractor data take-off process from the images collected. The S04B data collection contractor would survey the site before starting work in that region and periodically throughout the regional data collection effort. The data collected would be processed and provided to the S04A contractor, who would compare the data to reference data and previous historical data from the S04B contractor to verify that its systems are maintaining the appropriate level of calibration.

Precision and Accuracy

The S03 study resulted in the evaluation of the precision and accuracy of mobile roadway and pavement inventory data collection services as they relate to selected roadway safety data elements collected at highway speeds. The results of the rodeo, along with the discussion in the Assessment of State of the Practice in Chapter 3, provide a background related to the expected precision and accuracy of mobile data collection units for the S04A and S04B projects.

Recommended Roadway Data Elements

A reduced set of data elements for collection during the S04B project was developed by considering the following four items:

- Data elements reported by the teams;
- Rodeo target accuracies for each data element;
- Desired data element accuracies to research the causes of rural, run-off-road, single vehicle accidents, as presented in SHRP 2's forthcoming S01E report (*1*); and

- Best accuracy achieved by the teams during the rodeo for each data element reported.

Items reported by none of the participants were removed. The remaining data elements were reviewed to determine the accuracies to be sought during the S04B data collection effort. This resulted in the 88 data elements listed in Table 3.1.

If the purpose of the S04B project is to answer questions relating only to rural, run-off-road accidents, then the list of data elements to be collected under this project can be further reduced. This reduced list of 53 data elements is shown in Table 4.1.

Cost Implications of Recommended Data Set

Prior to the rodeo, the research team asked the participants to fill out a questionnaire regarding the approximate costs associated with three scenarios of data collection. The three scenarios presented are summarized in the following sections.

Regional Data Collection Scenario 1

- Survey location with a 200-mi radius.
- Approximately 4,000 survey miles within survey location.

Table 4.1. Data Elements for Rural, Run-off-Road Accidents in SHRP 2 Safety Project S04B

Feature	Data Element	Definition	Rodeo Target Accuracy	CTRE Desired Accuracy	Best Achieved Accuracy	Recommended Accuracy
			Assets			
Barrier Systems	Barrier type	Cable, W beam, tri beam, box beam, concrete barrier, other	100%	100%	64%	100%
Pavement Markings	Location	Roadside or median	100%	100%	73%	100%
Roadside Obstacles	Barrier beginning location	GPS coordinates of the beginning of entire barrier system	±3 ft	±3 ft	±3 ft	sub-1 m
	Barrier ending location	GPS coordinates of the end of entire barrier system	±3 ft	±3 ft	±3 ft	sub-1 m
	Barrier offset—beginning	From edge of lane to face of barrier (in.)	±0.25 ft	±0.25 ft	–4.03 ft	±3 in.
Rumble Strips	Barrier offset—ending	From edge of lane to face of barrier (in.)	±0.25 ft	±0.25 ft	–2.96 ft	±3 in.
	Barrier height	From ground surface to top of barrier (in.)	±1 in.	±1 in.	1.23 in.	±1 in.
	Post type	Strong post (metal [6-in I beam]), weak post (metal [C-channel, box post, 3-in I beam]), wooden post, n/a, other	100%	100%	42%	100%
Signs	End treatment type—beginning	Impact Attenuator, buried end, terminal end, fist, bridge connection, none, other	100%	100%	18%	100%
Street Lighting Driveways	End treatment type—end	Impact Attenuator, buried end, terminal end, fist, bridge connection, none, other	100%	100%	15%	100%
	Location of marking—begin	GPS coordinates of start of pavement marking	±3 ft	±3 ft	±3 ft	sub-1 m
	Location of marking—end	GPS coordinates of end of pavement marking	±3 ft	±3 ft	±3 ft	sub-1 m
	Marking type	Centerline; lane lines (skips); edge/fog line	100%	100%	99%	100%

(continued on next page)

Table 4.1. Data Elements for Rural, Run-off-Road Accidents in SHRP 2 Safety Project S04B (continued)

Feature	Data Element	Definition	Rodeo Target Accuracy	CTRE Desired Accuracy	Best Achieved Accuracy	Recommended Accuracy
Assets						
Pavement Markings (continued)	Marking offset	Offset of each type of line (center, lane and edge) from right edge of pavement. Measured to the nearest edge of marking from the right edge of pavement.	±1 in	±1 in	1.49 in	±1 in
	Centerline marking type	Broken yellow, broken/solid yellow, double yellow, etc.	100%	100%	100%	100%
	Special pavement marking location	GPS coordinates of edge of marking nearest to the data collection vehicle.	±3 ft	±3 ft	±3 ft	sub-1 m
	Special pavement marking description	RXR, SCHOOL, arrows, stop bar, etc.	100%	100%	24%	100%
	Raised pavement markers present	Yes/No	100%	100%	74%	100%
	Location of raised pavement markers	Centerline; lane lines; edge/fog line; center and edge lines; center, lane and edge lines	100%	100%	73%	100%
Lanes	Type of roadside obstacles	Tree, Shrub, Building, Mailbox, Pole, Fence, Stone, etc.	100%	100%	39%	100%
	Offset of roadside obstacle	From edge of lane to nearest point on obstacle	±0.25 ft	±0.25 ft	7.72 ft	±3 in
	Location of roadside obstacle	GPS coordinates of each obstacle	±3 ft	±3 ft	±3 ft	sub-1 m
	Rumble strip lateral location	Centerline or shoulder	100%	100%	100%	100%
	Location of rumble strip—begin	GPS coordinates of start of rumble strips	±3 ft	±3 ft	±3 ft	sub-1 m
	Location of rumble strip—end	GPS coordinates of end of rumble strips	±3 ft	±3 ft	±3 ft	sub-1 m
	Rumble Strip Offset	From edge of lane to point on rumble strip nearest to the lane	±1 in.	±1 in.	0.08 in.	±1 in.
	Support type	Post, pole, sign structure, bridge, other	100%	100%	74%	100%
	Support location	GPS coordinates of the location where the nearest post/pole of the support enters the ground. For an overhead sign, the post/pole on the right side of the road will be used. If the overhead sign is mounted on a bridge, the location where the right-hand side of the sign is mounted.	±3 ft	sub-2m	±3 ft	sub-2m

(continued on next page)

Table 4.1. Data Elements for Rural, Run-off-Road Accidents in SHRP 2 Safety Project S04B (continued)

Feature	Data Element	Definition	Rodeo Target Accuracy	CTRE Desired Accuracy	Best Achieved Accuracy	Recommended Accuracy
		Assets				
Signs (continued)	Multi-sign	Yes/no	100%	100%	78%	100%
	Sign type(s)	Record the MUTCD code for each sign. If not a standard sign record sign legend.	100%	100%	36%	100%
Median	Location of street lighting	GPS coordinates of light pole	±3 ft	±3 ft	±3 ft	sub-1 m
		Roadway Inventory				
	Driveway location	GPS coordinates of near side of driveway	±3 ft	±3 ft	±3 ft	sub-1 m
	Driveway type	Residential, farm, retail/ commercial, industrial	100%	100%	70%	100%
	Number of lanes	Number of full-width lanes at a location	100%	100%	33%	100%
	Lane widths	Report lane width to the nearest whole foot.	±6 in.	±0.328 ft (0.1 m)	–0.02 ft	±0.328 ft (0.1 m)
Shoulder Grade	Location of measurement	GPS coordinates of reported data. Reported when the number of lanes changes, or lane width changes more than 1 foot, but not in transition areas.	±3 ft	±3 ft	±3 ft	sub-1 m
	Lane add point	GPS coordinates of start of a full lane width.	±3 ft	±3 ft	n/a	sub-1 m
	Lane drop point	GPS coordinates of end of a full lane width.	±3 ft	±3 ft	n/a	sub-1 m
Cross Slope	Special lane function type	Two-way left turn lane, HOV lane, bicycle lane, reversible lane, bus bay, etc.	100%	100%	11%	100%
	Median type	Soil, paved (striped), paved (barrier), raised curb, none, other	100%	100%	80%	100%
Curvature	Location of measurement	GPS coordinates or Reference post of reported data. Reported when the type changes, or the width changes more than 1 foot, but not in transition areas.	±3 ft	±3 ft	±3 ft	sub-1 m
	Median width		±0.5 ft	±0.5 ft (0.15 m)	–0.13 ft	±0.5 ft (0.15 m)
	Shoulder type	Paved, unpaved, composite (part paved, part unpaved), and curb	100%	n/a	100%	100%
	Shoulder paved width	Width of paved portion of shoulder. Reported from edge line to edge of paved surface to the nearest foot.	±0.5 ft	±0.5 ft (0.15 m)	–0.03 ft	±0.5 ft (0.15 m)

(continued on next page)

Table 4.1. Data Elements for Rural, Run-off-Road Accidents in SHRP 2 Safety Project S04B (continued)

Feature	Data Element	Definition	Rodeo Target Accuracy	CTRE Desired Accuracy	Best Achieved Accuracy	Recommended Accuracy
Roadway Inventory						
Shoulder (continued)	Shoulder total width	Total width of shoulder (composite only), including paved and unpaved parts. Measured to the first obstacle, or the break in slope.	±0.5 ft	±0.5 ft (0.15 m)	–0.29 ft	±0.5 ft (0.15 m)
	Location of measurement	GPS coordinates of reported data. Reported when the shoulder type changes, or the width changes more than 1 foot, but not in transition areas.	±3 ft	±3 ft	±3 ft	sub-1 m
Geometric Features						
	Grade in direction of travel	Direction ("+" uphill in direction of travel, or "—" downhill in direction of travel) and percent of slope	±0.5%	±0.5%	–0.164%	±0.5%
	Location of measurement	GPS coordinates of reported data.	±3 ft	±3 ft	n/a	sub-1 m
	Location of measurement	GPS coordinates of reported data.	±3 ft	±3 ft	n/a	sub-1 m
	Roadway cross slope	Cross-slope of lane being driven. Direction ("+" slopes towards side of road or "—" slopes towards center of road) and percent of slope.	±0.01%	±0.10%	–0.2045%	±0.2%
	Horizontal curve PC (point of curvature)	GPS coordinates where curve begins	±3 ft	±3 ft	–154.97 ft	sub-1 m
	Horizontal curve length		±2 ft	±25 ft (7.62 m)	–17.5 ft	±25 ft (7.62 m)
	Horizontal curve radius		±25 ft	±25 ft (7.62 m)	128.48 ft	±25 ft (7.62 m)

- Mixed road types from interstates to locals.
- Discontinuous survey segments.
- Survey segments of 5–10 mi each.
- Data to be processed and provided to SHRP 2:
    - Research grade data for all 113 rodeo data elements;
    - Geographic information system (GIS) map of surveyed roadways; and
    - Georeferenced video images, with camera configuration files for future data analysis.

Regional Data Collection Scenario 2

- Survey location with a 200-mi radius.
- Approximately 4,000 survey miles within survey location.
- Mixed road types from interstates to locals.
- Discontinuous survey segments.
- Survey segments of 5–10 mi each.
- Data to be processed and provided to SHRP 2:
    - Research-grade data for *selected* groups of rodeo data elements (53 data elements), as follows:
        - Assets (barrier systems, pavement markings, signs, and street lighting)
        - Geometrics (all)
        - Intersections (configuration and traffic control)
        - Pavement condition (pavement profile and texture)
        - Roadway inventory (railroad crossing and ramps)
    - GIS map of surveyed roadways; and

- ○ Georeferenced video images, with camera configuration files for future data analysis.

Regional Data Collection Scenario 3

- Survey location with a 200-mi radius.
- Approximately 4,000 survey miles within survey location.
- Mixed road types from interstates to locals.
- Discontinuous survey segments.
- Survey segments of 5–10 mi each.
- Data to be processed and provided to SHRP 2:
  - ○ Research-grade data for *selected* groups of rodeo data elements (9 data elements), as follows:
    - ▪ Geometrics (all)
    - ▪ Pavement condition (pavement profile and texture)
  - ○ GIS map of surveyed roadways; and
  - ○ Georeferenced video images, with camera configuration files for future data analysis.

Responses were received from seven out of 10 participants. Table 4.2 summarizes the responses received from all participants. Teams 03, 04, 05, 08, and 10 did not seem to understand that Scenario 1 required the most intensive data processing, as evidenced by their costs going up for Scenarios 2 and 3, even though data processing for the latter two was less.

Considering the responses received from the participants, the reduced data elements list for S04B, and the research team's experience with research-grade, nationwide data collection efforts, SHRP 2 can expect the effort for this work to be in the range of $350–$1,000 per survey mile. This could go even higher, depending on the region and the density of the assets to be collected.

Cost implications for mobile data collection are dependent on several items and can vary greatly from firm to firm. Some of the items that affect the cost of mobile data collection include the following:

- Size of the network to be surveyed—number of miles or sections;
- Geographic coverage of the network to be surveyed—local, regional, national;
- Environment in which the network is located—rural, suburban, urban, or heavy urban;
- Road types to be surveyed—e.g., interstate, rural primary, urban local;
- Time frame within which work is to be performed;
- Number of data elements to be recorded;
- Grade of data being collected—network, project, or research; and
- Data analysis methodology(ies).

For example, performing network-level, statewide collection of pavement profile (IRI), rutting, and digital images on 1,000 lane miles of mixed rural and urban interstate highways would cost in the order of $35–$40 per mile.

Table 4.2. Data Collection Cost Summary Based on Questionnaire

Team	Scenario 1		Scenario 2		Scenario 3	
	"Ball Park" Costs ($/mile)	Estimated "Normal" Turnaround Time (days)	"Ball Park" Costs ($/mile)	Estimated "Normal" Turnaround Time (days)	"Ball Park" Costs ($/mile)	Estimated "Normal" Turnaround Time (days)
Team 01[a]	330	100	280	90	230	60
Team 02	no response		no response		no response	
Team 03	100	15	300	200	130	30
Team 04[b]	30	30	100	90	50	45
Team 05	55	60	90	60	60	75
Team 06	80	30	70	30	50	20
Team 07	no response		no response		no response	
Team 08	1,000	60	1,500	90	1,200	80
Team 09	no response		no response		no response	
Team 10[c]	40	60	120	180	no response	

[a]Does not include pavement profile & texture.
[b]Does not include geometrics or pavement profile & texture data.
[c]Response came from one part of the team.

Summary

Overall, the rodeo was considered a success. Analysis of the data provided by rodeo participants revealed some issues to be addressed before the commencement of the S04B data collection. The two most critical of these issues are the following:

- Develop a SHRP 2 Safety Data Collection Manual that defines each data element, how it should be measured and reported, including the units to use, and other necessary information. The manual should include photographs, diagrams, formulas, and any other items necessary to ensure SHRP 2 receives the desired data in the appropriate format. This will likely be an iterative process between the S04B contractor and the S04A contractor during the first few months of the contract.
- As part of the quality assurance for the S04B project, it is recommended that short validation sites be established in each region. These sites would be about 0.2 or 0.3 mi long and be laid out to verify the following: DMI, GPS, image interval and quality, cross-slope, grade, and the contractor data take-off process from the images collected.

Two reduced lists of data elements have been produced considering the data elements reported by the rodeo participants and the desired data element accuracies from both the rodeo and CTRE's white paper on rural run-off-road accidents.

- Table 3.1 contains a list of 88 data elements that can be used to help researchers answer a wide range of highway safety questions for both urban and rural environments; and
- Table 4.1 contains a list of 53 data elements that can be used to help researchers answer highway research questions relating to issues in rural environments, most notably rural, run-off-road accidents.

The cost implications for research-grade mobile data collection depend on the following general items:

- Cost of the field data collection;
- Data analysis methods employed;
- Quality control measures needed to reach the desired data accuracies; and
- Project time frame.

The cost for collecting research-grade highway safety data cannot be obtained from previous contracts inasmuch as there have not been any previous large-scale highway safety research projects before, and in particular not any completed nationwide. On the basis of the responses of some of the participants to the data collection scenarios questionnaire and the experience of ARA with nationwide research-grade data collection during the SHRP Long-Term Pavement Performance program, SHRP 2 can expect the cost for the S04B project to range between $350 and $1,000 a survey mile. Considering that the study areas include North Carolina, Pennsylvania, Florida, and Washington, the costs will probably be toward the high end of this range.

Reference

1. Hallmark, S., Y.-Y. Hsu, L. Boyle, A. Carriquiry, Y. Tian, and A. Mudgal. *SHRP 2 Report S2-S01E-RW-1: Evaluation of Data Needs, Crash Surrogates, and Analysis Methods to Address Lane Departure Research Questions Using Naturalistic Driving Study Data.* Transportation Research Board of the National Academies, Washington, D.C., forthcoming.

Glossary

Accuracy. A measure of how well the data provided by a participant matches the reference data for a particular data element.

Completeness. A measure of how well a participant was able to provide the correct number of a specific data element when compared to the reference data for that data element.

Consistency. A measure of how well the data provided by a single participant for one repetition compares to the data provided by the same participant for his or her other two repetitions. These data are not compared to the reference data.

Coverage. A determination of whether a participant provided the required three repetitions of both the initial and final data sets.

Final data set. The purpose of the final data set was to determine how well the participants could collect the specific data elements of interest to the roadway safety community. The final data set contained the full set of data elements for the three repetitions on the six specific test site locations for the Roadway Measurement System Evaluation Rodeo. Roadway assets and features were to be recorded as they were encountered and provided in the designated data delivery format. Geometrics data (grade, cross-slope, and curvature) were to be processed and provided at 0.01-mi intervals. All data elements were to be provided in the prescribed format, with associated GPS coordinates.

Initial data set. The purpose of the initial data set was to determine the ability of the individual participant to consistently collect roadway data under real-world conditions. The initial data set contained the images and processed geometric data for all three repetitions on the two rodeo survey routes. Three repetitions were performed on both routes in both directions for a total of 258 survey miles. All images collected were to be provided with the associated GPS coordinates. The geometrics and road profile data were to be processed and provided as IRI, grade, cross-slope, and curvature. These processed data were to be provided at 0.1-mi intervals, along with the associated GPS coordinates by the end of the rodeo week.

Precision. A measure of how well a participant's data for a specific data element from one repetition matched the participant's data for the same data element from the other two repetitions.

Semiautomated data reduction. The recording of roadway assets and/or features by a trained data reduction person using specialized software. One type of specialized software is Geo3D's Trident 3D Analyst. A trained operator uses this software in combination with georeferenced digital images to digitize the geolocation of roadway assets, such as signs. Operators also use the software's data entry interfaces to enter data, such as support type and MUTCD code.

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Related SHRP 2 Research

Development of Analysis Methods Using Recent Data (S01A–E)

Roadway Information Database Development and Technical Coordination and Quality Assurance of the Mobile Data Collection Project (S04A)

Mobile Data Collection (S04B)

Design of the In-Vehicle Driving Behavior and Crash Risk Study (S05)

Technical Coordination and Quality Control (S06)

In-Vehicle Driving Behavior Field Study (S07)

Analysis of the SHRP 2 Naturalistic Driving Study Data (S08)

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