Evaluating the Relationship between the Driver and Roadway to Address Rural Intersection Safety using the SHRP 2 Naturalistic Driving Study Data

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16. Abstract

Rural intersections account for 30% of crashes in rural areas and 6% of all fatal crashes, representing a significant but poorly understood safety problem. Transportation agencies have traditionally implemented countermeasures to address rural intersection crashes but frequently do not understand the dynamic interaction between the driver and roadway and the driver factors leading to these types of crashes.

The Second Strategic Highway Research Program (SHRP 2) conducted a large-scale naturalistic driving study (NDS) using instrumented vehicles. The study has provided a significant amount of on-road driving data for a range of drivers. The present study utilizes the SHRP 2 NDS data as well as SHRP 2 Roadway Information Database (RID) data to observe driver behavior at rural intersections first hand using video, vehicle kinematics, and roadway data to determine how roadway, driver, environmental, and vehicle factors interact to affect driver safety at rural intersections.

A model of driver braking behavior was developed using a dataset of vehicle activity traces for several rural stop-controlled intersections. The model was developed using the point at which a driver reacts to the upcoming intersection by initiating braking as its dependent variable, with the driver's age, type and direction of turning movement, and countermeasure presence as independent variables. Countermeasures such as on-pavement signing and overhead flashing beacons were found to increase the braking point distance, a finding that provides insight into the countermeasures' effect on safety at rural intersections. The results of this model can lead to better roadway design, more informed selection of traffic control and countermeasures, and targeted information that can inform policy decisions.

Additionally, a model of gap acceptance was attempted but was ultimately not developed due to the small size of the dataset. However, a protocol for data reduction for a gap acceptance model was determined. This protocol can be utilized in future studies to develop a gap acceptance model that would provide additional insight into the roadway, vehicle, environmental, and driver factors that play a role in whether a driver accepts or rejects a gap.

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EVALUATING THE RELATIONSHIP BETWEEN THE DRIVER AND ROADWAY TO ADDRESS RURAL INTERSECTION SAFETY USING THE SHRP 2 NATURALISTIC DRIVING STUDY DATA

Final Report
February 2016

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EXECUTIVE SUMMARY

Rural intersections account for 30% of crashes in rural areas and 6% of all fatal crashes, representing a significant but poorly understood safety problem. Transportation agencies have traditionally implemented countermeasures to address rural intersection crashes but frequently do not understand the dynamic interaction between the driver and roadway and the driver factors leading to these types of crashes.

The Second Strategic Highway Research Program (SHRP 2) conducted a large-scale naturalistic driving study (NDS) using instrumented vehicles. The study has provided a significant amount of on-road driving data for a range of drivers. The present study utilizes the SHRP 2 NDS data as well as SHRP 2 Roadway Information Database (RID) data to observe driver behavior at rural intersections first hand using video, vehicle kinematics, and roadway data to determine how roadway, driver, environmental, and vehicle factors interact to affect driver safety at rural intersections.

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Additionally, a model of gap acceptance was attempted but was ultimately not developed due to the small size of the dataset. However, a protocol for data reduction for a gap acceptance model was determined. This protocol can be utilized in future studies to develop a gap acceptance model that would provide additional insight into the roadway, vehicle, environmental, and driver factors that play a role in whether a driver accepts or rejects a gap.

INTRODUCTION

In Iowa in 2015, rural intersections were the site of 52 fatalities, which amounted to 16% of all fatalities in the state that year based on preliminary data. Rural intersection crashes thus represent a significant but poorly understood safety problem. Transportation agencies have traditionally implemented countermeasures to address rural intersection crashes but frequently do not understand the dynamic interaction between the driver and roadway and the driver factors leading to these types of crashes.

The Strategic Highway Safety Program (SHRP 2) conducted a large-scale naturalistic driving study (NDS) using instrumented vehicles. The study has provided a significant amount of on-road driving data for a range of drivers. The research team of the present study utilized these NDS data to observe driver behavior at rural intersections first hand using video and vehicle kinematics data.

The project illuminated how drivers are interacting with roadway features (e.g., traffic control, intersection geometry, and other countermeasures) and the mistakes drivers are making that result in safety-compromising situations at rural intersections. The research resulted in a better understanding of where drivers are focusing their attention, the role of distraction, the effectiveness of current countermeasures, roadway factors leading to driver errors (e.g., sight distance issues), and the impact of environmental factors (e.g., winter weather or nighttime conditions) on driver error. The results can lead to better roadway design, more informed selection of traffic control and countermeasures, and targeted information that can inform policy decisions.

Objective

The objective of this study was to understand better how drivers react at rural intersections. This objective was accomplished through two different analyses. For the first analysis, a model was developed of driver braking behavior at rural intersections incorporating driver, environmental, and roadway characteristics, including different countermeasures commonly used at rural intersections to increase their conspicuity. The results of this research effort will be used to develop guidance that will allow transportation agencies to more efficiently apply countermeasures at rural intersections. For the second analysis, a proof of concept gap acceptance model was developed for rural intersections. The gap acceptance model will provide additional insight into the driver, environmental, and roadway factors that affect the gaps that drivers accept and reject at rural intersections.

Use of the SHRP 2 NDS data is resource and time intensive. As a result, there were not sufficient resources to conduct a full analysis. The intent of this project was, first, to demonstrate the utility of the SHRP 2 database in addressing rural intersection issues and, second, to provide a basis for leveraging the initial work to guide future research.

Background

In the US, rural intersections account for 30% of crashes in rural areas and 6% of all fatal crashes, representing a significant but poorly understood safety problem. Crashes at rural intersections are particularly problematic when high speeds on intersection approaches are present. Additionally, motor vehicle crash injury rates are higher in rural versus urban areas due, in part, to increased emergency response service (EMS) times, reliance on volunteer EMS personnel, and increased transport times to definitive care (Zwerling et al. 2005). EMS response times in rural areas are 1.6 to 2 times longer than those in urban areas (Gonzalez et al. 2009, NHTSA 2006), and fatal injury crash rates are 2 to 3 times higher in rural than urban areas (NHTSA 2006, Zwerling et al. 2005). Inappropriate gap selection has been found to be a major contributing cause of crashes at rural intersections (Preston et al. 2004), accounting for 56% of all right-angle crashes at Minnesota rural thru-STOP intersections according to a study conducted in 2003 (Harder et al. 2003). Drivers failing to stop on the minor approach because they did not recognize they were approaching an intersection accounted for 25% of right-angle crashes at these same types of intersections Therefore, addressing these two types of crashes will help to improve rural intersection safety.

Two surrogate measures for modeling safety at rural intersections that address the two crash causes identified above and that have been utilized in the past are braking behavior studies and gap acceptance models. The present study utilizes these models to determine the effect of countermeasures and other roadway, driver, environmental, and vehicle features on driver performance and safety.

Most studies to assess intersection braking behavior have used simulators (Montella et al. 2011), closed-course studies (Muttart et al. 2011), or controlled instrumented vehicles with test drivers (Bao and Boyle 2008). The drawbacks to these types of studies are that they are limited in the number of drivers that can be included and it is difficult to test real-world conditions. Some studies have collected driver stopping behavior by reducing video data collected at actual intersections. However, these studies require collecting data for significant distances upstream using multiple video data collection arrays, and driver characteristics cannot be obtained. With each of the above types of data collection, it is difficult to represent a wide array of different intersections. This project uses the SHRP 2 NDS data to help address the drawbacks of these previous studies.

A number of studies have also modeled gap acceptance behavior at rural stop-controlled intersections (Gorjestani et al. 2010), but the majority have utilized video data collection, which cannot account for driver characteristics and driver distraction. Use of the SHRP 2 NDS data allows the collection of data from multiple drivers over multiple intersections. It also allows the incorporation of specific driver behaviors. The SHRP 2 NDS data have been used in a study to model left-turn gap probability at urban intersections (Hutton et al. 2015), but the data have yet to be applied to studying gap acceptance at rural intersections.

Countermeasures have been utilized extensively at rural intersections to help improve safety. Previous research has been conducted to determine the effectiveness of these countermeasures in improving safety. Below is a description of countermeasures typically applied at rural intersections and a summary of studies on their effectiveness. Before-and-after crash studies and empirical Bayes analyses of crashes have been commonly utilized to assess the effectiveness of countermeasures, but the exact effect each countermeasure has on driving behavior is insufficiently understood. In the present study, it is hoped that the SHRP 2 data can be used to understand the direct effect these countermeasures have on driver performance by including them in braking and gap acceptance models.

Double Stop Signs

Double stop signs are countermeasures that involve installing a second stop sign either in the median, if present, as seen in Figure 1, or on the left side of the approach. This is done in order to increase the conspicuity of the intersection and draw drivers' attention to the signs (Atkinson et al. 2014).

FHWA 2008a

Figure 1. Example of a double stop sign

A study by Polanis (1999) found that installing double stop signs decreased angle crashes by 55%. Additional information on the use of double stop signs at rural intersections can be found on the Center for Transportation Research and Education (CTRE) Resources to Address Rural Intersection Crashes website (at http://ctre.iastate.edu/research-synthesis/intersections/stop-signs-double.cfm).

Transverse Rumble Strips

Transverse rumble strips, or advance stop line rumble strips, are grooved strips milled or rolled into the pavement and placed upstream of a stop-controlled intersection on the stop-controlled approach (Figure 2). These rumble strips provide drivers an auditory and tactile warning to alert them of the intersection ahead.

Shutterstock

Figure 2. Example of transverse rumble strips

A previous study found that the use of transverse rumble strips in Iowa and Minnesota reduced fatal crashes at T intersections by 59% and at four-approach intersections by 35%. However, total crashes at these sites were found to increase slightly (by 22% and 7%, respectively) (Srinivasan et al. 2012). Additional information and studies can be found on the CTRE Resources to Address Rural Intersection Crashes website (at http://ctre.iastate.edu/research-synthesis/intersections/advance-stop-line-rumble-strips.cfm) and in a related technical brief (at http://ctre.iastate.edu/research-synthesis/intersections/documents/ASLRS_tech_brief.pdf).

Flashing Beacons

Beacons are flashing lights intended to draw a driver's attention towards the associated traffic control. Flashing beacons supplement stop signs and are intended to reinforce awareness of existing stop signs. Two different types of intersection beacons are typically used, including standard overhead beacons mounted over the intersection, as in Figure 3, and sign-mounted beacons that may be mounted on the stop sign or stop ahead and intersection ahead signs.

Neal Hawkins, CTRE

Figure 3. Example of an overhead flashing beacon

Previous studies have found overhead flashing beacons to reduce crashes anywhere from 11.9% to 19% for angle crashes (Srinivasan et al. 2007/2008, Pant et al. 1992) and from 12% to 40% for total crashes (Murphy and Hummer 2007, Stackhouse and Cassidy 1996).

When mounted to stop signs, beacons were found to decrease angle crashes by 58.2% (Srinivasan et al. 2007/2008). When placed on stop ahead and intersection ahead signs, total crashes were reduced by 40% (Stackhouse and Cassidy 1996).

Additional information on flashing beacons, such as placement and other study findings, can be found on the CTRE Resources to Address Rural Intersection Crashes website (at http://ctre.iastate.edu/research-synthesis/intersections/flashing-beacons.cfm).

On-Pavement Signing

On-pavement signing uses wording such as STOP AHEAD or INTERSECTION AHEAD or a diagram of an intersection placed on the pavement to alert drivers of the upcoming intersection in a more dramatic way than vertical signing, which can get lost in the clutter of a streetscape. Figure 4 demonstrates the use of STOP AHEAD on-pavement signing.

FHWA 2008b

Figure 4. Example of on-pavement signing

A study by the Federal Highway Administration (FHWA) found through an empirical Bayes analysis that with the use of STOP AHEAD pavement markings, a 15% reduction in total crashes can be expected (FHWA 2008b).

Lighting

Roadway lighting (Figure 5) provides greater visibility of the intersection, signs, and markings (Atkinson et al. 2014, Neuman et al. 2003). It helps to address intersection crashes during nighttime hours that occur due to drivers being unable to see conflicting traffic or due to drivers being unaware of the intersection until it is too late to avoid a collision. A study in Iowa found that the mean number of nighttime crashes at intersections with no lighting was two times higher than at locations where lighting was present (Isebrands et al. 2010).

Hillary Isebrands et al. InTrans

Figure 5. Example of rural intersection lighting

Two studies conducted in Iowa found no change to a 49% reduction in nighttime crashes at rural intersections with lighting (Carstens and Berns 1984, Walker and Roberts 1976). More recent studies in Minnesota found reductions from 25% to 40% (Isebrands et al. 2010, Preston and Schoenecker 1999). Additional information on lighting at rural intersections can be found on the CTRE Resources to Address Rural Intersection Crashes website (at http://ctre.iastate.edu/research-synthesis/intersections/lighting.cfm) and in a related technical brief (at http://ctre.iastate.edu/research-synthesis/intersections/documents/Lighting_tech_brief.pdf).

Advance Warning Signs

An advance warning sign is placed upstream of a rural intersection. These signs can be W2 series signs from the *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA 2009) as well as the stop sign ahead sign shown in Figure 6. One or two signs can be installed.

MRI Global

Figure 6. Example of an advance stop sign

Improving the visibility of rural intersections by providing enhanced signing and delineation such as advance warning signs was found to reduce crashes by 40% (Gan et al. 2005).

Intersection Conflict Warning Systems

Intersection conflict warning systems (ICWSs) use sensors placed on the major approach to an intersection that alert drivers on the minor approach that vehicles are approaching on the major approach. These systems use either a static sign with a flashing beacon or a dynamic sign, as shown in Figure 7.

MnDOT Traffic Engineering

Figure 7. Example of a rural intersection conflict warning system in Minnesota

A simple before-and-after crash analysis by the Missouri Department of Transportation (DOT) indicated that crashes were reduced on average by 51% and severe angle crashes were reduced by 77% (Sorenson 2011) on intersections with ICWS. Research is currently underway by Iowa State University, the Minnesota DOT (MnDOT), and the University of Iowa to assess the safety benefits of ICWS in rural Minnesota.

DATA SOURCES

Data for this project came from the two main data sources, the SHRP 2 NDS and Roadway Information Database (RID). Additional data about study intersections were reduced from sources such as trip maps and Google Earth. A description of each data source and the data provided are summarized below.

Naturalistic Driving Study (NDS) Data

SHRP 2 conducted the largest and most comprehensive naturalistic driving study undertaken to date. The study collected data from over 3,000 male and female volunteer passenger vehicle drivers, ages 16 to 98, during a three-year period, with most drivers participating between one and two years. Data were collected from sites located in six states: Florida, Indiana, New York, North Carolina, Pennsylvania, and Washington.

In-vehicle data were collected via a data acquisition system (DAS). A number of vehicle variables were collected, including speed, acceleration, and braking, vehicle controls when available, offset from lane center, and forward radar. Multiple video views were also collected, including forward, toward the rear of the driver's face, and over the driver's shoulder toward the center console (Figure 8).

VTTI

Figure 8. Example of video views

The NDS data file contains about 50 million vehicle miles, 5 million trips, more than 3,900 vehicle years, and more than 1 million hours of video, for a total of about 2 petabytes of data.

Roadway Information Database (RID)

The RID contains detailed roadway data collected using mobile data collection for about 12,500 centerline miles in the SHRP 2 NDS study states. Roadway attributes include items such as curve radius and length, presence of rumble strips, lane width, grade, number of lanes, speed limit, etc. The RID also combines data from several sources, including state DOTs and highway performance monitoring systems (HPMS), and includes other supplemental data; the RID data thus cover most roadways for each study state. Time series vehicle activity traces can be linked to the RID using GPS location.

Time Series Data

Raw data collected through the DAS can be compiled into a data file. Variables such as speed and lateral acceleration were collected at 10 Hz (0.1 second intervals). Other variables such as GPS location were collected at a lower resolution. Data files report attributes at 0.1 second intervals. GPS location is also provided so that the data can be imported into a GIS program and overlain with the RID data and aerial imagery. These data are referred to as time series DAS data. Video and time series data are linked using time stamps.

Trip Density Maps

Trip density maps were created by Virginia Tech Transportation Institute (VTTI) to show the number of trips and drivers on individual roadway links. A geographic file was provided by VTTI that could be used in-house to identify roadways with a certain number of trips.

Google Earth

Some roadway variables utilized in the study were not available in the RID. In cases when variables were not included, such as presence of overhead flashing beacons, they were collected manually using Google Earth while the research team waited to receive the SHRP 2 NDS data and then were confirmed using the forward video from the DAS.

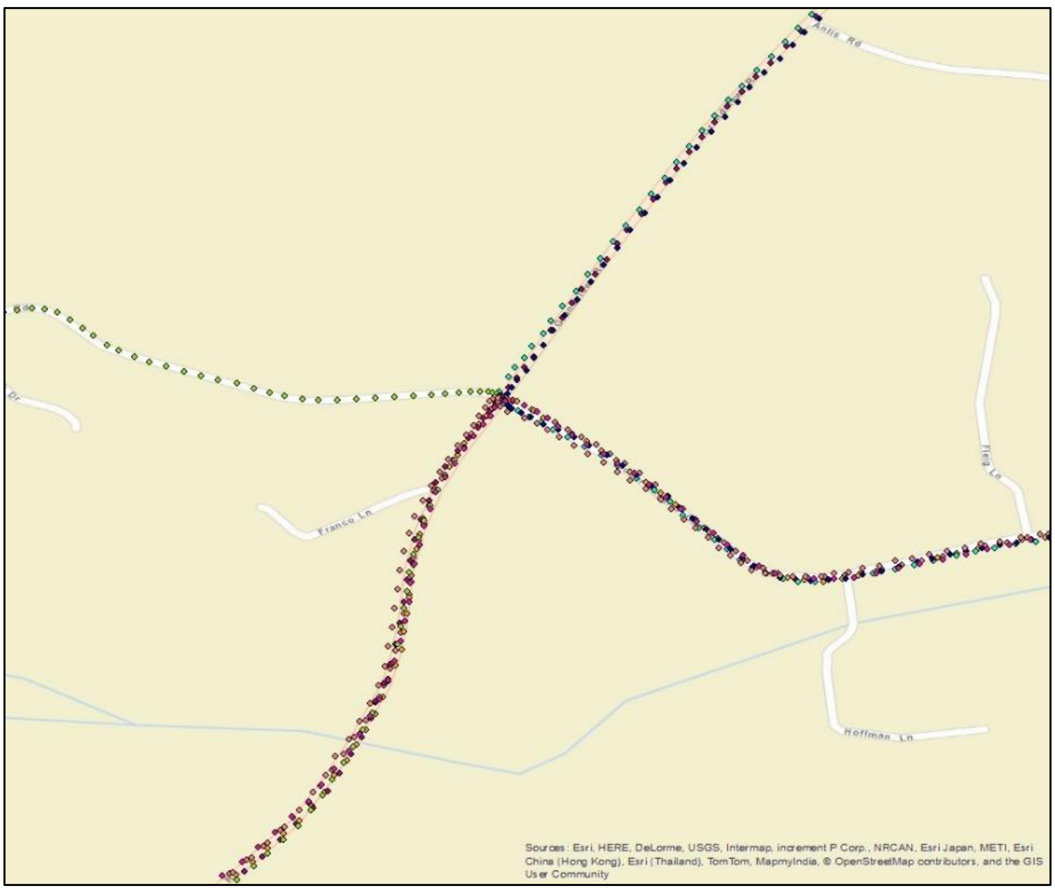
DATA SELECTION

It should be noted that when the data request for this study occurred, the RID and NDS data were not yet linked, and therefore manual data selection was required. Additionally, the NDS data were still being processed, so all data were not yet available.

Identification of Intersections

An early version of the RID mapped about 65,404 rural intersections. This map was overlain with an early version of the trip density shapefile in ArcMap. Both files were created when approximately one-third of the NDS data had been collected. The trip density attribute only showed the number of trips along a link, so it was not possible to tell whether turning movements had occurred.

Rural intersections with trips were manually identified (Figure 9) in Washington, Pennsylvania, North Carolina, and New York.



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, ® OpenStreetMap contributors, and the GIS User Community

Figure 9. Study intersection with multiple driving traces

Florida was not included in this phase due to time constraints. About 836 intersections on rural two-lane roadways were identified. Each was also viewed using aerial images and Google Forward View. Intersection characteristics including type of control and countermeasures (e.g., overhead beacons) were recorded. Locations with unusual geometry (e.g., significant skew), unusual land use, or signals were removed. About 100 intersections were determined to be viable for analysis.

The list of intersections was provided to VTTI. A list of trips by turning movement was provided by VTTI, and the research team was able to select intersections and trips with turning movements. The focus was on left-turn or straight movements from the minor approach. However, the NDS data collection was in the early stages, so fewer trips than expected that met the desired criteria were available.

A vehicle activity trace was defined as one trip through one intersection. A total of 557 traces for 64 intersections, including 346 traces at two-way stop-controlled intersections and 211 traces at controlled T intersections, were received. Of these, 270 traces were minor to major movements, while 287 were major to minor movements. The breakdown of left, right, and through movements are listed by intersection type and movement in Table 1.

Table 1. Intersection breakdown

Two-Way Stop-Controlled Intersections				
	Major to Minor	Minor to Major	Minor to Minor	Grand total
Left	79	99	0	178
Right	98	67	0	165
Through	0	0	3	3
Grand Total	**177**	**166**	**3**	**346**
Controlled T Intersections				
	Major to Minor	Minor to Major	Grand Total	
Left	75	46	121	
Right	35	55	90	
Grand Total	**110**	**101**	**211**	

A variety of countermeasures were present on these intersections, including overhead flashing beacons, double stop signs, on-pavement signing, and advance warning signs for intersection ahead and stop sign ahead. Unfortunately, none of the intersections appeared to have transverse rumble strips or intersection collision warning systems.

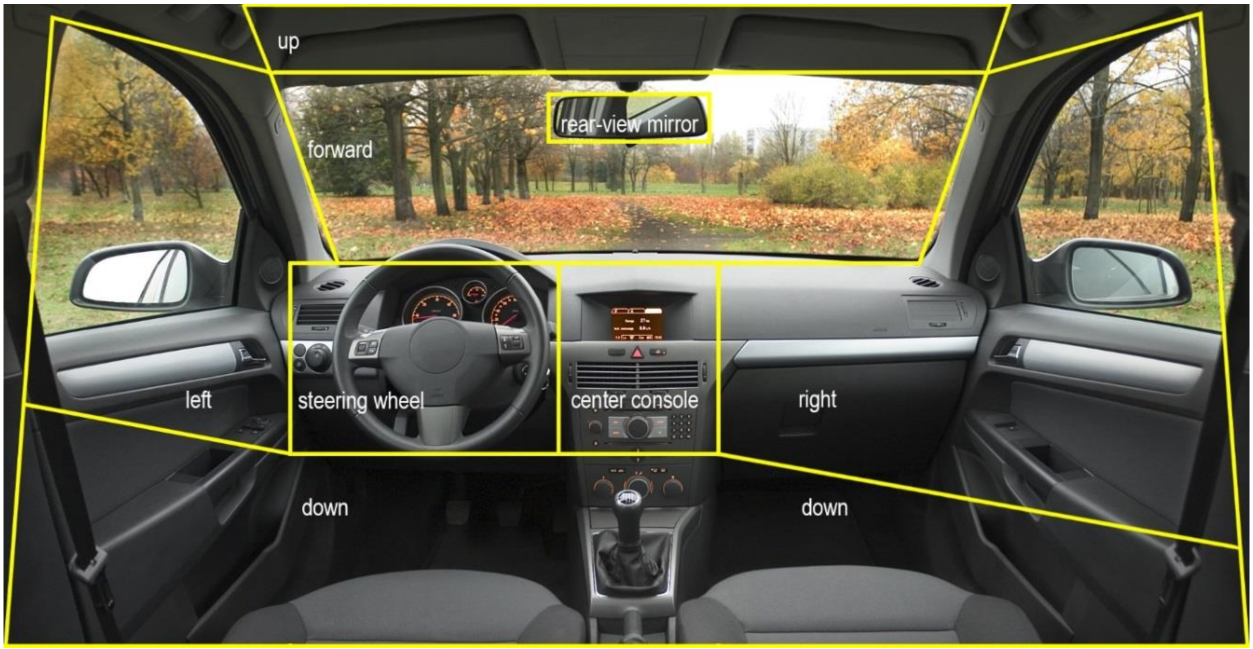
DATA REDUCTION

Data reduction efforts consisted of first finding the location of the intersection within the time series data. This was done by comparing the GPS coordinates in the time series data to the GPS coordinates of the intersections provided in the RID and finding the closest point to each intersection. The coordinates of the intersection in the RID are at the center of the intersection and not at the stop bar. This center location was used because the data were readily available and consistent. Once the intersection was found within the time series data, speed and time were used to calculate the distance from the intersection.

Additional work was done to code driver kinematic data (e.g., glance locations and distractions) for a subset of the data. Because this coding had to be done manually at the VTTI secure site, only a subset of the data was able to have this kinematic data reduced. A total of 126 traces were reduced for the 200 meters upstream of the intersection until they were approximately 50 meters downstream of the intersection. This distance provided the distance outside the suspected reaction distance as well as data through the intersection and onto the second leg. A mix of intersection types (stop-controlled T and two-way stop-controlled) and intersection movements (major to minor or minor to major) as well as a sampling of ages and genders were included in these 126 traces.

These kinematic data were reduced using a tool VTTI developed that allowed the analyst to code the glance location and distractions while observing the various camera views simultaneously. Driver attention was measured by the location the driver was focused on for each sampling interval. Because eye tracking is not possible with NDS data, glance location was used as a proxy.

The glance locations shown in Figure 10 represent practical areas where a driver might glance. These locations were used for manual eye glance data reduction.



Original image from Shutterstock modified with annotations and lines

Figure 10. Glance locations

Note that Figure 10 does not show over the shoulder glances, missing glance data, and other eye glance locations. The “missing” category was used when a driver’s face was obscured due to glare or when a glance location was not able to be determined. Glance locations were established based on previous work the research team performed on the SHRP 2 S08D project using recommendations based on University of Iowa researchers’ extensive eye glance reduction experience. Glance locations were coded using the camera view of the driver’s face, with a focus on eye movements, but head tilt was taken into consideration when necessary.

Potential distractions were determined by examining both the view of the driver’s face and the view over the driver’s right shoulder, which showed whether the driver’s hands were on or off the steering wheel. Distractions were identified as the cases when drivers took their eyes off the forward roadway. Potential distractions included the following:

- Route planning (locating, viewing, or operating)
- Moving or dropped object in vehicle
- Cell phone (locating, viewing, operating)
- iPod/MP3 player (locating, viewing, operating)
- Personal hygiene
- Passenger
- Animal/insect in vehicle
- In-vehicle controls
- Drinking/eating
- Smoking

Glance location and distractions were coded for each trace. The data reductionist recorded each time the glance location changed, and the data reduction tool recorded the time stamp. Similarly, the start and end times for distractions were also recorded.

Additionally, a database of roadway features for each of the intersections was compiled. This database included information for each approach. Included were the presence of countermeasures such as overhead flashing beacons, double stop signs, on-pavement signing, advance warning signs, intersection lighting, and stop sign warning signs. The database also included information such as the speed limit on the approach, the number of lanes, whether turning lanes or medians were present, and shoulder presence and type.

In addition to the reduction mentioned previously, additional data reduction occurred specific to each analysis. The description of these efforts are provided in the following sections.

Braking Analysis

The SHRP 2 NDS and RID data were the main data sources for this analysis. The NDS data used in this study included time series data and forward video data for each trace, or one trip through one intersection. The time series data included vehicle dynamics as well as other kinematic data at 0.1 second intervals. The data also included the GPS location once per second. Time series data for 392 traces through 58 intersections were reduced down to 129 traces through 38 intersections, and these reduced data were used in the analysis. The full set of 557 traces was not available for this analysis because some intersections and time series files were missing GPS data. The 263 unused traces were removed because brake pedal data were not present, forward video data were not available, the intersection approach was downhill or had a railroad crossing, or the vehicle was following another vehicle. The following drivers were removed so that only free-flow vehicles remained because the latter are not influenced by a leading vehicle. The traces where the approach was downhill or had a railroad crossing were removed because the reaction distance appeared to be more in response to these features and not to the upcoming intersection.

Using the time series data, the braking point where the driver reacted to the intersection was extracted. As mentioned previously, the time series data were linked to the roadway data to find the intersection location and the distance from the intersection at every 0.1 seconds. Using these data, the point where the driver initiated braking upstream of the intersection was identified as the point at which the brake pedal variable went from 0 to 1, and that location was determined to be the reaction point. An example of the braking point for an event is shown in Figure 11.

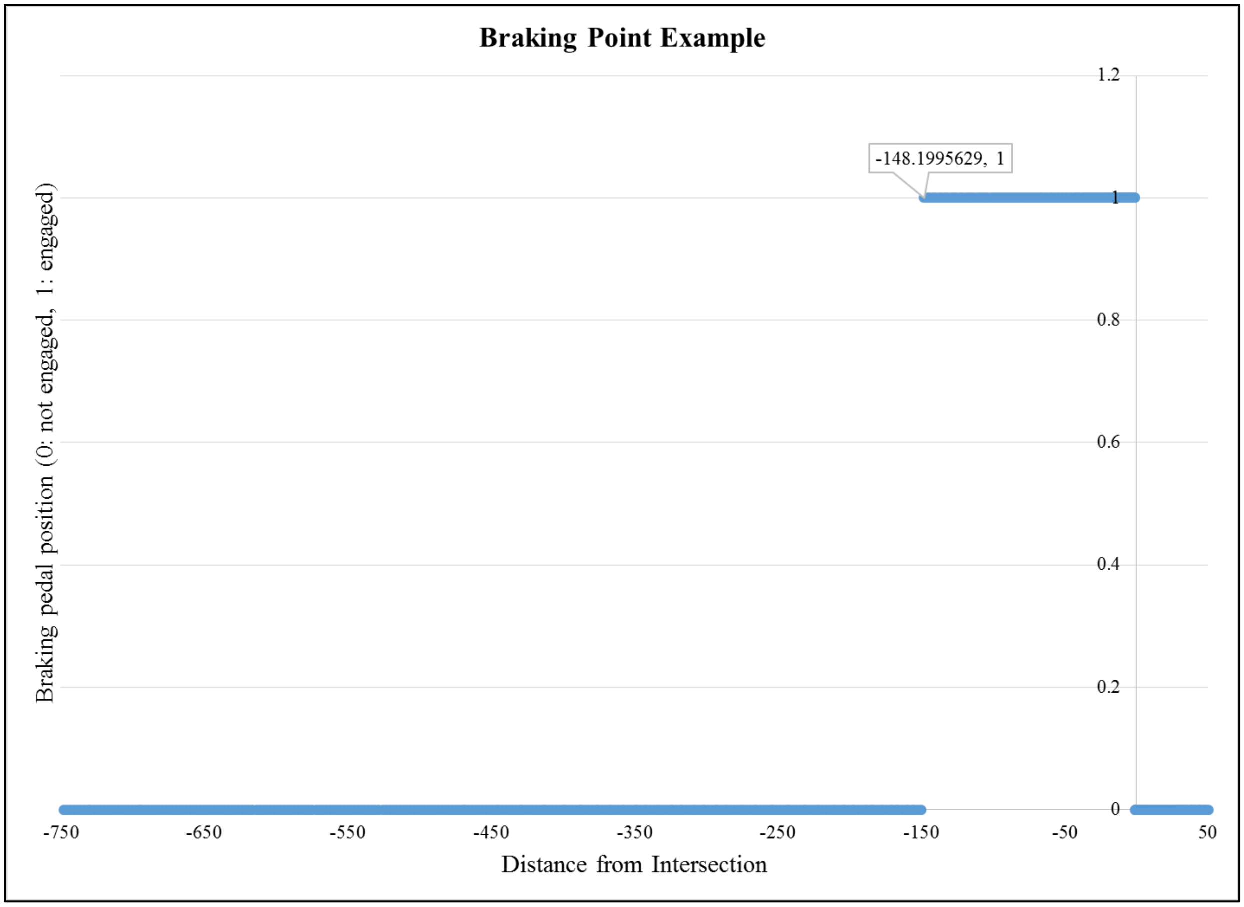


Figure 11. Example of braking distance

Additional data reduction included supplementing the roadway database described above with data regarding the approach for each trace. This supplementary information included data such as number of lanes, presence of turn lanes, type of intersection, turning movement, whether the driver was yielding (major to minor road) or stopping (minor to major road), whether the approach to the intersection was within a curve, and the presence of countermeasures. Environmental data, including time of day and whether the roadway was wet or snowy, were extracted from the forward video of each trip. Additional driver data, such as age and gender, were also included.

Gap Acceptance Analysis

The gap acceptance analysis required the combined use of the forward video, rear video, and time series data. The forward video was used to determine the length of the gaps rejected by the driver and was then used in conjunction with the rear video to determine the length of the gaps accepted. The rear video does not include a time stamp, and for this proof of concept study the ability to link the rear video to the forward video did not exist, so the two were manually linked using the time into the rear video to determine the approximate corresponding time stamp. For future studies, it is recommended that a tool that links these two data sources be utilized. The time series data were included to determine the time when the vehicle came to a complete stop, or reached the lowest speed, at the intersection. Gaps were determined manually at each minor stop-controlled intersection for the 56 traces for which driver glance and distraction data were available. These gaps were determined in the following manner:

- **Rejected gap, if first gap at intersection**: The time when the vehicle on the mainline reached the edge of the study vehicle minus the time at which the vehicle came to a stop, as determined from the time series data.

- **Rejected gap, subsequent**: The time when the vehicle on the mainline reached the edge of the study vehicle minus the time at which the vehicle before the initial vehicle on the mainline passed the edge of the study vehicle. An example of a 1.33 second gap is shown in Figure 12.

Figure 12. Example of calculating rejected gap

- **Accepted gap, if first gap at intersection**: The time when a vehicle reached the intersection on the mainline, determined from the rear view, minus the time at which the study vehicle came to a stop, as determined from the time series data. If no vehicle could be seen in the rear video, a note was made if the gap length could not be determined because it was too long to be determined from the rear video.

- **Accepted gap, after rejected gaps**: The time from when the previous vehicle on the mainline is just past the study vehicle until the time the driver on the mainline reaches the intersection, as determined from the rear video. A note was made if the gap length could not be determined because it was too long to be determined from the rear video.

Only those traces where rejected and accepted gaps occurred, which amounted to only 10 traces, were included in the gap acceptance analysis. Those traces with only accepted gaps were not included because either the lengths of those gaps were too great to determine their exact length or the gaps could not be determined due to poor rear video.

For the traces that included rejected and accepted gaps, the roadway feature database was incorporated. Additionally, environmental conditions, such as rain or time of day, and driver factors, such as age, gender, distractions, and glance locations leading to the intersection, were included.

ANALYSIS AND RESULTS

Braking Analysis

A linear mixed effects model was used to model braking distance. The mixed effects model allowed the multiple samples from some intersections to be taken into account. The model was developed using the lmer() function in the lme4 package in R, with the distance upstream (in meters) at which the driver began braking in response to the intersection as the dependent variable. Variables were included if they were significant at a 90% confidence level. Various models were compared using the Akaike information criterion (AIC) to determine which had the best fit. After each model was developed, it was checked to make sure it met the linear model assumptions. The best fit model can be seen in Table 2.

Table 2. Model results

Variable	Estimate	Std. error	P value	% samples
Intercept	133.30	10.04	< 0.0001	
Stop or Yield (1 = yield, 0 = stop)	41.10	10.58	0.0001	50.38%
Overhead flashing beacon present (1 = present, 0 = not present)	67.11	22.42	0.0028	11.62%
On pavement signing present (1 = present, 0 = not present)	46.34	20.84	0.0261	10.08%
Driver’s age is under 25 (1 = under 25, 0 = 25 or older)	-39.29	21.62	0.0691	7.75%
Drivers turning direction (1 = right, 0 = left)	-18.66	10.90	0.0869	45.7%

Also included in Table 2 is the percent of samples for each of the dummy variables where the value was equal to 1 (e.g., for stop or yield, the percent identified as yield).

This best fit model included five variables as well as an intercept. The results of the model show that when intersections with countermeasures were compared to intersections without countermeasures, the presence of countermeasures increased the distance at which drivers began reacting to the intersection. For example, the presence of overhead flashing beacons and on-pavement signing increased reaction distance by 67 m and 46 m further upstream, respectively. These findings show that the countermeasures appear to be working as intended by alerting the drivers to the intersections sooner and therefore causing drivers to react earlier. Younger drivers (under 25 years old) were found to begin braking approximately 40 m later than drivers 25 years old or older. It was also found that drivers turning from a major road onto a minor road (yielding) begin braking about 40 m earlier than drivers approaching a stop sign. The model also showed that a driver turning right began braking 18 m later than a driver turning left.

Gap Acceptance Analysis

Gaps were determined for 10 traces, which included both accepted and rejected gaps. It was found that all accepted gaps were longer in length than any of the rejected gaps, and therefore a logistic regression analysis was not able to be run successfully. In future studies, it is recommended that a mixed effects logistic regression model be utilized to run the gap acceptance model because the data will likely include repeated samples from the same driver and the same intersections.

CONCLUSIONS AND DISCUSSION

The goal of this study was to better understand how drivers are interacting with roadway features (e.g., traffic control, intersection geometry, and other countermeasures) and the mistakes drivers are making that result in safety-compromising situations at rural intersections. A braking model was developed to help understand how roadway features affect drivers' reactions to intersections. Additionally, a data reduction protocol for a gap acceptance model was developed that can be used to run a gap acceptance analysis, the results of which may lead to a better understanding of the ways roadway features, environmental conditions, and driver behaviors affect whether a gap is accepted or rejected by a driver.

Using linear mixed effects regression, a braking model was created that predicts how far upstream of an intersection a driver reacts to the intersection by initiating braking. The results of the model show that countermeasures that are intended to alert drivers to the presence of the intersection, such as overhead flashing beacons and on-pavement signing, increase the distance at which the driver begins braking. This result supports the use of these countermeasures because they appear to be working as intended by drawing drivers' attention to the intersections and causing drivers to react earlier. Younger drivers (those under 25 years old) were found to be more aggressive than older drivers, in that they began braking almost 40 m later than drivers over 25 years old. This finding supports continued education for younger drivers to make sure they pay adequate attention to the roadway. An additional finding is that drivers turning from a major roadway onto a minor roadway begin braking sooner than those turning from a minor roadway onto a major roadway. This may be due to the major roadway having a higher speed limit, which would necessitate braking earlier. Futures studies could address this ambiguity by incorporating speed limit data or indicating whether the driver was speeding within the model. Driver distraction and glance location data would also be useful if incorporated into the model to determine how these may affect a driver's reaction to the intersection.

The available data were insufficient to run a successful gap acceptance model. However, the data did allow for a data reduction protocol to be developed that can be used in future studies with additional data to conduct the analysis. This protocol includes a method for measuring the gaps, including a way to determine when to begin the first gap, as well as the requirement that the forward and rear videos be linked in order to utilize the time stamps on the forward video for both videos. The protocol also acknowledges the challenges associated with using the NDS data for the analysis, including the limited amount of time an accepted gap can be in length due to the constraints of the rear video view. Another potential challenge is that not all of the rear cameras are positioned in such a way that vehicles to the rear of the study vehicle can be seen, which is required to determine the length of accepted gaps.

FUTURE WORK

The work accomplished as part of this project and the data that this project has provided were used to help the research team win an FHWA Broad Agency Announcement (BAA) award. The work to be conducted under this award will expand on the work conducted as part of this study, as suggested in the conclusions and discussion, and will include additional analyses. The goal of the BAA as well as the research questions that will be addressed are summarized below.

Description of BAA Research

Safe intersection negotiation depends on drivers being able to recognize the presence of an intersection and then respond appropriately to applicable traffic control devices and prevailing conditions. When drivers are required to yield right-of-way to oncoming traffic, they also need to be able to identify and select appropriate gaps. Consequently, the proposed research for the BAA Phase I study will investigate the feasibility of answering the following research questions, which address the relationship between different stages of intersection negotiation and roadway and driver characteristics.

What is the relationship between rural intersection crash risk and driver, roadway, and environmental characteristics?

Logistic regression or other appropriate models will be used to evaluate the relationship between crashes/near-crashes and roadway geometry, traffic control, countermeasures, and driver characteristics (e.g., age, gender, distraction).

This analysis will provide information about the roadway factors that are present when safety-critical events occur.

What is the relationship between intersection recognition and stopping behavior and intersection geometry and countermeasures?

Vehicle activity traces will be used to develop a model of driver braking and stopping behavior using a small dataset of vehicle traces at rural stop-controlled intersections. The model will detect the point at which a driver recognizes and responds to the upcoming intersection. Driver reaction can be estimated from changes in vehicle factors such as pedal position, braking, or speed and driver characteristics such as changes in glance location.

Additionally, the model will capture deceleration and stopping behavior at the intersection, such as how far upstream the driver begins braking/slowing and the type and location of the stop (e.g., rolling or full).

Ultimately, intersection reaction point and deceleration/stopping behavior can be related to intersection geometry and countermeasures. For instance, the reaction point may be shown to be sooner when overhead beacons are present.

What are the primary influences for appropriate scanning behavior and gap acceptance at rural intersections?

The goal of this research question will be to model the relationship between gap acceptance and driver and roadway characteristics.

The first step is to refine an in-progress computer vision tool that extracts head pose from SHRP 2 video data. The process will be refined to extract the time and location of glance locations. Using this technique, driver scan behavior can be quantified and evaluated as a function of intersection and driver characteristics.

For the next step, gap length will also be extracted and a gap selection model will be developed that will relate gap selection to driver characteristics (e.g., distraction, turning maneuver) and roadway characteristics (e.g., intersection angle, sight distance).

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