Integration of Analysis Methods and Development of Analysis Plan

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Integration of Analysis Methods and Development of Analysis Plan

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FOREWORD

Kenneth Campbell, *Chief Program Officer, Safety*

This report provides an analysis plan for the SHRP 2 Naturalistic Driving Study (NDS). High-priority research questions were identified in Phase I. Phase II identified the critical elements and issues to address in the analysis of the SHRP 2 NDS data and provided sample work plans for five high-priority research questions. The resulting analysis plan will guide the development of the subsequent Safety Project S08, Analysis of In-Vehicle Field Study Data and Countermeasure Implications, and assist researchers planning to use the SHRP 2 NDS data.

The objective of the SHRP 2 NDS is to reduce traffic injuries and fatalities by preventing or reducing the severity of collisions. Every 1% reduction in crashes will prevent 330 deaths and about $2 billion in annual medical expenses and other losses from these crashes. Moreover, crashes are a leading cause of nonrecurring congestion. Collision prevention can reduce delay, fuel consumption, and emissions. The focus of the NDS is to provide objective information on the role of driver behavior and performance in traffic collisions and the interrelationship of the driver with vehicle, roadway, and environmental factors.

This project began with a review of the four S01 projects, Development of Analysis Methods Using Recent Data, and Safety Project S05, Design of the In-Vehicle Driving Behavior and Crash Risk Study. The initial focus was on the fundamental challenges facing researchers wanting to use this relatively new source of safety information, the SHRP 2 NDS. These challenges include the size and complexity of the database; the continuous nature of the data; sampling, defining, and finding events of interest; developing an exposure reference; reduction of video data; linking video data with roadway data; the use of collision surrogates; and many others.

The five top research questions identified in this report are based on the decision criteria developed in Phase I. Summaries of Phase I of the project are included as appendices. More than 400 research issues are listed. These questions were articulated and accumulated throughout the development of the SHRP 2 Safety program from committees, the annual SHRP 2 Safety Symposia, and the early SHRP 2 projects. The Phase I work describes the process for combining these issues into global research questions and establishing priorities. The report also provides a summary of Phase II of the project and the resulting five sample work plans to illustrate the application of these critical elements in the analysis plans for the top-priority research questions.

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Executive Summary

The primary goals of SHRP 2 Safety Project S02, Integration of Analysis Methods and Development of Analysis Plan, were to (1) identify and prioritize key research questions related to the SHRP 2 Naturalistic Driving Study (NDS) and (2) determine important research elements (e.g., methods, data, questions) that analytical plans must address to explore these key questions. The process began with more than 400 research issues defined by SHRP 2 Safety Projects S01, Development of Analysis Methods Using Recent Data, and S05, Design of the In-Vehicle Driving Behavior and Crash Risk Study. These research issues were grouped into 27 global research questions, prioritized during Phase I of this project, and are further summarized in Appendix A (Boyle et al. 2009).

The second phase of this project identified the highest-priority research questions according to the decision criteria developed in Phase I. These research questions and their rankings are presented in the main body of this report. They were developed to guide SHRP 2 and other researchers in preparing for analysis of the SHRP 2 NDS. They also were intended to guide the development of the statement of work for proposals for Project S08, Analysis of In-Vehicle Field Study Data and Countermeasure Implications.

The project team has developed a recommended list of essential elements to be covered in the analysis project work plans. Recommendations are based on the team's expertise in this area and a detailed review of the analytical methods used by the S01 and S05 research teams. Example work plans are offered to illustrate the type of information that is relevant to a proposed work plan, as well as methodological issues specific to that research question.

The five sample work plans in this report address the highest-priority research topics related to driver behavior (distraction, alcohol use, and fatigue) and infrastructure characteristics (intersection crashes and interaction of roadway features and lane departures). Each sample work plan provides a high-level summary of a possible approach to the research question, including the rationale for examining that question, an outline for the data collection plan, and a description of the analysis method. The sample plans do not provide an exhaustive description of the research approach, nor do they represent the ideal research approach. Instead, they outline some of the more important considerations and basic elements necessary to describe research using the SHRP 2 Safety project data. These plans also illustrate some of the fundamental challenges that researchers must address when using naturalistic driving data to answer driving safety research questions.

These sample plans may also be used by researchers as guides to the type of key information that may be required in S08 proposals. For example, the large amount of data collected as part of the SHRP 2 NDS will require careful attention in terms of how it is sampled, segmented, and aggregated. Equally important are the statistical methods used to extract policy- and design-relevant information from the data. Ideally, proposers to Project S08 will clearly explain their rationale regarding the selection of variables and data manipulation. Several other elements that should be included in the proposals, such as the analytical approach and potential pitfalls and limitations and how to address them, are explained in greater detail in this report.

Finally, because crashes are rare occurrences, only a small number of crashes will be recorded in the NDS database. Thus, crash surrogates will be an important component in many analyses. The SHRP 2 NDS data will be useful in identifying crash surrogates that can be proven to be sensitive to the same contributing factors as actual crashes.

CHAPTER 1

Introduction

Naturalistic studies involve direct observation of events as they occur in natural settings. Naturalistic driving studies capture driver behavior in a way that is most representative of typical driving and not influenced by the artificial features of controlled studies. This method allows researchers to study drivers in their own vehicles and environments. Such data are expected to provide insight into factors that can influence safe driving. Recent advances in data collection techniques have allowed capturing data on day-to-day driving behavior to be more feasible and cost-effective. Naturalistic driving behavior can be recorded with in-vehicle video cameras, and sensor arrays can detect brake and gas pedal changes, steering movements, and other vehicle and roadway factors.

A central challenge of using naturalistic driving databases to identify the factors influencing driving safety is the selection of data analysis techniques that can address relevant research questions. In contrast to simulator studies, there is no experimental control in naturalistic studies. The causal mechanisms associated with safe driving are difficult to identify. Researchers must recognize and manage potential confounders and covariates to reveal the influence of events or features of interest on driving safety. In the naturalistic setting, no two events are the same. For example, no two curves are the same. As a consequence, researchers must define equivalence classes to specify how a group of events can be considered as the same in an analysis. Defining equivalence classes requires that researchers define the driving context (e.g., road type, weather, traffic conditions, and time of day), as well as the specific parameter range (or threshold) that defines the event (e.g., equivalence classes for 500-ft-radius curves). To some degree, these equivalence classes substitute for the scenarios and experimental conditions that are used in driving simulator and other experimental studies. A key challenge in the analysis of naturalistic driving data is thus how to enhance the precision with which the researcher can infer the influence of driver, vehicle, and roadway characteristics on driving safety.

Although naturalistic driving data can be used to analyze transportation safety and driving behavior in ways that were not previously possible, the spatial, dynamic, and temporal nature of the data adds to the complexity of such analyses. Sifting through the large volume of data collected can be extremely labor intensive and computationally difficult. Thus attention to methods of sampling, integration, and analysis is critical to reaching useful conclusions. The main goal of this project was to address the issues raised above in preparation for Project S08's analysis of the full-scale NDS.

Project S02 had two primary objectives. The first was to identify and prioritize critical research issues related to driver safety (Phase I); the second was to determine the key research elements (e.g., methods, data, and questions) that will need to be addressed in analytical plans developed to explore these critical issues (Phase II). This report identifies a proposed set of high-priority research issues and presents a framework for developing work plans that include considerations related to data sampling and analysis. Five example work plans are provided.

CHAPTER 2

Review of Analytical Methods Proposed in SHRP 2 Safety Project S01

The goal of the Safety Project S01 studies was to develop and demonstrate analytical methods that could be used with naturalistic driving data and to formulate additional research questions. As discussed in Appendices A and B, these research questions, together with those developed in Safety Project S05, were used to prepare a set of global research questions.

S01 studies provided examples of the different analytical approaches that can be used with naturalistic driving data. Each of the individual S01 studies is reviewed below to provide context for the recommendations of the present study. The S02 team also considered information on data type and quality in formulating the sample work plans to demonstrate the types of information that will be necessary in a successful S08 proposal.

Four contractors contributed to S01: the University of Minnesota, the University of Michigan Transportation Research Institute (UMTRI), the Pennsylvania State University Transportation Institute (PTI), and the Iowa State University Center for Transportation Research and Education (CTRE). These institutions developed and tested analytical methods for existing data sets that are similar to but much smaller than the data set to be developed under SHRP 2.

University of Minnesota

The University of Minnesota study focused on crashes and near crashes involving more than one vehicle. Researchers used data from the Virginia Tech Transportation Institute (VTTI) 100-car study and from two University of Minnesota projects: the Minnesota Traffic Observatory and the Cooperative Intersection Collision Avoidance Systems project. The study produced three main outcomes for examining car-following and gap-selection crashes: it (1) identified an appropriate class of structural models for crash and near-crash events and the analytic tools needed for fitting these models to the data, (2) performed a counterfactual screening of near-crash events to determine their similarity to crashes, and (3) developed models of evasive actions that drivers take as a function of the situation.

The researchers introduced a Bayesian approach to microscopic modeling of crash and near-crash events that accounted for vehicle kinematics, trajectories, and driver evasive actions. Several methodological conclusions resulted from the study. The first was that trajectory-based reconstruction of crashes and near crashes is feasible using vehicle and site data when the direction of travel is roughly constant. Examining crash and near-crash events from the perspective of a second vehicle is possible using a two-directional trajectories approach. The second conclusion was that research on the feedback loop between existing conditions and driver actions is both recommended and necessary for an accurate microscopic traffic simulation. The third conclusion was that model estimation methods should be enhanced for serial correlation, which is critical for appropriately sized standard errors and confidence intervals for parameter estimates. The findings of this study demonstrated that site- and vehicle-based data can provide complementary results. Finally, the authors recommended that all aspects of such studies, including data collection setup, postcollection processing, and the storage and availability of data, be well documented to ensure the usability of the study data by future researchers.

University of Michigan Transportation Research Institute

UMTRI research focused on capturing the associations among highway factors, crashes, and driving behavior for road-departure crashes. The underlying hypothesis was that connections could be drawn between variations in continuous driving behavior (as seen in normal driving) and the discrete crash events recorded in crash databases. This focus was addressed using spatially referenced databases with geographic information system (GIS) tools and the concept of disturbed control. Disturbed control was defined as any interruption or delay in the process of driver perception, recognition, judgment or decision making, and action. Bayesian multivariate generalized models, seemingly unrelated regressions (SURs), and extreme value theory were used to test this association. Naturalistic driving data from the UMTRI Field Operational Test (FOT), highway data from the enhanced Highway Performance Maintenance System (HPMS), and Michigan crash data were included in the analysis.

The Bayesian and SUR models were applied to road-departure crashes that occurred on the right side and to three potential surrogates for this type of event: right-lane deviation, right-lane-departure warning, and time-to-right-edge crossing (TTEC). The analysis suggested that TTEC was the best surrogate, right-lane departure warning was an intermediate surrogate, and right-lane deviation was the weakest of the three surrogates for right-sided road-departure crashes. Extreme value analysis was used to model rare events that lie outside the range of available observations. UMTRI researchers modeled the TTEC variable on a specific roadway and determined that this variable may also be a good surrogate from an extreme value analysis perspective, a finding that warrants further investigation. They also found that the yaw rate error might be a better surrogate than TTEC for right-hand roadway departures. The yaw rate error generates a smooth, continuous, and differentiable data series even when a lane boundary crossing occurs. In contrast, TTEC includes discontinuities whenever the vehicle crosses the lane boundary. Yaw rate error strongly correlates with rapid steering interventions by the driver and may be a useful predictor of degraded or ineffective lane keeping.

The analysis of SUR models and the yaw rate error provided evidence that disturbed control is a fruitful perspective for interpreting naturalistic driving data. In addition, these analyses demonstrated that roadway departure surrogates could be useful for future naturalistic driving studies. The researchers demonstrated that exposure should be based on instrumented vehicle traversals of directional road segments. The researchers noted that refinements to roadway data are needed; for example, HPMS roadway data are not directional and lack adequate curve information. They also noted that many innovative analysis methods can potentially be developed to link crash, roadway, and naturalistic driving data.

Pennsylvania State University Transportation Institute

PTI examined the relationship between various precrash events and identified methodological paradigms that can be used to answer research questions specific to roadway departures. PTI used run-off-road (ROR) events from the VTTI 100-car study and data from the UMTRI Roadway Departure and Curve Warning FOT. The goal of the project was to explore structural paradigms in order to better analyze naturalistic driving data. Analysis of naturalistic driving data is inherently complex as a result of the obscure interactions between physical infrastructure and human factors. PTI explored how to address this complexity by using linear regressions, count regressions, and categorical and hierarchical Bayesian models tested at both the driver and the event level. For analyses at the driver level, drivers were treated individually and also grouped by gender. Three events were analyzed for the event models: crashes, near crashes, and critical incidents. In addition, kinematic models were constructed using the kinematic data from UMTRI.

PTI researchers considered regression models from both a frequentist and a Bayesian perspective to describe the benefits and limitations of each technique in the analysis of naturalistic driving data. A negative binomial model was constructed to evaluate the relationship between driver characteristics (e.g., gender, education level) and the probability of a ROR event. This is appropriate when events (crashes) are overdispersed (i.e., the variance is larger than the mean). Zero-inflated Poisson or negative binomial models better account for the abundance of zeros in the data sets. A logistic model was constructed to evaluate dynamic and static driver factors (e.g., distraction, Dula Dangerous Driving Index score) and environmental factors (e.g., surface condition).

It has been suggested that hierarchical models can capture driver differences over time and space, depending on how the data are clustered. The ability to model such driver differences would allow the classification of static and dynamic driver parameters to be treated as random effects. It has also been suggested that naturalistic driving data analysis would benefit from the use of hierarchical models when the parameters are largely unknown. The frequentist approach may be hindered by sample-size limitations, however, and while driver, event, and context variables are known in the data, the relationships between these variables in crash modeling have not been well examined (Shankar et al. 2008).

PTI researchers found that even with large data sets, rigorous application of Poisson, negative binomial and zero-inflated Poisson, zero-inflated negative binomial, and other count regressions were needed. Main effects alone were insufficient to generate consistent model parameters, and they produced reduced goodness-of-fit statistics. Although including explanatory variables improved the fit of some data, the overdispersion parameter in negative binomial models warrants further study.

With naturalistic driving data, it is important that models integrate kinematic data along with event, driver, and context attributes. Hierarchical models offer some specific advantages given their flexibility and the relaxation of assumptions of probability distributions for dependent and independent variables. PTI also found evidence of driver adaptation to technology, including changes in driver behavior with and without warning systems. Models need to take into account how driver behaviors change over time and in response to technology.

Overall, the PTI results confirm that the simple statistical approaches commonly used in experimental and epidemiological studies fail to address the complexities of naturalistic driving data. Such failures in managing complex data can result in erroneous conclusions.

Iowa State University Center for Transportation Research and Education

CTRE studies focused on lane-departure and ROR crashes. They defined the following crash surrogates for these types of crashes: nondeparture lateral drifts, nonconflict road departures, and road-departure conflicts. The effectiveness of these surrogates depends on the potential hazard (i.e., what the vehicle will strike if the driver does not recover control), as well as the time to collision, time to lane departure, and time to hazard (e.g., oncoming vehicles, adverse slopes, and fixed objects). Vehicle kinematic signatures were used to define events (e.g., lateral acceleration, forward acceleration, and speed). The CTRE team developed three approaches to answering lane departure research questions using naturalistic driving data: data mining, logistic regressions and odds ratios, and time–series analysis.

Using the three approaches, CTRE researchers estimated the odds of lane departures on the basis of a series of independent factors. For example, left- and right-side lane departures, respectively, were 10.9 and 29.2 times more likely to occur on curves with a very small radius (less than 200 meters) than on a tangent section. This analysis shows that to appropriately apply logistic regression to the full SHRP 2 NDS, the data must be aggregated to identify event and nonevent driving periods. This aggregation process is problematic with naturalistic driving data because all situations are unique and are only identified as being similar when researchers decide they differ in ways that are considered unimportant for their analysis.

Data mining methods were used to explore associations and patterns in events such as event sequencing, clustering, and association with future events. CTRE researchers constructed classification and regression trees to find associations between environmental, roadway, and driver factors for lane departures in the UMTRI FOT data. The main advantage to data mining is that it can be used to identify relationships in the data that were not apparent a priori or that may not be found using methods that focus on linear relationships and simple combinations of predictor variables. Data mining can also use automated processes to evaluate large amounts of data. However, because many researchers are not familiar with data mining, it may be difficult to interpret results in a manner that will allow practitioners to incorporate the information into decision-making models, such as a model for comparing the costs and benefits of a particular countermeasure.

Summary of Safety Project S01

The results of the four studies undertaken in Project S01 provide a basis for understanding what research questions can be posed using naturalistic driving data and how different analytical methods can be applied to these data. The studies demonstrate the use of Bayesian methods, logistic and SUR models, kinematic models, and microscopic event models. These very different approaches underscore the wide range of methods that can be used with naturalistic driving data. Identifying the most appropriate approach depends on the research question and the sampling plan selected for the data. Importantly, the different approaches govern both the types of questions that can be asked *and* the validity of the resulting answers. The studies show that the approach and variables considered in the analysis can be complementary but also produce potentially conflicting outcomes. These reports should serve as illustrative examples for S08 proposers and help guide them toward selecting the most appropriate approach from the wide range of available analytical techniques.

CHAPTER 3

Overview of Phase I: Analysis Plan

The main goal of Phase I of this project was to identify and prioritize research questions in order to focus resources for Project S08. Detailed information is available in Appendix A, but for the sake of context the methodology is summarized below.

The project team considered using research questions developed by S01 and S05 researchers, as well as other methods to identify additional research questions. Other methods included holding focus groups with traffic safety experts, developing research questions related to each major crash type, and reviewing existing driving safety literature. However, feedback from SHRP 2 indicated that the S01 and S05 researchers had already devoted significant resources to developing appropriate research questions. As a result, the 56 research questions from the S01 reports and the 392 questions from the S05 report were used as the source for research questions. These research questions were organized into groups according to commonalities in categories of explanatory (or independent) variables corresponding to environmental, driver, vehicle, roadway, and nondriving factors. The variables were further categorized according to their static or dynamic characteristics and safety outcomes. The groupings reflect a systems-based perspective that considered driving safety implications and the feasibility of potential safety interventions.

A decision tree was created to provide a systematic mechanism for prioritizing the global research questions. The decision tree emphasized questions that provide greater insights about drivers, that appear to support safety interventions, and that provide insight into large-scale morbidity and mortality consequences. Each global research question was evaluated using the decision tree to determine a priority ranking. More details about the decision tree and the prioritization of global research questions can be found in Appendix A.

Of the 27 global research questions, 16 addressed the goals of SHRP 2. The other 11 were beyond the scope of SHRP 2's focus on safety research or were condensed into more representative global questions. In Phase II the global research questions have been revised through several iterations with selected reviewers. They are presented here in a form slightly modified from that of the Phase I report. The central themes of the questions relate to the influence of driver behavior on crash likelihood, the influence of roadway improvements on crash likelihood, and how to define good crash surrogates. Eight of the SHRP 2–relevant questions have been identified as having the highest priority. (The Phase I report had nine high-priority global research questions. The team removed one question related to dynamic driver characteristics [as opposed to static characteristics such as age or gender] because the team later determined that distraction, fatigue, and impairment [which are captured in the other research questions] are already exemplars of dynamic driver characteristics.) The unranked list of eight questions is as follows:

- How do driver interactions with roadway features influence the likelihood of lane-departure crashes?
- How do driver interactions with intersection features (configuration and operations) influence crash likelihood?
- What is the influence of driver impairment (e.g., alcohol) on crash likelihood?
- How does driver distraction influence crash likelihood?
- How does driver fatigue influence crash likelihood?
- How do driving behaviors influence crash likelihood?
- How do advanced driver support systems influence crash likelihood?
- What variables or pre-event factors are the most effective crash surrogate measures? What explanatory factors are associated with crashes or crash surrogates? And what analytical models can be developed to predict crashes or crash surrogates?

The last global research question is particularly important and related to the other seven. The development of surrogate measures can provide insights on crashes when there are too few actual crashes to complete an effective analysis. Because demonstrating effective crash surrogates can support other means for addressing important research questions on driver safety, this is considered one of the highest-priority questions.

CHAPTER 4

Overview of Phase II: Formulating the High-Priority Research Topics

One of the tasks in Phase II of the S02 project was to assess the viability of answering the global research questions prioritized in Phase I and presenting them in a manner that was understandable to prospective S08 proposers. To accomplish this, the global research questions were refined into global topics areas. The topic areas reflect the scope of the research questions presented in the Phase I report, but they were revised to better convey the intent of the research questions and to clarify their wording for a broader audience.

Of the eight high-priority topics listed above, six were considered to be the highest-priority topic areas for Project S08 within the time frame and constraints of SHRP 2. These six topics and the factors leading to their selection are presented next.

The first high-priority topic, the influence of driver interactions with roadway features on lane-departure crashes, is timely because the evaluation of current roadway designs may offer recommendations to reduce the number of lane-departure crashes and subsequent fatalities. Crashes of this type represent a significant percentage of all crashes, and FHWA estimates that 39% of roadway fatalities are single-vehicle roadway departures. Naturalistic driving data provide a good way to examine such crashes, especially because exposure to different roadway features may not be accessible in other data sources. Countermeasures or safety interventions for this type of crash are highly feasible because roadway features (e.g., variable signs, lighting conditions, and pavement markings) can be modified.

The second high-priority topic concerns the influence of driver interactions with intersection features (configuration and operations) on crash likelihood. In particular, red light running (RLR) contributes to more than 100,000 crashes and over 1,000 fatalities each year (NHTSA 2007); crash rates at nonsignalized intersections are also high and cause a significant portion of annual crash fatalities (Burgess 2005). Naturalistic driving data provide a way to quantify the relationship of driver factors with intersection features that may not be observed by using crash data only. Given the crash rate and fatalities associated with intersection navigation, interventions and crash countermeasures are both feasible and necessary.

Driver impairment from the use of alcohol, prescribed medication, or illicit drugs is a major contributor to crash risk (NHTSA 2001). Although the influence of driver impairment on crash likelihood, the third high-priority topic, has been extensively studied, naturalistic driving data provide a means to quantify a more appropriate estimate of the frequency of alcohol exposure while driving. Safety countermeasures and interventions are entirely plausible and can include enhanced alcohol detection systems, policy changes, and better driver education.

The fourth high-priority topic examines the influence of driver distraction on crash likelihood. Driver distraction is a major issue in terms of traffic safety and was identified as contributing to 5,870 fatalities and over 515,000 injuries in 2008 (NHTSA 2009). Both the public and state and federal agencies are strongly interested in reducing driver distractions. The diverse array of potential sources of distraction from within and outside the vehicle makes this area of research timely and significant for public safety. Because NDS data are particularly suited for capturing the prevalence of distracting activities and identifying more accurate rates of engagement, feasible safety interventions and mitigation strategies for driver distraction can be better realized with information gained from this naturalistic driving data set.

The fifth high-priority topic, the influence of driver fatigue on crash likelihood, is less well known by the public but is estimated to have involved over 1.35 million drivers in fatigue-related driving crashes over a 5-year period (Royal 2003). The NDS offers a means to quantify exposure to fatigued driving that is not possible using other study designs. This area represents a major source of research and offers opportunities for highly feasible and potentially implementable interventions that can substantially reduce the number of driver fatigue–related crashes.

Effective crash surrogate measures and the analytical models necessary to predict suitable crash surrogates form the sixth high-priority topic. While each of the preceding areas of research is critically important in terms of its potential to reduce the number of fatalities, injuries, and crashes, crash events are anticipated to be rare in the NDS data. It is therefore important to identify and determine events that can be used as precursors or surrogates for severe crash events. NDS will provide a means of evaluating the relationship between surrogates and collisions. This topic is timely, as a large portion of the other analyses depends on appropriate crash surrogate measures. Moreover, without such surrogate measures, crash countermeasures and safety interventions may actually increase crash rates and decrease safety.

Two of the eight high-priority topics were excluded from consideration because it was unlikely that a specific outcome would be produced or that data to address the topic area would be available for the first S08 request for proposals (RFPs). The first of these relates to aggressive driving behavior and its influence on crash likelihood. This topic was excluded because the authors believed there may be difficulties in developing an operational definition of aggression as the affective state motivating this behavior. For example, one definition of aggressive driving behavior is to presume an emotional state (e.g., road rage) with the driving behavior being goal directed toward manifesting that state and harming the target of the emotion (Ward et al. 1998). This perspective is not amenable to naturalistic investigation because of the difficulties in measuring the emotional state of the driver independent of the observed behavior. Indeed, specific measures related to this construct are not well defined in the literature (Dula and Geller 2003; Shinar 1998; Smith et al. 2006). In the absence of valid measures of presumed states that motivate behavior, proposers must take care to relate what can actually be measured to hypothetical influences on behavior. For this reason, other recommended high-priority topic areas might be more appropriate to study in the first round of proposals. The challenge in operationalizing the concept of aggressive driving is illustrative of similar problems with other variables that may be of interest, such as drowsiness, distraction, or alcohol-related impairment.

However, while drivers' presumed mental states may be inaccessible or somewhat subjective, their behaviors are not. Aggressive driving behaviors, for example, can be quantified using data collected by SHRP 2 through the characterization of behavior as aggressive that is abrupt, impetuous, or risk taking by reducing the safety margin for the driver in a given driving scenario. Examples of aggressive driving behaviors include close headway distance, sudden or excessive acceleration or braking, speed exceedance, and frequency of lane departures (Fancher et al. 1998). These variables are typically included as indicators of unsafe driving and are of great interest to the transportation community. The SHRP 2 NDS will have data related to this construct so that it can be studied in greater detail.

Because the sample size associated with driver support systems in the first data collection year might not be sufficient to merit appropriate statistical analyses, this topic was also recommended for exclusion. A preliminary review of the types of vehicles to be included in Safety Project S07, In-Vehicle Driving Behavior Field Study (data collection in 2010 and 2011), suggested to the study team that the number of vehicles with advanced systems such as adaptive cruise control and lane-departure systems will not be large enough (at least not for the first set of S08 RFPs) to provide sufficient power in the statistical comparisons. In addition, because the characteristics and algorithms of driver support systems vary greatly among different makes and models, the team thought that comparisons would be challenging.

The team notes that these excluded topic areas are important, and outcomes from examining these issues could support interventions with large safety benefits. However, these topics would be better addressed in a simulator, on a test track, or in a separate NDS. Finally, the team deemed a third question ("How do dynamic driver characteristics, as observed through driver performance measures, influence crash likelihood?") to be redundant with other questions that relate to distraction and fatigue, and this question was also removed.

CHAPTER 5

Work Plan Requirements

This chapter outlines the team's recommendations for elements to be included in proposals submitted in response to the S08 RFP. The work plan elements described reflect the key information needed to assess the merits of a particular research question or approach. These elements provide a common format and template for guiding the development of RFPs and the review of research proposals.

The following sections describe the recommended requirements for S08 work plans. Example work plans, which briefly demonstrate how a researcher might address all of the key elements in a proposal, are provided in Chapter 6.

Defining a Specific Research Question

SHRP 2 will determine the topic areas to be examined for Project S08. For each research topic to be examined, a specific research question will be addressed by each proposer. Therefore, it is recommended that the first section of an S08 proposal, regardless of the topic area, include a well-defined specific research question. This question will most likely fall within one of the proposed research topic areas and should include a rationale for its selection.

Each specific research question should take into account what crash types (e.g., ROR, rear end, intersection) will be examined. The crash type does not necessarily have to fit into the traditional crash categories. Regardless of the crash type chosen, the proposer needs to explain the potential safety benefit of the research. The proposer should consider the possibility that there may not be enough samples of the events to be considered (e.g., intersection crashes, lane departures, or exposure to roundabouts) in a 2-year NDS to capture meaningful outcomes related to a particular crash type. Hence, potential crash surrogate measures and the rationale for their selection should be proposed.

Value and Limits of Naturalistic Driving Data for the Proposed Research Question

It is very important that the proposal demonstrate the value of using naturalistic driving data to study the selected question, explain how using naturalistic driving data could offer substantial insights unavailable using other methods, and address why the question cannot be answered using another data collection method.

There are many ways to examine driver safety, and each data collection method provides a unique opportunity to address a specific research question. Data collection methods can range from high experimental control with low levels of external validity/realism to high levels of external validity/realism with no experimental control (see Figure 5.1). There are advantages and disadvantages to each. For example, bench laboratory studies, such as assessing driver choice reaction time, have extremely high experimental control and the ability to assess response time, but typically have little external validity/realism because they lack driving context. On the other extreme, crash data have high validity/realism but lack specific driver performance data and depend on the reporting of driving situations and environmental characteristics. Naturalistic driving studies offer strong external validity/realism but lack experimental control. As a result, the use of naturalistic driving data is most appropriate for research questions that cannot be answered with more readily available methods. For example, a research question that attempts to relate crash rates to road geometry might be best answered by using existing crash and roadway data; it does not require the information about driver behavior that NDS data can supply. Similarly, a research question about where drivers need to look to safely traverse a horizontal curve may be more appropriate for a simulator study.

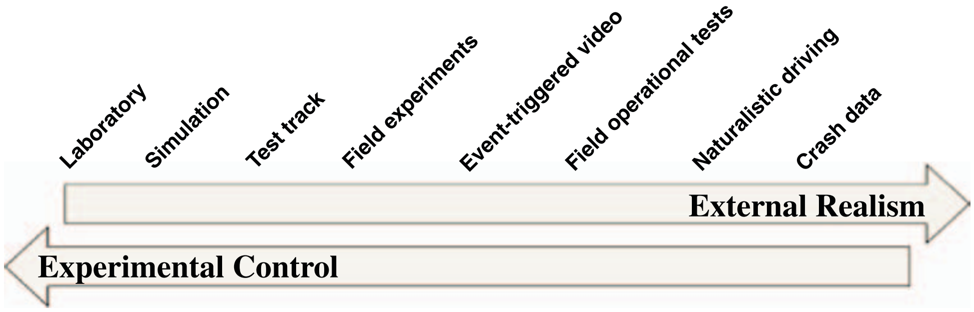

Figure 5.1. External realism and experimental control inhabit contradictory continuums.

Considerations for Data Analysis Plans

This section outlines the major considerations for the development of data analysis plans. S08 researchers will need to consider what variables and data sampling plans are needed to answer their proposed research questions. Data variables can be selected based on driver, vehicle, roadway, or environmental information. Within each variable, the data can be segmented into continuous data, sequential blocks, and sample- or event-based data. A description of each method is provided below. Data analysis plans must consider and justify the selected variables, sampling plans, data aggregation methods, and analytical tools. These are critical aspects of research using naturalistic driving data.

Data Levels and Variables

While approximately a petabyte of data will be collected from the SHRP 2 instrumented vehicles, the full data set will not be available to S08 researchers. Thus, they will need to determine what data they need, how they will process or extract it in preparation for analysis, and how it will be formatted. Data storage and computational limits will also affect S08 researchers. Some analyses may require continuous data (i.e., the data collected at the highest sampling rate), others are likely to require data sampled around specific events, and still others may need the data that describe each trip. If events, features, or other triggered events are desired, the researcher must clearly define how these will be used to extract the required data.

Proposers should demonstrate that they have the ability to work with spatial and temporal data sources. They should identify the challenges associated with naturalistic driving data that involve information such as roadway characteristics.

The data can be systematically separated into driver, vehicle, roadway, and environmental elements according to the model of the interactions between these factors (see Figure 5.2). Each of these elements is discussed below. The data collected from the SHRP 2 project will contain various data formats (e.g., video, numeric, and text contained in relational databases).

Driver characteristics include attention, perception, situation assessment, and motor control (Lee 2006). These characteristics vary among drivers and are influenced by individual differences such as age and driving experience. Drivers' psychological functioning also varies across time as a function of fatigue and impairment caused by alcohol or drug use (these factors are identified as the driver state in Figure 5.2). In addition, nondriving-related activities, especially those leading to driver distraction, influence driver attention, perception, situation assessment, and motor control. Technology (e.g., cell phones, MP3 players, and Internet connectivity) enables a wide range of nondriving activities that can distract drivers. The effect of such technology on crash risk clearly depends on more than vehicle characteristics. It is very dependent on how drivers use and react to the technology according to the roadway characteristics (Lee 2006).

Vehicle characteristics also influence driver behavior (e.g., advanced braking systems influence the braking effectiveness of the driver). Rear-end collision avoidance systems have been shown to have a safety effect in reducing crash frequency (Lee et al. 2002). Other technologies, such as adaptive cruise control or crash warning systems, change the driving task more fundamentally and may lead drivers to disengage from the driving task and lose situation awareness (Stanton and Young 2005; Young and Stanton 2004). The interaction between the driver and the vehicle is a critical aspect of the safety of the driver–vehicle system. Although advanced vehicle technology represents a critical emerging issue for driving safety, assessment with SHRP 2 NDS data will depend on the market penetration of such systems at the time of data collection and the number of participants who have cars with such systems.

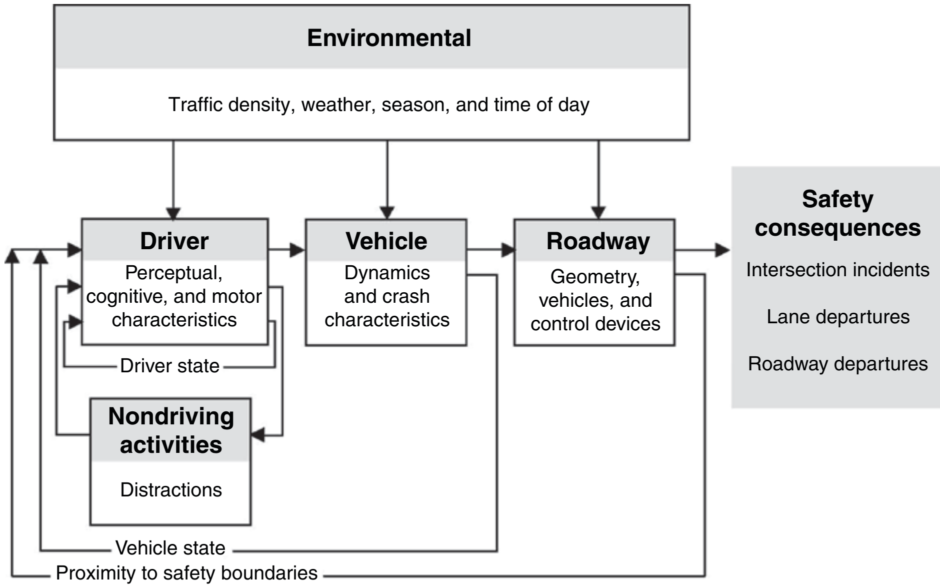

Figure 5.2. The dynamic relationships between driver, vehicle, roadway, and environment and the resulting safety consequences.

Roadway characteristics influence the safety consequences associated with changes of vehicle position on the roadway. A narrow lane or shoulder magnifies the safety consequences of a deviation from the center of the lane. Isolated roadway characteristics such as shoulder width and curve geometry can influence crash risk, but the interaction of these factors with driver characteristics may have a more powerful influence on risk. Lane width and shoulder treatment influence lane-keeping behavior, and drivers' ability to anticipate curves based on signage, geometry, and other factors influence road-departure crashes. The overrepresentation of older drivers in intersection crashes also demonstrates how roadway characteristics interact with driver characteristics.

Environmental characteristics influence the safety consequences of driver characteristics, vehicle dynamics, the demands of nondriving tasks, and roadway characteristics (Lunenfeld and Alexander 1990). Environmental characteristics include traffic density, ambient lighting, weather conditions, and pavement surface conditions. These elements not only represent situational factors considered (or ignored) by the driver in planning behavior (or triggering errors), but they also define boundaries for the operation of the vehicle on a particular roadway (e.g., ice reduces the speed at which a vehicle can negotiate a curve without sliding). Thus, research questions must be framed to consider the relevant context of the driving environment.

Data Sampling and Aggregation Plans

Research questions can be examined in various ways depending on the chosen analytical method and will therefore require different data sampling plans. Each of the data elements described above can be sampled in different ways. Table 5.1 demonstrates how the data can be described in the proposal to address each specific research objective. Some research questions may require data sampled from a specific cell of the matrix, while others may require a grouping of the cells. For example, to address a specific research question that relates vehicle kinematics to curves, only vehicle data would be needed at the event level when the events are defined as

Table 5.1. Matrix of Data Elements and Data Sampling Levels

		Data Sampling Strategies			
		Random Epochs	**Event Epochs**	**Periodic**	**Trip**
Data Elements	Driver				
	Vehicle				
	Roadway				
	Environment				

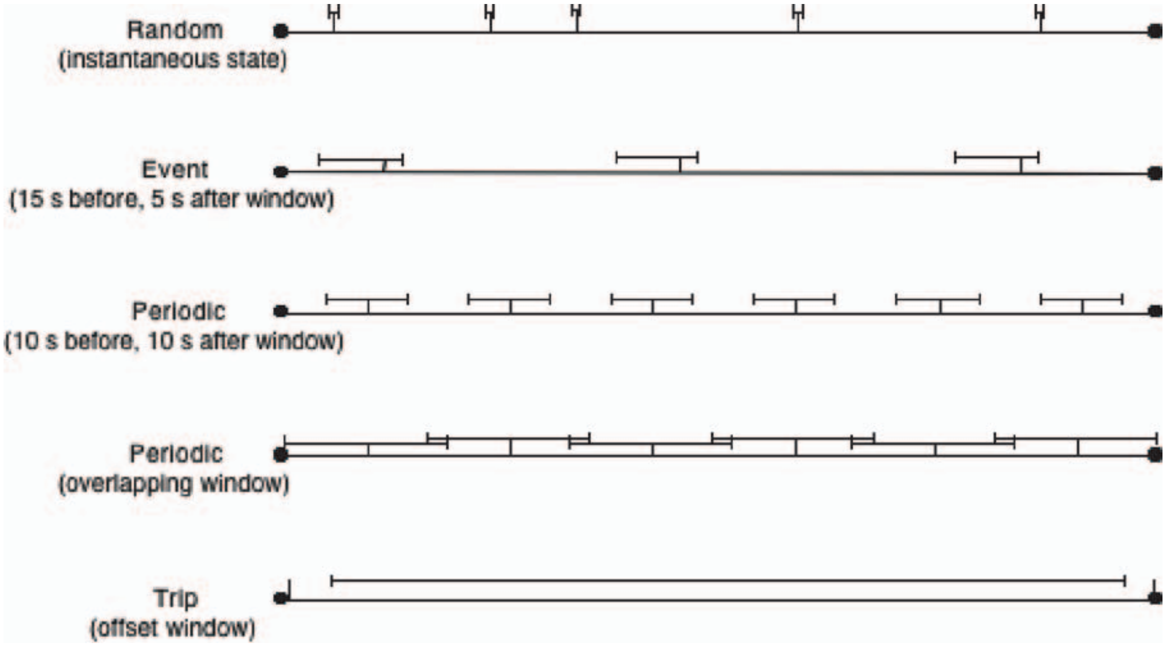

Figure 5.3. Data sampling strategies (figure not to scale).

curves. However, a research question related to driver behavior in response to lane departures would also require event-based data related to the driver.

Figure 5.3 puts the specific sampling strategies in Table 5.1 into a more general context. Sampling can be defined in terms of the factors that define the period of interest and the way the data are aggregated from these periods. Often the period of interest can be defined in terms of a triggering condition or a window around an event. Figure 5.3 shows sample triggering conditions ranging from random instances and specific events (e.g., acceleration threshold exceedance or intersection traversal) to periodic samples that occur at a set number of seconds or miles traveled. The initiation of a trip can also serve as a triggering event. Figure 5.3 also shows how the windows around events that define the data of interest can vary in length. An extremely small window will capture only the instantaneous state of the vehicle (as shown at the top of the figure); a long window can almost encompass the entire trip (as shown at the bottom of the figure). The data window for the trip excludes the start and end of the trip to protect the anonymity of the participant. As the second example in Figure 5.3 shows, the window around critical events is typically asymmetrical because more data are collected before the event than after the event. Some algorithms to identify driver state might use overlapping windows, as shown in the fourth example.

Once the data sampling strategy is characterized, the aggregation and transformation of the data over each sampled window will also need to be defined. If the instantaneous state of the driver, vehicle, roadway, or environment is of interest, then a single measure at the point of the event may be all that is required. In the other sampling plans shown in Figure 5.3, the data associated with each variable from the sampled window will most likely need to be aggregated into a single descriptive number (e.g., the mean speed over the window or the standard deviation of the speed or lane position). In some instances the raw data are of interest, such as in the University of Minnesota study described above, in which microscopic models of driver behavior were fit to the continuous data. The following paragraphs describe some possible combinations of data sampling and aggregation strategies. The number of combinations defined by the triggering condition, window, and aggregation strategies is very large, and the specific selection must be tailored to the specific research issue.

Continuous data encompass the raw data and are not aggregated. Figure 5.4 shows how continuous data could be used to construct a speed profile of a trip for a single driver. Some research questions of interest can only be addressed with this fine-grained detail.

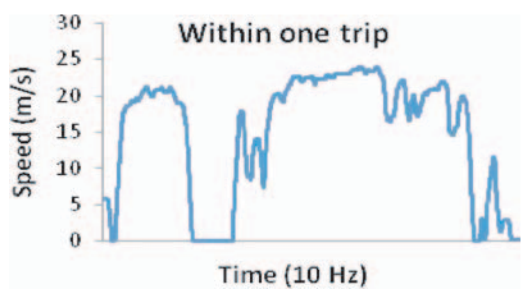

Figure 5.4. Example of a continuous data stream used to produce a speed profile.

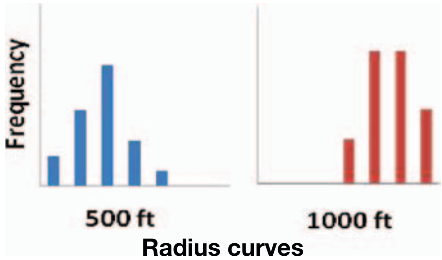

Figure 5.5. Event epochs of roadway departures at given speeds for curves with different radii.

Figure 5.7. Sample trip-level data.

Random epochs provide random snapshots of the state of the driver and vehicle. Data samples might be collected every minute, every 5 minutes, or every hour. For each random epoch, speed or lane position would be available for a specified period around that epoch. For example, for a specific epoch, a researcher may be interested in the 20 seconds before and after the epoch (see Figure 5.3). The analyst could aggregate these snapshots to generate mean speeds or other descriptive statistics.

Unlike epochs based on random or periodic sampling, event-based epochs provide a means for examining data for a predefined event or feature of interest. This method is useful for addressing research questions related to critical or non-critical events. For example, the number of lane departures at specific curves of specific radii may be considered at the event level (see Figure 5.5). Examples of events of interest include a lane departure, a headway distance of less than 20 feet, dialing a cell phone, or an intersection crash. A specific interest may also be a feature, such as curves greater than 500 or 1,000 feet or mountainous roads with no guardrails. As with all the other types of data-sampling schemes (except continuous), the researcher will need to develop a plan for reducing the data to these triggers, events, or features of interest.

Periodic sampling provides data aggregated for a given block of time (e.g., seconds, minutes, or hours) that can include measures of interest such as mean speeds or standard deviation of lane position for each block of time (see Figure 5.6). This level of data sampling provides researchers with more manageable data sets while still capturing insights for research questions that require observations over time. As observed in Figure 5.6, the blocks of time associated with the period of interest may actually overlap, and the data analyst will need to take this overlap into account.

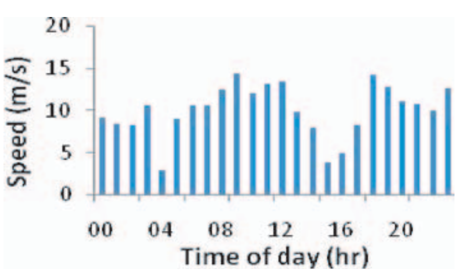

Figure 5.6. Periodic sampling with hourly collection of mean speeds.

Trip-level samples in which the trip start time and end time define the duration of the trip will also be available to S08 researchers. Figure 5.7 is an example of trip-level data.

Coding Video Data

Because transforming video into numerical data that can be included in an analysis can require significant resources, this process merits particular attention. Before embarking on the analysis of video data, such as eyeglances, the researcher should consider the magnitude of work that may be involved. Depending on the research question, various elements may need to be reduced from the video data that will require either manual reduction or the development of some automated functions by S08 researchers. Potential elements of interest that may be reduced from the data include information related to driver distraction, as well as roadway, environmental, lane position, and traffic operation elements.

Although most eyeglance data reduction is automated, manual reduction may occasionally be required. Such manual coding allows for a more refined, context-specific analysis. Specialty analyses might be required around events of interest such as extreme acceleration, crashes, or near crashes. Other incidents of interest may be related to dialing on a cell phone, typing or reading text messages, or a positive indication on the passive alcohol sensor.

Visual scanning measures of the interior of the vehicle and the view outside of the vehicle will be accomplished by placing cameras throughout the vehicle as specified by VTTI (Figure 5.8). From these videos of the driver's eyes, face, and head, eyeglance direction can be estimated. Eyeglance estimations demonstrated in research conducted at the University of Iowa and the Crash Avoidance Metrics Partnership (Angell et al. 2006) classified glances into nine zones (see

Figure 5.8. VTTI example video views (based on presentation material from SHRP 2 July 2009 meeting).

Figure 5.9). A trained data reductionist can take the context of an eyeglance and assign it a position in one of these nine areas:

1. Forward (road scene);
2. Center rearview mirror;
3. Up (including visor and road scene);
4. Left (including outside mirror);
5. Right (including outside mirror);
6. Steering wheel/cluster area (includes meters—e.g., speedometer, tachometer);
7. Center stack (e.g., radio, CD player);
8. Down (below steering wheel and center stack); and
9. Other (all glances that are not assigned to one of the above eight zones—e.g., a glance toward passengers).

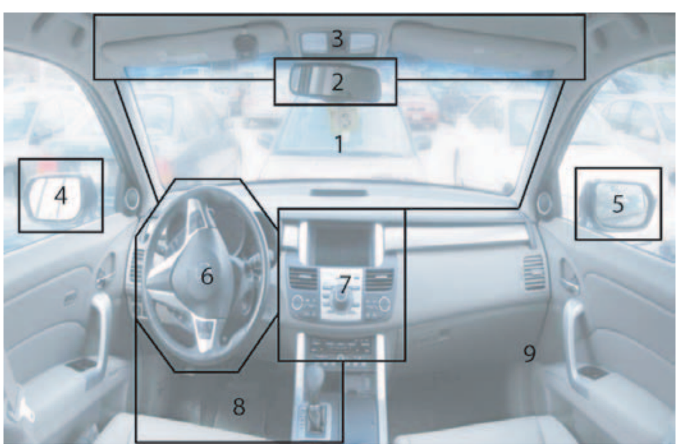

Figure 5.9. Nine eyeglance zones.

Video with assigned areas of interest can be created with specialty packages such as Noldus Observer or custom software that enables analysts to view and code VTTI digital videos frame by frame (i.e., 1/30th of a second). Video reductionists may also want to use a programmable jog-and-shuttle video editor to help expedite data entry and scrolling to specific locations of interest. Jog-and-shuttle keyboards have programmable keys so that single keystrokes can be made for each of the physical visual locations of interest.

The level of effort for coding manual data can vary substantially across projects and data sources. For estimating purposes, manual video reduction may take anywhere from five to six times as long as the actual video clip. For example, if a video clip of interest is 30 seconds long, it will usually take 150 to 180 seconds to manually code the clip.

VTTI's MASK software is expected to be able to automatically and accurately code a high percentage of the eyeglance data. Manual coding will only be required when the automatic coding is not able to code the data or when specific behaviors need to be logged. The effort associated with this will depend on the precision and reliability of the MASK system.

From this more precise frame-by-frame coding, the frequency and duration of eyes-off-road can be computed for each event of interest, and various descriptive statistics can be applied to these reduced data. Specific variables of interest are the number and duration of glances to complete a task. Total glance times can then be computed for each task.

Issues Related to Time-Dependent Variables

The NDS data that will be collected will have inherent time dependencies that will occur at all sampling levels from seconds to weeks. Several time domain methods could be used to account for this dependency, including moving averages, exponential smoothing, autoregressive moving average models, and distributed lags analysis. Frequency domain methods (e.g., Fourier transforms) can also be used to examine time-dependent outcomes.

When considering a time–series analysis, researchers will need to demonstrate an understanding of how to examine the underlying patterns (e.g., trends, serial correlation, seasonal effects, and residuals) in the data because outcomes that do not account for these patterns may have confounding effects and inappropriate conclusions. For example, if a researcher is considering an autoregressive moving average model for the analysis plan, trends and cyclical effects anticipated from the segmented data should be identified. The researcher's explanation should include an example of a time–series plot of anticipated events (e.g., number of text messages, cell phone calls, or even lane departures). Figure 5.10 shows an example plot of events over several study days. A preliminary observation of this plot indicates the existence of a downward trend and the appearance of cyclical patterns (with a higher number of events at the start of each day). As random variation in data is inevitable, researchers should identify how they will observe emerging patterns within a time period (e.g., by using moving averages, exponential smoothing, or some other technique). The data may also exhibit cyclical or seasonal patterns that will need to be considered in the model by differencing or accounting for the order of the data.

Issues Related to Spatially Dependent Variables

In addition to time dependency, certain spatial effects will be inherent in the data collected in the SHRP 2 NDS. An analysis with intrinsic geographic, geometric, or topological relationships needs to account for the spatial dependencies related to roadway characteristics, travel routes, or region. Spatial relationships can be defined and measured in many ways (e.g., travel start and end points, travel distances, crash or incident locations, and the relationship between crash or incident locations). Researchers need to address these issues in their proposal or describe the analytical methodology that accounts for these factors.

Crash- or incident-migration behavior is an example of a research area that requires an understanding of spatial relationships. Several spatial methods can be used to address this complexity, including spatial cluster analysis, *T*-squared sampling, artificial neural networks, and geographically weighted regression.

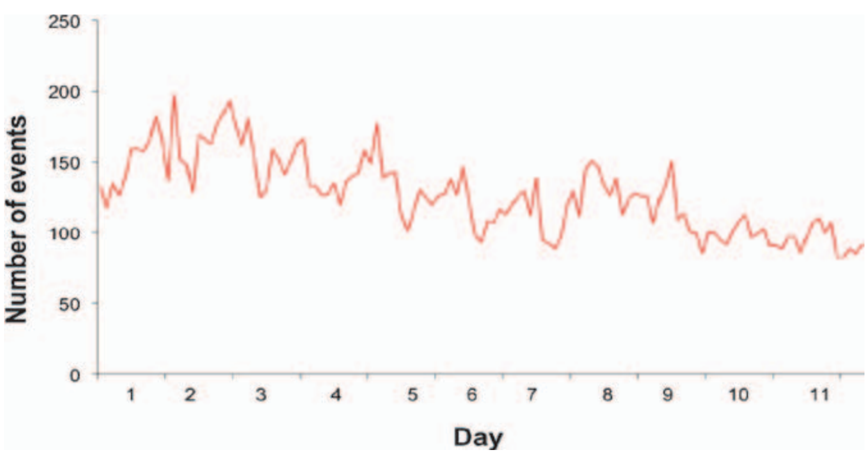

Figure 5.10. Number of events per day.

In assessing the appropriate spatial technique, the proposal should explain the types of geospatial data that will be used and how these data will affect the segmented data that will be used in the analysis. Researchers should take care to recognize that some spatial data analysis techniques (e.g., *T*-squared sampling) may not be appropriate for transportation research because of constraints in intersection configuration. Techniques that have demonstrated usefulness in transportation research include spatial cluster analysis (Miller and Wentz 2003) and spatial autocorrelation-corrected regression modeling (LaScala et al. 2000). A cluster is a group of data points that exhibit some similarity to some subset of the rest of the data and dissimilarity to all of the other data (Jacquez 2008). There are many methods for determining clusters and evaluating the statistical difference between them. However, this is only one of many possible techniques. In general, the researcher needs to explain and justify the spatial method chosen. Because GIS data will be needed to complete the spatial analysis, proposers should document how the databases will be combined and the data analyzed.

Model Formulation

Analysis models developed for Project S08 will most likely be formulated with both static and dynamic variables. Within each sampling plan, some variables will generally be static for an entire trip or study period, while other variables will vary greatly within trips. Thus, variables' characteristics can range along a continuum from static to dynamic. One would expect static variables such as the driver's age and gender, the vehicle make and model, and the region to remain unchanged at all sampling levels. At the epoch level (random or event), road type, pavement markings, and visibility should also be static. (An event epoch is a 5- to 15-second period surrounding a notable state change.) In contrast, the characteristics of dynamic variables can change during the time period of interest. For example, a driver might be distracted for only part of a trip; hence distraction is a dynamic variable within a trip. At the trip level, unlike at the epoch level, the curvature of the road, the pavement markings, and the speed of the vehicle may change.

The distinction of dynamic and static is based on the time constant of the variables relative to the time period over which the data are aggregated. A variable could be dynamic in one sampling plan but static in another. For example, at the trip level, there are no static roadway variables because the roadway is expected to change continuously. However, a researcher might wish to examine event epochs such as lane departures; for these events roadway variables such as road curvature and pavement markings are static. Similarly, environmental variables are expected to be static at the event epoch level. Visibility can change on the order of minutes, making it a dynamic variable at the trip level, but at the event level visibility is considered static because it is likely to change minimally if at all.

While some variables are essentially constant (e.g., driver age), others are constantly changing (e.g., speed without cruise control). Still other variables will change at different rates, some gradually, others essentially instantaneously. Thus, the research question must explicitly define the level of sampling for the analysis (see Chapter 6). It is then necessary to identify which variables of interest are static and which are dynamic within these levels. The answer may differ from level to level; for example, speed may be constant in some, variable in others.

Defining Crash Surrogates

Although crashes will occur in this study, their rarity makes it difficult to directly address most safety issues that need crashes to analyze. Hence, crash risk will have to be estimated using crash surrogates. Crash surrogates represent events that are equivalent to crashes except that a crash was avoided. Researchers have identified variables to define potentially viable crash surrogates. Some of these are described in S01 reports (e.g., lane departures or a specific time period for roadway departure, and drops below a threshold value of time to lane crossing). As appropriate, Project S08 proposers will need to define appropriate crash surrogates and a sampling approach to ensure there are enough surrogate events to justify the analytical approach. They must also demonstrate that the surrogate event belongs to the same equivalence class as the crash it is used to represent. Justifying membership in the same equivalence class as a crash is currently based on the somewhat informal judgment that a crash would have occurred had the driver not intervened. Analytic justification of crash surrogates is a critical issue facing the interpretation of naturalistic driving data.

The proposer will also need to demonstrate the relationship of the surrogate measure to the safety outcome being examined. Examples of this include the association between close headway distance and the likelihood of rear-end crashes or the relationship between variation in lane position or speed for alcohol-, fatigue-, or distraction-related crashes. Considering drivers' dynamic adaptation at the level of the second or even millisecond also has important consequences for defining safety surrogates. For example, when examining driver adaptation, one might expect a linear relationship between lane-keeping performance, lane departure, and roadway departure. A perspective that acknowledges driver adaptation may clarify the factors that lead to safety boundary violations and how these factors affect drivers' subsequent ability to recover and avoid a more severe incident. The crash surrogate should also support interventions for roadway and vehicle design, as well as changes in driver behavior that might be induced through training, policy, or regulation.

Identification and Justification of Analytical Approach

The range of approaches to data sampling makes selecting the appropriate statistical technique a challenge. The traditional techniques commonly used in simulator studies are often inappropriate for the temporal and spatial nature of data generated by naturalistic studies. Each research question can be answered from different analytical perspectives depending on whether an outcome of interest is to be discovered, confirmed, or further explored. S08 project proposers will need to justify the analytic technique they plan to use and explain why the chosen technique is the best choice to address the specific research question. For example, a researcher may be interested in examining the factors that relate to speed propensity in order to address the research question, "How does speeding behavior influence the likelihood of a crash?" A potential technique could be factor analysis, in which latent variables can be uncovered from several seemingly unrelated variables. The proposer would have to justify why factor analysis was superior to other techniques, such as cluster analysis or principal components analysis. Finally, proposers should also justify the sample size and how they will validate the model or approaches that they propose.

Pitfalls and Limitations That May Be Encountered and How to Address Them

Potential limitations associated with using the SHRP 2 NDS data will also need to be discussed in the Project S08 proposals. For example, if a proposal uses an uncommon crash surrogate, finding an answer to a research question may not be feasible because the data may be insufficient. Initial results from the VTTI 100-car study suggest that approximately 10,000 cases (crash surrogates and baseline events) are likely to be needed to achieve sufficient statistical power. Therefore, proposers should address sample size and power issues, how the power of an analysis might affect their ability to reach conclusions, and how much they expect to rely on surrogates. In other cases, there may be substantial challenges in linking data sets, such as linking GIS data to the vehicle data. These limitations of data availability, data format, and linkages between data sets require that researchers demonstrate their understanding of the issues and provide a plan for how they will be addressed. It should be noted that the discussion here involves some early assumptions about data availability and formatting. Significant additional information should be available by the time the first round of S08 RFPs is issued.

Data Format

Initially, VTTI will be the steward of the SHRP 2 NDS data. They will also manage access to the data by S08 researchers. While some quality assurance will be performed, the naturalistic driving data that will be provided will essentially be in the form of raw video and data streams from sensors located in the instrumented vehicles. The list of data elements that will be reported from the in-vehicle sensors is included in the Project S05 final report. It is expected that the data from vehicle sensors will be reported at 10 Hz, even if the data are collected at a higher or lower frequency.

In addition to providing the raw continuous data, it is expected that VTTI will aggregate vehicle sensor data to the trip level. This data can then be manipulated and aggregated to various levels by S08 researchers to suit their particular purposes. However, it is important to recognize that although the data will be available in several formats (continuous or raw data, reduced data sets, and trip-level data), S08 researchers who require the data at any other level of aggregation will need to perform the aggregation themselves or request that the reduction be performed by VTTI. Some data reduction may also be necessary to prepare the data for use in the appropriate format. As a result, researchers should describe and justify the level of data aggregation desired for their specific research question. Additional details on data sampling levels are provided in the next sections.

Several sources of data will be available to S08 proposers and could be used in conjunction with the data collected from the instrumented vehicles. The roadway data will consist of existing data sets, as well as data collected as part of mobile mapping data collection in Safety Project S04B, Mobile Data Collection. Existing data sets may include roadway centerline and attribute data, crash data, aerial imagery, roadway weather information system data, video log data, automatic traffic recording data, and archived weather data. Researchers for Safety Project S04A, Roadway Information Database Development and Technical Coordination and Quality Assurance of the Mobile Data Collection Project, will organize existing data and reduce collected mobile data sets into a database format to be determined by the S04A team. Although the final format for this database is currently unknown, S08 proposers may assume that the final data sets will be provided in the form of a GIS. It is expected that preliminary lists of data elements to be collected will be available for release with the S08 RFP.

S08 researchers should address the methods they will use to transform data into the final format required to answer their specific research question. This explanation includes demonstrating the scope of work required to accomplish this. Proposers should also demonstrate their ability to understand how to use and manipulate the various other data sets. Finally, they should articulate the limitations inherent in these data sets.

Data Availability

Because the field data collection will not be complete until 2013, the initial S08 researchers will have only a few months of naturalistic driving data available to them. Additional data will become available while the S08 projects are under way.

There will also be some limitations on the availability of roadway data. Assuming S04A researchers are selected and under contract by March 2010, existing data sets will be acquired from NDS sites by December 2010. While it will be necessary to process these databases into consistent formats, the data sets may be usable by S08 researchers in the interim. Mobile mapping data collection will commence approximately mid 2011, and results from initial sites may be available early in 2012.

Thus, S08 researchers initially will not have access to final formatted roadway data sets. If access is provided to existing data sets before formatting and processing is completed, S08 researchers may need to overlay and link instrumented vehicle data with the roadside data, and they should demonstrate that they understand how to do so. They will also need to consider other sources for the necessary data until roadway data sets are available. For instance, some roadway features can be determined from the instrumented vehicles' forward video. Aerial imagery such as that available on Google could be used, although it is likely to require additional data reduction.

In brief, S08 researchers will need to demonstrate their understanding of the potential limitations in data availability and have a plan to address associated uncertainties.

Linking Between Data Sets

Researchers should address how different data sets will be linked to combine or extract information. As noted above, there are a number of existing data sets that S08 proposers may want to consider, including those listed in Chapter 6. It is expected that all databases will be available in a spatial format that can be linked and manipulated in a GIS. It is important that proposers planning to use these data sets identify how this data linking will be accomplished. Researchers may wish to use additional databases outside those collected by Project S04A. It is recommended that these proposers consider submitting a letter of collaboration or agreement from the organization that maintains the external data confirming that data can be accessed.

Documentation of Results and Data Warehousing

This section describes the elements that should be addressed regarding documentation of the research results and data sharing between contractors and the data warehouse.

Documentation of Research Results

Proposers should outline the way research results will be reported to SHRP 2 according to the set guidelines for report formats. If the results of the research will be presented in technical briefs, conference presentations, or journal articles, this should also be discussed. If an analysis tool is developed, researchers will be expected to fully describe the tool and discuss its availability to other researchers.

Warehousing and Data Sharing

New data sets are anticipated from the S08 studies. Proposers should describe their plan for preparing the data they have aggregated or extracted so that it can be accessed by other researchers. The plan should include what data will be available; descriptions of how data will be reduced, extracted, or aggregated; and a data dictionary describing the data elements.

Data sharing between the S08 researchers and the data warehouse is a significant issue that must be carefully addressed. Details of the data-sharing agreements must be determined and mechanisms created for data transfers. An important concern with data sharing is protecting the privacy of participants. Any data sharing must conform to the requirements of the institutional review boards (IRBs) of the organizations involved. Privacy issues are particularly acute if face video or identifying global positioning system (GPS) data are needed. Data use may require that researchers physically travel to the site that hosts the data.

Another potential concern involves data reduction. Because raw data require substantial processing before they can be interpreted, the algorithms for data reduction play a critical role in deriving meaning from the data. Extracting seemingly simple measures such as distance to the vehicle ahead or time to lane crossing can involve substantial processing of radar and video data. Such processing might involve proprietary algorithms or data coding that make it difficult or impossible to replicate studies.

Expected Outcome

The outcomes of the research conducted as part of the S08 projects should relate to the goals of SHRP 2. More specifically, S08 proposals should be able to clearly demonstrate that project outcomes directly contribute to enhancing driving safety. It is the understanding of the Project S02 team that S08 projects should result in outcomes that can be directly used by engineers and policy makers to guide decision making. This may include information that

- Leads to better selection and application of roadway or vehicle design and countermeasures; and
- Leads to more informed regulation and policies.

The focus of SHRP 2 is on identifying safety interventions, not on developing statistical methods or understanding driver behavior not specifically related to safety. Given that resources are limited, research projects with the potential for large safety impacts are vital for SHRP 2 goals. Potential safety-related outcomes of S08 projects include identifying factors related to possible reductions in crash fatalities, reductions in crashes, improved policies and infrastructure, and improved driver licensing protocols (e.g., graduated driver licensing). It is strongly recommended that S08 researchers include a section that clearly delineates the expected safety outcomes of their project, the stakeholders affected, and the method by which research results will be transmitted to relevant stakeholders.

CHAPTER 6

Examples of Summary Work Plans

This chapter provides sample work plans for five global research areas: lane-departure crashes, intersection crashes, driver distraction, driver fatigue, and alcohol-impaired driving.

Overview of Work Plans

Each proposed Project S08 work plan should follow this outline:

1. Overview of research topic.
2. Specific research question(s).
   2.1. Crash type(s) addressed.
   2.2. Proposed surrogate measures.
   2.3. Rationale for research questions and use of naturalistic driving data.
   2.4. Hypotheses to be tested.
3. Data analysis plan.
   3.1. Data sampling, segmentation, and aggregation.
   3.2. Model formulation.
   3.3. Analytical approach.
   3.4. Model validation.
4. Pitfalls and limitations that may be encountered and how to address them.
5. Documentation of results.
6. Expected impact or outcome of research on countermeasures or policy implications.

Each work plan needs to clearly identify the global research area being addressed and how the research will contribute to the knowledge in this area. Typically, the research area will be specified by the RFP. Otherwise, the proposer needs to justify the prioritization of the proposed global research question.

Proposers should articulate both the importance of the specific research question to SHRP 2 goals and why NDS data are required for their analysis. The specific research question should also identify what types of crashes the study will address (rear end, angular, intersection, roadway departures, or some combination of crash types). The intent of SHRP 2 is to improve traffic safety, and all funded projects should contribute to the goal of reducing crashes, particularly fatal or injury crashes. Research questions that are mainly relevant to low-severity or low-incidence crash types (e.g., property only) would be a lower priority for SHRP 2. If crash type is not specified, the conclusions of the research cannot direct interventions to improve safety. Accordingly, the work plans should demonstrate that the specific research question is relevant to a specific crash type.

The S02 team has developed five work plans to demonstrate issues that may be encountered when preparing a proposal and how a team might address some of the RFP requirements. Each example work plan addresses one of the global research topic areas:

1. Lane-departure crashes;
2. Intersection crashes;
3. Driver distraction;
4. Driver fatigue; and
5. Alcohol-impaired driving.

The work plans briefly illustrate what might be included in a proposal. It is important to note that these are examples only. The specific research questions used are not necessarily the most important questions regarding the particular global topic area, and the data reduction and analytical methods may not be the best or the only tool to answer the questions posed. Project S08 researchers are not expected to use the same examples or generate similar outcomes. On the contrary, the goal is to provide enough examples to guide researchers in the development of their own innovative ideas.

These work plans provide concrete examples of the challenges associated with naturalistic research and how they might be overcome. The work plans vary in the level of detail they provide to most efficiently highlight the range of issues that researchers need to consider. The first research plan (the lane departure work plan) provides the most detail, and the subsequent plans highlight issue-specific considerations, such as alcohol-impaired driving.

The research question related to crash surrogates is not a separate work plan but is incorporated into each example work plan. The crash surrogate question can of course be a research question in itself, but for the purpose of these examples, the team elected to focus on the various ways crash surrogates can be used for driver behavior and roadway improvements.

With minor variations, each sample work plan follows the suggested six-part outline shown above. Explanatory comments from the S02 team are included in italics. These comments concern the main issues associated with each section of the proposal and the information that should be provided in each part of the work plan.

Example Work Plan 1: Lane-Departure Crashes

Overview of Research Topic

This work plan focuses on the global topic area of "the influence of driver interactions with roadway features on lane-departure crashes." This topic area was assigned a priority one level on the Project S02 decision tree described in the Phase I report because research on driver interactions with roadway features leading to lane-departure crashes is relevant to safety, has the potential to reduce fatalities, would benefit from additional data sources, and is focused on driver behavior. Moreover, the behaviors are available in the naturalistic driving data set, and research outcomes may propose straightforward interventions, as well as provide broader insights into driving safety.

Comment: This example summarizes one research approach to addressing a question within this topic area. It does not represent a complete or ideal work plan, nor does it advocate a preferred research methodology.

Specific Research Question

What roadway and driver factors influence the frequency and outcome of lane departures on horizontal curves?

Crash Type(s) Addressed

The ROR crash is the most likely crash type to result from right-side lane departures; however, head-on crashes and opposite-direction sideswipes can occur when a vehicle runs off to the right and then overcorrects in returning to the roadway. Head-on crashes and opposite-direction sideswipes are the typical crash types associated with left-side lane departures.

Proposed Surrogate Measures

Because crashes are relatively rare events, other factors, such as the amount of lane deviation, will be used as a crash surrogate. While it is assumed that lane deviation is correlated to crash occurrence, the team is not aware of any studies that have proven this relationship. If a sufficient number of relevant crashes are available in the final data set, the team will devote some resources toward developing a model that relates lane deviation to lane-departure crash occurrence. Related measures, including time to lane crossing and yaw rate, have also been shown to be effective surrogates for lane departures.

Several studies have used lane position as a surrogate measure to assess the effectiveness of lane-departure countermeasures. Stimpson et al. (1977) identified lateral placement and speed as the best indicators for assessing driver behavior on horizontal curves. Donnell et al. (2006) used mean lateral vehicle position within the travel lane to assess the effect of wider-edge lines on horizontal curves on two-lane rural highways. Zador et al. (1987) used lane placement to assess the effect of post-mounted delineators and raised pavement markers on driver behavior at curves. Charlton (2007) used speed and lane position to compare the effectiveness of advance warning, delineation, and road marking treatments on horizontal curves. Finally, Porter et al. (2004), Taylor et al. (2005), and Hallmark et al. (2009) also used lane position to assess the effectiveness of lane-departure countermeasures.

Rationale for Research Question and Use of Naturalistic Driving Data

IMPORTANCE OF ANSWERING RESEARCH QUESTION

FHWA (2009) estimates that 58% of roadway fatalities are lane departures and 40% of fatalities are single-vehicle ROR crashes. Horizontal curves have been correlated with crash occurrence in a number of studies. Curves have approximately three times the crash rate of tangent sections. Seventy-six percent of curve-related fatal crashes are single vehicles leaving the roadway and either striking a fixed object or overturning; another 11% of curve-related crashes are head-on collisions (AASHTO 2008).

Studies on roadway factors such as degree of curve, presence of spirals, or shoulder width and type suggest that curve characteristics are the most relevant factors to crash occurrence, but information is still lacking. In addition, little information is available that identifies which driver behaviors contribute to curve crashes. As a result, a better understanding of how drivers interact with various roadway features, such as curve radius or countermeasures like advance signage, will provide valuable information to highway agencies in determining how resources can best be allocated to maximize driver performance and reduce the incidence and severity of crashes.

The study results related to this research question should provide agencies with additional information to implement curve countermeasures or policies that will allow them to make better decisions to target resources in order to improve safety. Information that leads to a reduction in crash severity is a high priority for state highway agencies.

Rationale for Use of NDS Data

Crash data can be used to evaluate some factors related to curve crashes, but such analysis is limited by the amount and type of data provided in crash reports. Usually only aggregate information about roadway features is requested on crash forms. Even when more specific information might be available, police officers may not choose to spend time collecting details on all roadway variables. Thus such data are inconsistently reported. For example, an officer may code a crash as occurring on a curve, but will most likely not include any information about curve geometry or signage. In addition, minimal information on driver distraction is requested on police crash reports, and what is reported can be highly subjective. For example, an officer may or may not report that the driver was distracted by cell phone use, depending on whether that officer attempted to ascertain whether this was the case and whether it was a contributing factor. Other driver factors, such as driver forward attention, are not included in crash report data.

A driving simulator could be used to assess how drivers interact with roadway features, since simulator data can provide information on a specific driver's performance. However, simulator studies do not represent normal driver behavior (e.g., natural engagement in driver distraction). In addition, addressing the wide variety of curve radii and varying roadway features that would be necessary to have representative samples would result in a very large and costly simulation study requiring a large number of drivers. Moreover, simulator studies, like crash data, do not yield exposure data.

Thus, the use of NDS data was determined to be the best method to address this research question.

Hypothesis to Be Tested

Relationships exist between driver and roadway factors and the frequency and outcome of lane departures. To assess these relationships, the study will use lane deviation as a crash surrogate as described in the crash surrogate measures section.

Data Analysis Plan

Comment: The following sections outline the major components that would need to be included in a work plan for this research question. Specific tasks are not broken out, but the components could easily be divided into tasks.

Data Sampling, Segmentation, and Aggregation

Data Request

Since the SHRP 2 NDS will generate a significant amount of data and because a disproportionate number of lane-departure crashes occur on two-lane roadways, the focus of the research will be curves on rural, dry, paved, two-lane roadways. Gårder (2006) indicated that two-thirds of all fatal crashes in Maine take place on rural, two-lane collector or arterial roads. Studies from other states have also indicated that a large number of lane-departure crashes occur on rural two-lane roads (ETSC 1995; Fitzpatrick et al. 2002; KTC 2006). FHWA (2009) also found that most lane-departure crashes occur on two-lane rural roadways. It is also relevant that a review of the most recently available information on the lane-positioning system that will be included with the SHRP 2 data acquisition system (DAS) suggests that the system does not perform well on unpaved roadways (Dingus et al. 2008a; Dingus et al. 2008b). As a result, the research team does not expect to be able to include unpaved roadways in the analysis. As to the focus on dry roadways, although adverse weather conditions increase the likelihood of lane-departure crashes, inclusion of varying weather and road conditions increases the complexity of the model and would require much larger sample sizes than can be included in the scope of this research.

A review of data that will be collected at the NDS sites suggests that several of the sites are likely to include a large amount of rural road driving. (This is based on information available as of December 2009.) The team will therefore request data from the following sites:

- Central Indiana will have 150 DAS units. The study area has 192 miles of rural principal arterial and 202 miles of rural minor arterial roadways.
- Durham, North Carolina, will have 300 units. Although they do not distinguish between rural and urban in their study site description, they list 605 miles of primary road without limited access that are expected to include a large number of rural two-lane roadways.
- Erie County, New York, will have 450 units. Although they do not list by rural and urban, the scheduled study site has 185 miles of primary road without limited access and 1,117 miles of secondary state and county highways that are expected to include a significant number of rural two-lane roadways.
- Central Pennsylvania will have 150 units and has 568 miles of principal arterial and 734 miles of minor arterial roadways, the majority of which are expected to be rural roadways given the location of the study site.

- Seattle, Washington, will have 450 units with a total of 174 miles of rural principal and 444 miles of minor rural arterial roadways.

The Tampa, Florida, site has 450 units scheduled, but the site description specifies only 23 miles of rural principal arterial and 37 miles of rural minor arterial roadway. As a result, data will not be requested from the Tampa site.

Comment: More detailed information about the amount and location of data to be collected and the schedule for data collection will be available once NDS data collection begins and researchers from Project S04A prioritize collection of roadway data elements. S08 researchers should indicate that they understand where roadway and NDS data will occur and what data collection schedule constraints may exist that will affect their ability to obtain data in a timely manner.

Extraction of Data Elements

The data elements necessary to answer the research question will include roadway, vehicle, driver, and environmental characteristics. Table 6.1 indicates the necessary data elements and their expected source. The accuracy necessary for each data element is also provided.

The majority of roadway data elements will be collected by using mobile mapping or will be gleaned from existing state databases. Depending on where mobile mapping data are collected and what other data sets are available, some data will need to be reduced from sources such as forward images or aerial images. Vehicle factors (e.g., speed, acceleration, spatial position, and lane position) will be provided by DAS. Driver face video, passive alcohol sensor data, and potentially some face tracking will also be available from DAS. All other driver factors will have to be reduced from the video.

Because the analysis will include only dry road conditions, it will be necessary to determine a method for selecting only the desired environmental conditions, since roadway surface or ambient environmental conditions will not be provided by any of the data sources that are expected to be available. If possible, archived roadway weather information system (RWIS) data or other meteorological records may be used.

Number and type of driver distractions will be extracted for each sampling interval. To ensure consistency among research team members, a protocol for extracting and coding driver distractions will be developed based on the driver distraction coding system developed by VTTI for the 100-car NDS (Dingus et al. 2008a; Dingus et al. 2008b).

Driver forward attention will be measured by the location of driver focus for each sampling interval. Scan position or eye movement has been used by several researchers to gather and process information about how drivers negotiate curves (Shinar et al. 1977; Suh et al. 2006). The majority of these researchers conducted simulator studies in which it was possible to collect eye-tracking information. Since eye-tracking data are not available in naturalistic driving studies, forward scan position will be used as a proxy. DAS is expected to have some eyeglance positioning capabilities. Information on driver face position will be used to infer driver scan location. Bao and Boyle (2009) used driver scan behavior as a metric to assess age-related differences in how drivers perform various turning maneuvers at rural expressway intersections. They divided the forward view into seven scan locations (see Figure 6.1). A protocol to measure location of driver forward scan position for each sampling period will be developed based on the method used by Bao and Boyle (2009).

Comment: At this point the final accuracy and resolution of data from the various data sources have not been finalized. As a result, the accuracies desired for this sample work plan may not be available in the final data sets. If accuracies for certain elements are lower than desired, a determination will have to be made as to whether the accuracy is sufficient to answer the research question. The expected accuracy should be available for the S08 studies, and researchers should demonstrate that they understand what will be available and whether it is adequate to answer the specific research question they have posed.

Database Structure

The database will be set up so that it can be shared with other researchers. Shared information will include a description of the data extraction, reduction, and processing methods used, as well as a data dictionary with an operational definition for each term or variable used.

IRB Requirements

Although the final requirements are not available, it is anticipated that the team can meet the IRB requirements in order to obtain and use forward video, driver face video, and GPS data for the sections sampled.

Segmentation Approach

The sequential block data segmentation approach was selected as the most appropriate method for sampling data for classification and regression tree (CART) analysis. Data will be sampled at 30-second intervals on tangent sections and at four points for each curve. Campbell et al. (2008) indicated that the driving task through a curve can be divided into four areas (approach, curve discovery, entry and negotiation, and exit). Each area requires different levels of attention and involves different driving tasks, so every curve will be sampled at each of the four points. Driver (e.g., distraction type, head position), vehicle (e.g., speed, acceleration, lane position), roadway (e.g., lane width, shoulder type and width, curve radius), and environmental (e.g., day, night) factors will be reduced from the corresponding data for 1 second for each sampling point. A 30-second sampling period for the tangent sections

Table 6.1. Necessary Data Elements for Lane-Departure Work Plan

Data Element	Data Stream	Minimum
Vehicle Factors		
Latitude, longitude	In-vehicle DAS	±6.6 ft
Distance between vehicle and nearest strikeable object	In-vehicle DAS	±6.6 ft
Vehicle position from lane center	DAS lane position tracking system	±0.1 ft
Forward and lateral acceleration and speed	In-vehicle DAS	±0.1 ft/s^2 and 0.1 ft/s
Pitch, roll, yaw	In-vehicle DAS	NA
Roadway Factors		
Lane and shoulder widths	Mobile mapping	±0.25 ft
Roadway and shoulder surface types, number of lanes, presence and type of edge and centerline rumble strips	Mobile mapping	NA
Horizontal and vertical curve lengths and radii, distance between successive curves, type and characteristics of curve spirals, curve start and end points	Mobile mapping	±25 ft
Superelevation, grade	Mobile mapping	±0.5%
Lane cross slope	Mobile mapping	±0.1%
Curve direction	Will be extracted using DAS forward imagery	NA
Type and location of signage (e.g., chevrons), type and location of roadside objects	Mobile mapping	±6.6 ft
Pavement marking type and condition	Extracted from DAS forward imagery	NA
Location and type of roadside objects	Mobile mapping	±6.6 ft
Speed limit and curve advisory speed	Mobile mapping	NA
Exposure Factors		
Traffic volume (annual average daily traffic)	State databases	NA
Time into trip	Extracted from DAS	NA
Traffic density	Extracted from DAS forward imagery	NA
Lane-departure crash data	State databases	NA
Percentage of time driving on various roadway types under different conditions	Extracted from DAS	NA
Driver Factors		
Age and gender	Driver questionnaire	NA
Driver distraction	Extracted from DAS driver videos	NA
Alcohol use	Inferred from DAS	NA
Driver fatigue	Extracted from driver video	NA
Driver forward attention	Inferred from driver face tracking	NA

Note: DAS = data acquisition system; NA = not applicable.

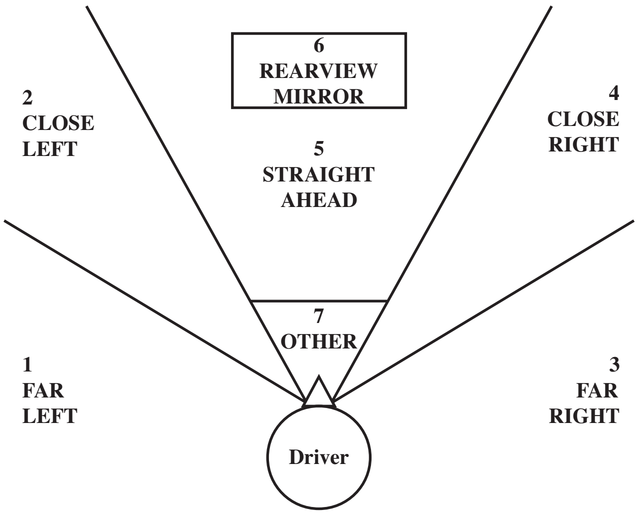

Figure 6.1. Seven visual scanning areas as defined by Bao and Boyle (2009).

was selected because reduction of driver video is expected to be time consuming and resource intensive.

Sampling on tangent sections will be used to account for exposure. The oversampling of curves compared with tangent sections will be accounted for in the analysis.

Vehicle variables can be extracted automatically by using an extraction tool that will be developed. Most roadway variables will also be extracted from existing data (i.e., roadway data sets and mobile mapping data). Some roadway data may need to be extracted from the forward video or other sources such as aerial photos. However, at this point the amount of data reduction is unknown. Data reduction can be time consuming and depends on the time frame, the number of variables, and the amount of data filtering needed. For data sampled at 30-second intervals, data reduction time can be anywhere from 2 weeks to 2 months depending on the amount of data. The amount of data available on rural, dry, two-lane roadways in the NDS is unknown at this point, so an estimate cannot be made of the total resources that would be required to reduce the data. Depending on the amount of data available and project resources requested, a subset of the data meeting study conditions can be reduced.

Comment: Although information on possible sample size and resource needs cannot be estimated at this point given the available information, S08 proposers should demonstrate that they understand what data are likely to be available and the resources that will be required to reduce sufficient data to ensure a statistically representative sample.

Justification for Sampling Approach

Several different sampling approaches (e.g., continuous, sample based, or event based) could be used to extract data. The sequential block method was selected for several reasons. Continuous data segmentation would represent all driving situations and would provide a high level of confidence that meaningful patterns in the data could be detected. However, reduction of driver data at the continuous level is not practical given the amount of data that is expected to be available for rural two-lane paved roadways. A sample-based segmentation approach would result in data that were overly aggregated. An event-based approach could also be used. However, the purpose of data mining is to uncover patterns in the data, and an event-based approach focuses on predetermined events that may prejudice the results. In addition, unless combined with another approach, an event-based approach may exclude drivers who did not engage in a predefined event. As a result, it was decided that the sequential block data segmentation approach provided sufficient randomness to uncover data patterns and was achievable given the time and resource constraints.

Development of Analytical Tools

The team will develop a processing tool since none is expected to be available.

Model Formulation

CART analysis, a data mining approach, will be used to address this research question and evaluate the data. This approach iteratively generates a tree structure by splitting the sample data set into two subsets based on a predictor variable and the value of that variable that produces the maximum reduction in variability. The algorithm will continue creating splits until some minimum criteria are met.

Tree-based models are used for both classification and regression. A tree-based analysis uses a response variable (Y) that can be either quantitative or qualitative and a set of classification or predictor variables (X_i) that may be a mixture of ordinal or nominal variables. For classification trees the response is categorical, and for regression trees the dependent variable is quantitative (Nagpual 2009). Classification and regression trees use algorithms to determine a set of if–then logical split conditions that divide the data into subsets. One of the advantages of regression tree analysis over traditional regression analysis is that because it is a nonparametric method and does not require assumptions of a particular distribution, it is more resistant to the effects of outliers, since splits usually occur at nonoutlier values. Tree models are nonlinear; that is, there are no assumptions about the underlying relationships between the response and explanatory variables. In addition, independent variables do not have to be specified in advance.

A regression tree selects only the most important independent variables—and values of those variables that result in the maximum reduction in deviance—and does not require an assumption of best fit (Roberts et al. 1999).

Regression tree analysis allows patterns in data to emerge that may not be uncovered using other approaches. Regression tree analysis also reveals relationships between variables that may not be determined using other methods (StatSoft 2011). This method only allows variables to split at the value at which a correlation exists. For instance, shoulder width may only be relevant in determining whether a right-side lane departure results in a lane-departure crash on curves of a certain radius, and may be completely irrelevant for tangent sections or curves with larger radii.

The response variable will be the amount of right- or left-side deviation from the lane center. Explanatory variables will include driver, roadway, vehicle, and environmental factors as discussed in the sections above on data extraction and segmentation approach. A sample analysis is presented in Figure 6.2; the data are plausible but hypothetical and are provided to illustrate how the method works. As shown, the hypothetical probability of having a right-side lane-departure conflict is related to curve radius, driver distraction level, and presence of edge-line rumble strips.

Analytical Approach

Various methodologies could be used to answer the research question and identify relationships between lane departures on curves and driver and roadway factors. Jovanis et al. (2009) evaluated data from the VTTI 100-car study by using both event-based and driver-based approaches and generalized linear and Bayesian models. Gordon et al. (2009) used NDS data from existing FOTs to capture the association between highway factors, crashes, and driving behavior. They used Bayesian multivariate generalized models, SURs, and extreme value theory to test this association. Hallmark et al. (2009) used an event-based approach to model the relationship between lane departures and roadway factors. Data were reduced from UMTRI's lane-departure and collision-warning system FOT data. Odds ratios were calculated using logistic regression. A time–series analysis that used continuous data from UMTRI's FOT data was also used to predict vehicle position according to a vehicle's previous position and some roadway characteristics.

Comment: CART analysis was selected for this sample work plan because the S02 team wanted to showcase a different analysis method for each work plan presented in Chapter 6. The goal was to allow potential task force members and S08 proposers to see a variety of segmentation and analytical approaches that could be used to answer research questions. Other work plans presented in this report showcase time–series analysis, risk ratio, odds ratio, and crossover design. Data mining using CART analysis was selected for this first work plan because it was thought that data mining might not be as familiar to task force members as other methods. The authors acknowledge that this is certainly not the only valid approach for analysis of lane departures, and might not even be the best approach to answer the research question posed.

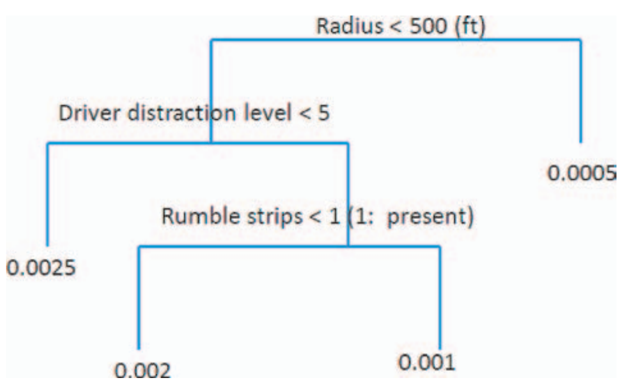

Figure 6.2. Example of regression tree analysis.

Model Validation

To assess how well the data mining models perform against real data, the data will be randomly partitioned into training and testing sets. The training set will be used to develop the model, and the testing set will be used to validate the model's accuracy (how well the model correlates with the attributes in the data provided), reliability (how well the model works for multiple situations), and usefulness (whether the model provides useful information for the stakeholders).

Pitfalls or Limitations That May Be Encountered and How to Address Them

In order to represent a large number of lane-departure crashes and surrogates so that patterns in the data can emerge, a large amount of data is required, and reducing the data required at the level of 30-second intervals will be quite time consuming. When possible, the team will automate the process. Another limitation lies in whether the research team can demonstrate that lane deviation is a reliable surrogate for lane-departure crashes. In addition, data mining using CART analysis is not as commonly used as methods such as calculation of odds ratios or generalized linear models, and as a result it may not be well understood by the highway agencies that will need to use the information. Care will be taken in the dissemination of the project results so that stakeholders will have a general idea of how data are derived from data mining using CART analysis and specific knowledge of how such data can most reasonably be used.

Documentation of Results

Project outcomes will be presented in a final report that will include a description of the data, data reduction, model formulation, analysis, results, and conclusions. The team will also prepare several two-page technical briefs geared toward nontechnical persons who may benefit from project results.

Expected Impact or Outcome of Research on Countermeasures or Policy Implications

This research is important because a large number of fatal crashes occur on curves. The results will aid agencies in understanding the relationship between driver behavior, including distractions, and curve negotiation. The results will also allow agencies to better understand which curve treatments result in fewer and less severe lane departures and will provide insight into which distractions have the most significant impact on the likelihood of a lane departure on a curve.

Most highway agencies are proactive in implementing a range of countermeasures to reduce lane departures on curves, but they are hampered by having only limited information about the effectiveness of different countermeasures. The results of this research will provide more information about which specific roadway features are correlated to increased risk of lane departure. Study outcomes will also provide valuable information about how drivers interact with roadway features and how those interactions demonstrate the effectiveness of countermeasures. Understanding how drivers approach the task of negotiating curves, for example, will help to explain why certain countermeasures work. Increased understanding of the interactions of drivers with roadway features will allow agencies to make better decision about selection of countermeasures.

The research has implications for roadway design, selection of sign type and placement, sight distance, and selection and application of countermeasures. It is expected that more appropriate application of countermeasures to mitigate ROR or head-on crashes on curves will result in fewer fatal crashes.

Example Work Plan 2: Intersections and Crash Likelihood

Overview of Research Topic

Several issues associated with the interaction between drivers and the configuration and operation of intersections were observed in the S01 reports and the report for the S05 project, *Design of the In-Vehicle Driving Behavior and Crash Risk Study* (Antin et al. 2011). The questions related to the role of intersection characteristics include the effects on crash risk of left- and right-turn lanes, signal phasing, roundabouts, pedestrian crossings, and signage.

Specific Research Questions

The research outlined in this proposal will answer the following specific research questions: How do intersection geometric and operational features influence driver scan behavior and response? What is the effect of those influences on RLR violation and crash risk?

Comment: This sample work plan is based on the assumptions that either the forward video includes the signal head sufficiently far in advance so that the researcher can see if a driver ran a red light or that some other method will be available to identify instances of RLR. A review of the latest version of the forward video as shown in Figure 5.8 suggests that data reductionists will be able to determine signal head state, but at present the S02 team does not have sufficient information to determine whether a data reductionist would be able to identify RLR using only the forward video. A proposer who addressed the research question in this sample work plan would need to determine how RLR would be identified in the database, estimate the amount of resources to identify and reduce RLR events, and determine whether that method would be practical.

Crash Type(s) Addressed

Right-angle crashes are the most common crash type in RLR. Left-turn oncoming crash type, and opposite-direction sideswipe can also result from RLR. Some countermeasures, such as RLR camera enforcement, are believed to contribute to an increase in rear-end crashes.

Proposed Surrogate Measures

Even with the amount of data that will be provided by the full-scale NDS, it is expected that crashes will be rare events. RLR violation has been used as a safety surrogate for RLR crashes in a number of studies evaluating the safety impact of camera enforcement. Although a robust crash study requires several years of data after installation of the cameras, agencies often wish to evaluate the immediate impact of the cameras in order to justify their investment. As a result, a reduction in the number of RLR violations has been used by agencies as a safety performance measure (Bonneson et al. 2002; Fitzsimmons et al. 2007; Retting et al. 2007). While it logically follows that a strong correlation exists between RLR violations and RLR-related crashes, no studies were found that established a direct relationship between the two.

RLR violations will be the basic crash surrogate for RLR crashes. An RLR violation is defined as a vehicle crossing the stop line after onset of the red phase. Time to conflict between the study vehicle and an opposing vehicle or pedestrian once an RLR violation has occurred is the metric that will be used to evaluate risk. The model will attempt to derive a relationship between RLR crashes and time to conflict, if feasible.

Rationale for Research Questions and Use of Naturalistic Driving Data

Importance of Answering Research Questions

FHWA (2006) estimates that RLR contributes to more than 100,000 crashes and 1,000 fatalities annually and results in an estimated economic loss of over $14 billion per year in the United States. Retting et al. (1995) found that occupant injuries occurred in 45% of RLR crashes as compared with other urban crashes and that such crashes accounted for 16% to 20% of total crashes at urban signalized intersections. In Iowa, RLR crashes are estimated to account for 35% of fatal and major injury crashes at signalized intersections (Hallmark and McDonald 2007).

Rationale for Use of NDS Data

The goal of this project is to evaluate how drivers visually scan signalized intersections and what geometric, operational, and driver factors result in diminished scanning that can potentially lead to RLR. Visual scanning is very important in understanding how drivers perform under certain situations. Drivers must process information from a number of sources, and most studies agree that visual information plays a significant role in how they perceive and respond to driving situations (Bao and Boyle 2009).

Scanning behavior data cannot be obtained from crash data, nor can such data be easily captured in driver-in-the-loop simulation because of the wide variety of factors (e.g., inattention, aggressive driving, insufficient sight distance) that contribute to RLR. Since a large number of factors may contribute to RLR, use of a simulator would require a large number of scenarios to isolate factors such as clearance interval length. In addition, some studies have shown that RLR is related to driver factors that may be hard to replicate in a simulator. For example, being in a hurry (particularly if a driver is late for work) was identified as a factor in why drivers run red lights. However, it would be difficult to replicate being late in a simulator. Moreover, setting up a simulation to test a wide variety of intersection and signal timing configurations would be costly.

Scanning behavior must be collected from within the vehicle, and only NDS data will provide the amount and types of data necessary for a careful examination of drivers' scanning behavior relative to RLR.

Hypothesis to Be Tested

Certain intersection features may contribute to driver overload that reduces a driver's ability to perceive and process the information necessary to make the correct decision about whether to slow down or continue through the intersection during the yellow interval. The study hypothesis is that visual scanning behavior is a function of intersection geometry, operational factors, and driver factors and can be correlated to RLR crash risk.

Data Analysis Plan

Comment: The following sections provide a brief example of how a researcher might approach populating the work plan for this research question. A time–series analysis will be used to evaluate the data. Data will be sampled using a continuous segmentation approach. The data needed to answer the research question are listed, and how the data will be sampled, extracted, and aggregated for the time–series analysis is discussed.

Data Sampling, Segmentation, and Aggregation

Data Needs

The data variables necessary to answer the research question include intersection geometry, intersection operation, vehicle, and driver factors. Intersection factors include lane width and approach grade. Most roadway factors are expected to be available from either existing databases or from mobile mapping data. Some data elements, such as signal head configuration and sight distance, may need to be reduced from the forward video. It will also be necessary to develop a metric that subjectively measures intersection level of service from the forward or other outward-facing videos. It is assumed that a database that indicates location of signalized intersections will be available from either existing data sets or from mobile mapping data sets.

Signal timing, particularly clearance interval length, is an important factor in RLR. However, most agencies do not maintain a database of intersection timing, and even when this information is available, it is often out of date. Signal timing information will not be available from the mobile mapping data. As a result, there will be no way to obtain green or red phase lengths. The only option for obtaining clearance intervals will be from the forward video if the signal head is visible for the entire interval. The team will evaluate 100 RLR incidents when the data are first received to determine whether it is feasible to include clearance interval length. If a success rate of 80% is not achieved, clearance interval will not be included as a covariate.

Seconds into the red interval (R_{time}) can be determined from the forward video. R_{time} will be calculated by measuring the amount of time that elapses from the time the signal head turns red until the vehicle crosses the intersection stop bar. The stop bar can be identified by locating a regular stop bar or pedestrian crosswalk or by observing the edge of the curb location in the forward video. A protocol will be established to measure R_{time}. Seconds into the red interval requires an accuracy of at least 0.1 second. The GPS trace will not be sufficiently precise to determine a vehicle's position to that level of accuracy. Figure 5.8 shows the forward view from an interim version of the DAS. Although the final DAS will have some differences, it is assumed that details related to the signal head and phasing can be determined from the camera views.

Driver distraction variables and driver scan behavior will be reduced from driver face video. Driver distraction will be coded using the methodology used by VTTI in the 100-car study (Dingus et al. 2006).

Comment: As of January 2010, information was not available on the quality of driver face video, camera angle in relationship to the driver's face, field of view, and other parameters that would be necessary to determine how driver scan behavior can be extracted. Face tracking may also be available in the DAS. It will be important for S08 researchers to be familiar with the types of data that will be available to assess driver scan behavior and driver distraction and to provide a methodology for how they will define and extract such behaviors.

Static vehicle characteristics (e.g., vehicle length and engine size), as well as dynamic vehicle characteristics (e.g., speed, acceleration, spatial position, and lane position), will be available from the DAS units in the SHRP 2 NDS.

Table 6.2 indicates which data elements are necessary and their expected sources. The accuracy necessary for each data element is also provided.

At the time this proposal was submitted the final accuracy and resolution of data from the various sources (e.g., Project S07 NDS and Project S04B) had not been finalized. As a result, the desired accuracies may not be available in the final data sets. If accuracies for certain elements are lower than desired, a determination will have to be made as to whether the accuracy is sufficient to answer the research question.

Comment: The expected accuracy should be available for S08 researchers, and they should demonstrate that they understand what will be available and whether it is adequate to answer the specific research question they have posed.

Data Request

The study will focus on intersections on four-lane arterials with posted approach speeds of 40 mph or greater on dry roads during daylight conditions and with approach grades of less than ±4%. Although RLR can be dangerous in any situation, the consequences are greater at higher speeds. Weather conditions can affect intersection crash risk and may contribute to increased likelihood of RLR. Weather will also affect traffic operations. However, although weather may be an important factor, inclusion of environmental factors would increase the complexity of the model and the amount of data required. As a result, the model will be limited to dry roads.

Likewise, it is assumed that driver behavior is affected by light conditions (e.g., daytime, dawn, dusk, night unlighted, or night lighted). Sight distance and field of view are decreased for nighttime conditions even when street lighting is present. Glare from oncoming vehicles, overhead street lighting, traffic signals, and other sources of light pollution may also significantly affect drivers. However, inclusion of light conditions would also significantly increase the complexity of the model and data needs; consequently the study will be limited to daytime hours. It should be noted that it is also difficult to account for the effect of glare on driver response and perception–reaction time.

The research team assumes that a database that spatially locates all signalized intersections will be available for each study area. Vehicle traces will be requested for all signalized intersections within a study area that meet the geometry requirements and occur during daytime hours. The team expects that environmental conditions will not be reduced, so vehicle traces in which rain, snow, fog, ice, or other low-visibility conditions exist will need to be identified and discarded. Data will be requested for 500 feet upstream and 20 feet downstream for each 40+ mph intersection approach; this area will define the vehicle trace for this RLR study. Several researchers have identified an intersection area of influence that extends beyond the boundary of the intersection itself. Upstream of an intersection, drivers must perceive and react to downstream conditions such as turning traffic, traffic signal changes, and queues. Although it is not simple to define the exact extent of the area of influence, studies suggest that an influence area of between 500 and 600 feet exists for a 40-mph approach (Stollof 2008; Stover and Koepke 2002).

Certain age groups may be more or less likely to use four-lane arterials than others and will therefore be over- or under-represented. Older drivers, for instance, may be more likely to use lower-speed alternate roadways. Since not all instances of RLR will be included, the team will attempt to sample each age cohort as it appears in the population of drivers selected for the NDS. For example, if 5% of drivers are aged 18 to 25 years, the team will attempt to sample 18- to 25-year-old drivers at the same rate.

Even with the constraints on geometry, time of day, weather conditions, and driver age cohorts, it is expected that a large number of vehicle traces will occur in the full NDS data set that meet the above criteria.

A review of data that will be collected at the SHRP 2 NDS sites suggests that all but one of the sites is likely to include many signalized intersections. Based on this information, which was available as of January 2010, the team will request data from the following sites:

- Tampa, Florida, has 450 units scheduled. The study area will include mostly urban roadways.
- Central Indiana will have 150 DAS units. The study area has 380 miles of minor and other principal arterial roadways.

Table 6.2. Necessary Data Elements for Intersection Work Plan

Data Element	Data Stream	Minimum
Vehicle Factors		
Vehicle length, center of gravity, acceleration capability, engine size	Driver questionnaire	NA
Latitude, longitude	In-vehicle DAS	±6.6 ft
Distance to nearest vehicle or pedestrian crossing path	In-vehicle DAS, forward video, forward or side radar	±6.6 ft
Forward and lateral acceleration and speed	In-vehicle DAS	±0.1 ft/s^2 and 0.1 ft/s
Pitch, roll, yaw	In-vehicle DAS	NA
Distance from intersection stop line	DAS, forward video	±1.0 ft
Clearance interval time	Forward video	0.1 s
R_{time}	DAS and forward video	0.1 s
Intersection Factors		
Lane width	Mobile mapping	±0.25 ft
Roadway and shoulder surface type, number of lanes, presence of bike lane, turn lane configuration	Mobile mapping	NA
Approach grade	Mobile mapping	±0.5%
Approach speed limit	Mobile mapping	NA
Presence, type, and condition of crosswalk	Mobile mapping or forward video	NA
Sight distance to signal head	Measured from forward video	±6.6 ft
Signal head type and configuration	Mobile mapping or forward video	NA
Clearance interval	Forward video	0.1 s
Exposure Factors		
Daily entering vehicles	State databases	NA
Time into trip	Extracted from DAS	NA
Traffic density	Extracted from DAS forward imagery	NA
Intersection crash data	State databases	NA
Percentage of time driving on four-lane arterials	Extracted from DAS	NA
Driver Factors		
Age and gender	Driver questionnaire	NA
Driver distraction	Extracted from DAS driver videos	NA
Alcohol use	Inferred from DAS	NA
Driver fatigue	Extracted from driver video	NA
Driver scan behavior	Inferred from driver face tracking	NA

- Durham, North Carolina, will have 300 units, and the majority of the study area appears to be in an urban area. Although they do not describe their study site as either rural or urban, they list 605 miles of primary road without limited access.
- Erie County, New York, will have 450 units and is located in a major urban area. Although they do not list by rural or urban, the scheduled study site has 185 miles of primary road without limited access.
- Seattle, Washington, will have 450 units with a total of 1,958 miles of urban principal arterial roadways.

The central Pennsylvania area is expected to have about 150 units and appears to be predominately rural. As a result, data will not be requested from the Pennsylvania site.

Comment: More detailed information about the amount and location of data to be collected and the schedule for data collection will be available once the SHRP 2 NDS data collection begins and researchers from S04A prioritize collection of roadway data elements. S08 proposers should indicate that they understand where roadway and NDS data will be obtained and what potential data collection schedule constraints may affect their ability to obtain data in a timely manner.

Database Structure

The database will be set up so that it can be shared with other researchers. Shared information will include a description of the data extraction, reduction, and processing methods used, as well as a data dictionary with an operational definition for each term or variable used.

IRB Requirements

Although the final requirements are not available, it is anticipated that the team can meet the IRB requirements to obtain forward video, driver face video, and GPS data for the sections sampled.

Data Segmentation and Reduction Approach

Data will be extracted and used at the continuous level (collected at the frame rate). This is expected be 10 Hz or 0.1-second intervals. It is acknowledged that reducing data at this level of segmentation will require significant resources. The following description provides a rough estimate of the time resources required to reduce a single vehicle trace.

A review of a short video clip indicated that an experienced data reductionist would require approximately 10 seconds for each vehicle trace to determine whether a driver ran the red light. Retting et al. (2007) found that approximately 3.2% of drivers run red lights. Using the Retting data as a reference, it will require approximately 1,000 seconds to find three red light running (RLR) vehicle traces, or 312 seconds per single RLR trace. Once an RLR event is identified, reduction of signal head configuration and sight distance requires approximately 15 seconds, and calculation of time into red requires 30 seconds, for a total of about 45 seconds.

The above estimates result in 312 + 15 + 30 = 357 seconds (5.95 minutes) to find and reduce intersection variables for a single RLR.

Vehicle and other variables available in raw format from DAS (e.g., speed and lateral acceleration) will be retained at the 0.1-second resolution. Driver scan position will be reduced at an interval of 0.5 seconds; it will be assumed to be constant over the 0.5-second interval and can be mapped to 0.1-second intervals.

The amount of eyeglance data to be coded depends on the first defining the relevant surrounding of the intersection. Coding data would be extracted approximately 500 feet (intersection influence area) before the intersection, 48 feet while in the intersection, and an additional 20 feet after the intersection for a total of 568 feet. If the minimum speed is around 40 mph (approximately 59 ft/s), then it would take 9.6 seconds to travel through the designated area: 568 ft ÷ 59 ft/s = 9.6 s.

From previous experience, it estimated that manual data reduction could take between five and six times the length of the actual video clip. As a result, driver data reduction will require approximately 9.6 s × 5 = 48 s per clip to code.

Summarizing all the above, the total time to identify, characterize, and code is 312 s + 45 s + 48 s = 415 s. This includes time to scan traces in which an RLR event did not occur. In addition to this estimate, locating files within the databases and opening files will take more time. Estimates of coding should consider such peripheral logistics that also add time to each clip that is analyzed.

Comment: The example is provided as an illustration that could be used to demonstrate that the proposer understands the amount of time and resources necessary for data reduction. Although it may not be necessary to provide this much detail, S08 researchers should provide some basis for why a data reduction interval was selected and should also make some estimate of how much time will be required to reduce data at the indicated level of segmentation.

Justification for Segmentation Approach

As time–series analysis was selected, a continuous approach was the only logical choice for data segmentation. It is acknowledged that this method will require a large amount of time for data reduction and will limit the number of samples that can be included in the model.

Model Formulation

A time–series analysis will be used to examine the propensity for RLR based on driver's visual scan patterns. The main advantage of using time–series analysis for NDS data is that it allows one to model the driver's scan behavior as the driver progress through the intersection and to examine how changes in one time period affect the scan patterns in the next time period.

Drivers' scan patterns can be examined in two time periods: before entering the intersection and while maneuvering through the intersection. The expectation is that the sequence of events in the first time period will provide insights into the likelihood of running a red light in the next time period. An autoregressive moving average approach may be appropriate to model and predict various types of driver behavior based on various scenarios.

Analytical Approach

A time–series analysis will be used to examine drivers as they encounter and go through a yellow phase as exhibited by speed and acceleration patterns. Speed and acceleration patterns in the vicinity of a signalized intersection that differ significantly, indicating RLR, can then be related to intersection geometry and operational factors. The model will be developed for dry roads during daylight hours to control for environmental factors. Data will be modeled for vehicles traveling through the intersection (not turning left or right). Crash risk will be modeled by time to conflict.

Comment: The section above on issues related to time-dependent variables discusses issues related to time-dependent methods. As a result, model formulation is not further expanded on here.

A time–series approach was selected because it was determined to be the best method to account for dependencies in driver behaviors from previous time intervals. The main advantage of time–series analysis for naturalistic driving data is that it allows relationships between variables across time to be incorporated into the model. As a result, relationships such as driver distraction in previous time periods and probability of an RLR crash in a subsequent time period can be established.

Comment: The authors acknowledge that this is certainly not the only valid approach for the research question and may not even be the best approach.

Model Validation

Approximately three-fourths of the data will be used to develop a time–series model. The remaining one-fourth of the data will be input to the model to determine how well it performs.

Pitfalls or Limitations That May Be Encountered and How to Address Them

It is expected that the request for vehicle activity in the vicinity of signalized intersections along major arterials will result in a significant amount of data to process. The time–series method may also be more difficult to present to lay persons at transportation agencies who are the most likely stakeholders to benefit from the results.

Documentation of Results

Project outcomes will be presented in a report that will include a description of the data, data reduction, model formulation, analysis, results, and conclusions. The team will generate a white paper on the algorithm developed to flag RLR. The team will also make several presentations at national conferences.

Expected Impact or Outcome of Research on Countermeasures or Policy Implications

The main outcome will be information about which intersection geometric, operational, and driver characteristics result in increased RLR and crash risk. This information will be useful for cities and other transportation agencies to make intersection improvements. For example, if the study demonstrated that yellow-phase length is correlated to RLR, traffic engineers could make recommendations for better signal-timing practices.

This research has implications for intersection design, intersection signal timing and coordination, and for application of countermeasures such as all-red phasing or use of RLR camera enforcement.

Example Work Plan 3: Driver Distraction and Crash Likelihood

Overview of Research Topic

Driver distraction has recently emerged as a high-profile driving safety concern. The increasing popularity and complexity of electronic devices that are either built-in or carried into cars makes distraction an increasing threat to driving safety. Designers and legislatures work to balance convenience and access to information with driving safety, but much critical research regarding the risks posed by various types of distractions is still missing. In addition, sophisticated sensor systems may enable future vehicles to track drivers' eye movements, identify distracted drivers, and potentially warn drivers before mishaps occur. Naturalistic driving data can help identify the distractions associated with different activities and provide the data necessary for the development of eye-tracking sensor systems.

Specific Research Question

What pattern of glances away from the road and steering wheel movements predicts breakdowns in lateral and longitudinal control?

Crash Type(s) Addressed

Rear-end crashes are most commonly associated with distraction, which was found to have contributed to 93% of rear-end crashes in a recent NDS (Klauer et al. 2006). Less commonly, distraction also contributes to ROR crashes and head-on crashes. Although less frequent, ROR and head-on crashes are disproportionally responsible for fatalities and serious injuries. Recent crash data show that distraction contributed to 16% of fatal crashes and 21% of injury crashes (NHTSA 2009). Similarly, in a study of NDS data, Klauer et al. (2006) report that distraction contributed to 25% of all crash and near-crash events and approximately 65% of rear-end crashes and near crashes.

Proposed Surrogate Measures

Two general approaches to selecting crash surrogates will be employed to assess the sensitivity of the results to the choice of surrogate. The first approach considers driver response. In the case of rear-end crashes, a crash surrogate based on driver response would be a severe braking event. Severe could be operationalized as an absolute value, such as 0.5 *g*. Because maximum deceleration value is a function of initial speed, vehicle braking system characteristics, and driver response, a normalized value such as 99% for a given speed range would likely provide a more precise indicator of severe braking events. Dividing the speeds into ranges based on a maximum entropy function would guarantee a well-distributed set of ranges (Tan n.d.; Tan and Taniar 2007), but this choice would be vulnerable to any unequal distribution of rear-end crashes across speeds. To address this problem, a second approach uses information regarding close proximity to the vehicle ahead as a crash surrogate. Close could be operationalized using algorithms developed to trigger forward-collision warning alerts. A simple forward-collision alert algorithm could be triggered by situations that cross a time-to-collision threshold of 2 seconds. A more complex algorithm might include the distance, speed, and acceleration of the two vehicles.

Most likely these crash surrogates will co-occur—if a driver gets very close to the vehicle ahead, the driver is more likely to need to brake severely. Therefore, three analyses will be performed: one using the instances in which both surrogates agree, one in which only severe braking occurs, and one in which the driver only gets dangerously close to the vehicle ahead. Assessing the type and degree of distraction associated with these three crash surrogate combinations might suggest different crash types and crash severity associated with different types of distraction.

Rationale for Research Question and Use of Naturalistic Driving Data

Importance of Answering Research Question

Distraction represents a clear threat to driving safety, accounting for 5,870 deaths and 515,000 injuries in 2008 (NHTSA 2009). While a great diversity of sources both within and outside the vehicle account for these deaths (e.g., eating, grooming, other motorists, and billboards), the soaring popularity of in-vehicle information and entertainment systems (e.g., navigation systems, MP3 players, and cell phones) and the potentially distracting tasks introduced by these systems could increase the influence of distraction on driving safety. Although some tasks associated with these systems are driving related, such as in the case of navigation systems, these tasks may interfere with safe driving and thus are still considered distracting (Lee et al. 2008). Developing distraction countermeasures and reducing distraction-related crashes require an understanding of how the broad variety of secondary tasks associated with new information technology affects driver behavior.

Rationale for Use of NDS Data

Over the last decade, hundreds of studies have investigated how distraction can undermine driver performance and safety. The vast majority of these studies involve experiments conducted in driving simulators. These studies carefully control for confounding variables and provide a precise indicator of how distraction affects drivers' performance in controlling the vehicle. Generalizing the effect of distractions on performance in the simulator to driving safety on the road represents an important challenge. Drivers may adapt their driving and engagement in distracting activities on the road in a way that they do not in the simulator. Other studies have used epidemiological analysis of crash data to estimate the contribution of distraction to crashes. Understanding the effect of distraction on driving safety from such analysis is problematic because crash records may fail to identify the presence of a distraction. Moreover, crash data do not provide a detailed description of the role of the distraction as a contributor to the crash. Naturalistic driving data help to fill the gap between simulator and crash data by providing a detailed account of the driver's engagement in the distracting activity in the driver's natural environment.

Hypothesis to Be Tested

Drivers' glance patterns and steering behavior can indicate increased crash risk associated with breakdowns of both lateral control (e.g., lane-departure crashes) and longitudinal control (e.g., rear-end collisions). Both lateral and longitudinal events will be examined to assess whether distraction indicators from steering control can predict breakdown in longitudinal control. This relationship will be robust to differences in road type, distraction type, and driver age and gender. An extended interaction with a distraction will magnify crash risk defined by glance patterns and steering behavior.

Data Analysis Plan

Comment: The following sections provide a brief example of how a researcher might populate the work plan to address this research question.

Data Sampling, Segmentation, and Aggregation

An event-based sampling approach will be used to describe the 180-second period preceding the event and the 5 seconds following the event. The relatively long period preceding the event will be used to assess the broad driving context leading up to the event and the contribution of the duration of the distraction to the likelihood of a crash or near-crash event. A case–control method will match the event-triggered sample as closely as possible with another sample selected at the same time of day on the same day of the week for the same driver in the week preceding that in which the event occurred. The continuous data will be aggregated using algorithms that maximize the ability of a sequence of eye movements to differentiate between distracted and attentive drivers. The data variables necessary to answer the research question include road type (e.g., residential urban arterial, freeway), driver factors (e.g., age, gender), and driver behavior (e.g., steering wheel movement, speed, frequency and duration of off-road glances, distraction type). Driver distraction variables will be reduced from the driver's video data. Ideally, on-road and in-vehicle gaze location information will be extracted with a machine vision algorithm. It is assumed that a database that links GPS location to road will be available either from existing data sets or from mobile mapping data sets.

Data Request

Epochs consisting of the 180 seconds preceding and the 5 seconds following each crash and near-crash event will be requested, along with three matching epochs. The epochs will be matched by driver, road type, time of day, and type of day (weekday versus weekend) rather than on a random selection to minimize extraneous variation and to identify the increased risk of distractions associated with the behavior of an individual rather than the overall safety profile of that individual.

Database Structure

The database will be set up so that it can be shared with other researchers. Descriptions of data extraction, reduction, and processing methods, as well as a data dictionary with an operational definition for each term or variable used, will be provided. One database will include the continuous data for each epoch, including steering behavior, speed, and eye gaze location. Each row of this database will represent the state of the driver and vehicle sampled for each 0.1 second of the epoch. Driver and epoch number will key a second database to this database. The second database will summarize the first by aggregating the data to the level of the epoch. Each row will represent a single epoch, and the eye gaze and steering data will be combined in several possible algorithms that can represent crash risk associated with different patterns of eye gaze and steering movements.

Analytical Approach

The statistical modeling involves two phases: the first combines gaze and steering data over the 180-second epoch preceding the event to arrive at an index of expected risk. Long glances away from the road, short glances back to the road, a long interaction with a distraction, and lapses in steering followed by abrupt corrections might contribute to a higher degree of expected risk of a mishap. This index of expected risk can be derived from previous research or through data mining methods that identify the combination of variables and their weighting that best reflect the likelihood of a crash or near-crash event. The second phase evaluates the ability of this index to differentiate between crash and near-crash events. A conditional logistic regression model will calculate the odds ratios associated with the various risk indices. Risk indices associated with high odds ratios are those that accurately integrate gaze and steering data to predict distraction-related crash and near-crash events.

Model Validation

The statistical model will be validated with a sensitivity analysis that will examine the extent to which model predictions depend on the parameter values. The model will also be validated by assessing its performance by using a subset of the data that is withheld from the data used for model estimation.

Pitfalls or Limitations That May Be Encountered and How to Address Them

Video review and coding could be prohibitively expensive. Machine vision approaches to automatic gaze tracking are at the research prototype stage, and their output would require validation. Coding of distraction types would require manual coding. Currently available surrogate measures reflect abrupt responses of the driver in the form of braking and steering wheel reversals and do not capture lapses related to near-crash events such as failing to stop for a red light. The surrogate defined by driver response and by the lack of driver response outlined in this proposal begins to address this problem, but only for rear-end crashes.

Documentation of Results

Project outcomes will be presented in a report that will include a description of the data, data reduction, model formulation, analysis, results, and conclusions. Beyond the standard reporting of the overall results, a detailed description of the algorithms used for data segmentation and aggregation will be produced so that the process can be exactly duplicated. This description of the algorithms will be accompanied by intermediate data sets.

Expected Impact or Outcome of Research on Countermeasures or Policy Implications

The main outcome will be an algorithm that relates patterns of eyeglances and steering wheel reversals to crash risk. If such an algorithm predicts rather than coincides with crash risk, then it might be used as the basis for an in-vehicle countermeasure to mitigate driver distraction. To be useful, the algorithm must also be robust across different types of drivers and roadway situations.

This research could identify effective algorithms for detecting distraction and thereby support interventions to prevent or mitigate distraction. The role of extended interactions with distractions could provide justification for greater legal sanctions associated with such behavior, such as those being adopted in Great Britain.

Example Work Plan 4: Driver Fatigue and Crash Likelihood

Overview of Research Topic

Several issues associated with driver fatigue were observed in the S01 and S05 reports. The original questions related to the role of driver fatigue in various crash types (i.e., rear-end, head-on, backing, and lane change) and in crashes involving other vehicles, pedestrians, and other objects. Issues related to the influence of fatigue or drowsiness on driver behavior were also of concern.

Specific Research Question

How do episodes of fatigue affect drivers' lane-keeping ability?

Crash Type Addressed

This study focuses on ROR crashes. Drivers' lane-keeping ability is influenced by driver fatigue and sleepiness and hence may affect ROR crashes.

Proposed Surrogate Measures

This specific research question is based on examining crash surrogate measures (i.e., lane keeping) that have been shown to relate to crash likelihood in drowsy drivers. It is likely that crashes will be rare events in the naturalistic driving data, and ROR crashes may be even rarer. Hence, lane-departure and lateral drift events and standard deviation of lane position are considered as ROR crash surrogates for this specific research question. Other possible crash surrogates include lateral acceleration and speeding, which have been shown to relate to the likelihood of ROR events and safe negotiation on curves and through intersections (Reymond et al. 2001; Classen et al. 2007; Fildes et al. 2005). Each crash surrogate will be evaluated, and a determination of the best crash surrogate will be made after examining the available naturalistic driving data.

Rationale for Research Question and Use of Naturalistic Driving Data

Importance of Answering Research Question

Driver fatigue is a major contributor to motor vehicle crashes and is responsible for approximately 40,000 injuries and 1,500 deaths each year in the United States alone (Knipling and Wang 1995; Laube et al. 1998; Lyznicki et al. 1998). Royal (2003) estimated that 1.35 million drivers were involved in a fatigued driving–related crash over a 5-year period. A NHTSA study revealed that there are six million crashes annually resulting in an economic impact of over $230 billion (Blincoe et al. 2002). Thus, over 4% of these costs are probably attributed to fatigue, and even this estimate may be low. In a separate study conducted by McCartt et al. (1996) approximately 55% of 1,000 drivers surveyed indicated they had driven while drowsy, and 23% had fallen asleep at the wheel. This confirms other findings that fatigue may play a role in crashes that are erroneously attributed to other causes (Connor et al. 2001).

Rationale for Use of NDS Data

Naturalistic driving data can provide insights into how frequently drivers exhibit safety-relevant errors while fatigued. Crash data are generally poor at identifying behavioral causes, and driving simulators cannot tap into how frequently or at what time of day or night such events occur. Crash data do not provide enough details to answer this specific research question since there is no preimpact information. Obviously crash data do not describe how frequently a fatigue event has occurred without a negative outcome (e.g., crash). There is also no way to observe speed, acceleration, and lane offset as the driver progresses on his or her trip or gets sleepier.

Driving simulator studies can control for environmental situations and can capture the performance of fatigued drivers by having them traverse over monotonous drives (Boyle et al. 2008; Reyner and Horne 1998). However, sleepiness can occur even during complex driving situations that can increase the already high workload encountered by the sleepy driver. These complex and varied situations can only be observed in a naturalistic environment.

Hypothesis to Be Tested

It is hypothesized that drivers' lateral control ability is affected by fatigue. By capturing the influence of fatigue on lateral control, insight can be gained on ROR crashes.

Data Analysis Plan

Comment: The following sections provide a brief example of how a researcher might approach populating the work plan for this research question.

Data Sampling, Segmentation, and Aggregation

The specific research question will be answered with data gathered from random and event epochs. The specific data will include roadway features such as road type, curve radius, and lane width; time of day; and weather and lighting. The majority of these elements would need to be provided from mobile mapping or state databases, as well as in-vehicle data collection. Weather and lighting information may need to be reduced from forward images.

Vehicle kinematic data such as speed, acceleration, curve speed information, and lane position will be obtained from the in-vehicle DAS. Lane and roadway departures will be detected by automated lane position data from DAS.

Driver face video and face and eye tracking would also be used and captured from DAS. If possible, evidence of eyelid closure (e.g., PERCLOS) would be determined.

Model Formulation

A case-crossover design will be used to compare cases (drivers during fatigued episodes) with control or baseline situations (drivers during nonfatigued episodes). In this analysis, each participant will serve as his or her own control, thus minimizing confounding effects of age, gender, driving records, and other fixed characteristics (Maclure 1991). Thus, data from multiple baseline drives and events will be needed for each driver. If there are not enough fatigued episodes, the study can be set up to oversample the control condition such that a 2:1 matched approach can be used with one case (fatigue) episode matched to two control (nonfatigue) episodes, with all episodes based on the same roadway condition (urban or rural) for the same driver.

It is important to note that because driving performance tends to be similar for each driver (i.e., within-driver data are highly correlated), using analysis measures based on an assumption of data independence would not be appropriate. Thus, a repeated measures analysis of variation and conditional logistic regression will be used depending on the nature of the dependent variables.

Fatigued episodes will be identified from driver face video. Screening criteria for fatigue can include driver's eye movements (e.g., eyelid closures for more than 2 seconds, multiple blinks), number of head-nodding events (Heitmann et al. 2001), and yawning. However, the research team notes that an examination of eye movements is highly dependent on the driver's eye and eyelid geometries and whether sunglasses conceal the eyes.

Sampling Approaches

The continuous data will be examined during the events when drowsy episodes are observed. Continuous data are necessary because they provide the only means for observing fine eye movements. A comparative sampling set will be needed for two nondrowsy episodes (or epochs) for the same driver.

A 5-second sample of the vehicle kinematics will be used for the case and crossover events. This sample-based approach will help reduce the fluctuation and noise that are typically observed when examining raw data. Hence, calculations of mean and standard deviation for vehicle kinematic information (e.g., speed, acceleration, lane position) will be potentially smoothed at this level.

Data for all roadway types will be requested from the NDS. Video and driver (e.g., driver eye position, distraction type), vehicle (e.g., speed, acceleration, lane position), roadway (e.g., lane width, curve radius), and environmental (e.g., time, weather, lighting) factors will be used for the baseline and case episodes.

The influence of sleepiness will be time dependent and will most likely degrade driver performance over the length of a trip. Since the effect of fatigue is continuous and may have an extended duration within a trip, the baseline episodes will come from separate trips from the same driver.

Sampling both urban and rural roadways will allow the research team to compare the effect of fatigue under different road type and traffic conditions; it is expected that the driving environment will be more critical (i.e., there will be more traffic and the distance between vehicles will be closer) in urban areas.

Database Structure

The database will be a flat file indexed by driver number, event index, and state of the driver. Each line will represent a summary of 5-second interval data, including numerical vehicle kinematic data (e.g., speed, acceleration, lane position), environment information (e.g., weather, roadway conditions, time of day), and reduced driver behavior data for that time interval (e.g., normal driving, fatigue).

The database will be set up so that it can be shared with other researchers. Shared information will include a description of data extraction, reduction, and processing methods, as well as a data dictionary with an operational definition for each term or variable that will be used.

Statistical Analysis

Repeated measures analysis of variance (ANOVA) will be used to analyze the speed and standard deviation of lane position. Conditional logistic regression will be used to analyze the likelihood of lane departure and lateral drift incidents. Depending on data availability, time of day, weather, lighting, and roadway features will be controlled to investigate the influence of fatigue under different environmental conditions.

Model Validation

The statistical models will be validated with a sensitivity analysis that will examine the extent to which model predictions depend on the parameter values. The model will also be validated by assessing its performance by using a subset of the data that will be withheld from the data used for model estimation.

Pitfalls or Limitations That May Be Encountered and How to Address Them

The raw video data will require extensive data reduction to capture driver fatigue. This process can be very time consuming and will add to the cost of this study. It is also important to note that distinctions between driver sleepiness, fatigue, and drowsiness will not be made because video data can only provide the analyst information on whether the driver appears to be tired. In addition, distinguishing between a driver's fatigued and normal appearance using naturalistic driving data might be difficult and depends on individual eye and eyelid geometries (e.g., a driver with droopy eyelids may always look tired). However, the kinematic variables in combination with the video data will provide insights on the propensity of drivers to drive in an unsafe manner given the indicators of sleepiness.

Documentation of Results

Project outcomes will be presented in a report that will include a description of the data, data reduction, model formulation, analysis, results, and conclusions.

Expected Impact or Outcome of Research on Countermeasures or Policy Implications

The results of this research will provide insights in how fatigue could affect driving safety. By analyzing lateral control, the research team will gain a better understanding of the role that fatigue plays in safety incidents and ROR crashes. Such data will also help determine what types of countermeasure technologies are most effective.

This research will have implications for the development of driving assistance systems, such as drowsy driver detection and alerting systems, as well as for driver education policies.

Example Work Plan 5: Influence of Driver Impairment Caused by Alcohol on Crash Likelihood

Comment: This work plan demonstrates the issues and implications related to the use of the NDS alcohol sensor data. The alcohol sensor provides continuous sampling of cabin air and may have some utility in identifying driving segments where alcohol may be present. Several confounding factors include whether a window is open or the HVAC system of the vehicle is on refresh (i.e., if the cabin air is recirculated) and the possibility that the alcohol being detected stems from mouthwash or even perfume. Hence, the following example is focused on the challenges that can be encountered if a proposal includes alcohol sensor data. Data from other sensors can also produce ambiguous and noisy estimates (e.g., precision of lane position depends on the clarity of lane markings and other road textures), and each S08 proposer needs to account for and manage these limitations.

Specific Research Questions

Do speed and variation in steering and speed differ when alcohol is detected in a vehicle compared with situations in which alcohol is not detected? If differences exist, how do they affect the likelihood of ROR crashes?

Crash Type(s) Addressed

All crash types related to speeding are relevant, most particularly ROR crashes on both straight and curved roadway segments. Most ROR crashes occur on curves and are more typical in rural roadway environments (Liu and Subramanian 2009). Hence, this specific research question has high relevance to SHRP 2 safety improvement objectives.

Proposed Surrogate Measures

A key finding of the UMTRI S01 study was that yaw rate error could be a good surrogate for roadway departures on curves. As described by UMTRI, the yaw rate error generates a smooth, continuous, and unique data series, even when a lane boundary crossing occurs and appears to be a better predictor than TTEC. Both these measures will be used as initial surrogates for ROR probability. However, their performance is based on a field operational test that considered only one vehicle type and whose primary focus was on evaluating a roadway departure system. Therefore, other variables will also be considered for crash surrogates in SHRP 2, and the outcomes will be compared to yaw rate error.

Rationale for Research Questions and Use of Naturalistic Driving Data

Importance of Answering Research Questions

In 2006, there were 35,588 fatal crashes in the United States (NHTSA 2007). Twenty-eight percent of drivers (and motorcycle operators) involved in fatal crashes failed to keep proper lane position or ran off the road (NHTSA 2007). ROR crashes are related to both alcohol and speeding (Liu and Subramanian 2009). In addition, alcohol and speeding are significant behavioral risk factors for other crash types (ETSC 1995; NHTSA 2001). Therefore, this research is relevant to the SHRP 2 traffic safety goals.

The influence of alcohol is a behavioral crash factor of great concern given its impact on crash fatalities (NHTSA 2001). The research questions also identify the targeted form of driver error in terms of lane-keeping and selection of appropriate speeds (ETSC 1995).

Rationale for Use of NDS Data

Current research on the crash risk associated with alcohol use is based on epidemiological studies or derived from driving simulator or test track experiments. However, the data and conclusions from these studies are limited. Simulator and test track studies can identify the intervening behaviors that result in increased risk, but such studies involve artificial environments that lack the natural motivation factors inherent in the real world that might affect behavior such as speed choice. Drivers are less likely to misbehave in a driving simulator given the demand characteristics of a controlled experiment in which the driver knows he or she is being observed. Further, it is not ethically possible to test alcohol involvement at the high blood alcohol concentration (BAC) levels encountered in fatal crashes.

Hypothesis to Be Tested

Crash and near-crash events that occur when alcohol is detected are preceded by systematically different patterns of steering behavior and speed adjustment compared with those events when alcohol is not detected. Several shifts in driving behavior can occur as a result of alcohol-related driver impairment: (1) increased, but less effective, steering behavior; (2) diminished steering input punctuated by lapses; or (3) increased speed combined with less effective steering. The analysis will assess the prominence of these potential alcohol-induced shifts in steering behavior.

Data Analysis Plan

The data used for this analysis will be restricted to single-occupant vehicles (vehicles without passengers) to avoid any potential confounders from alcohol use by other occupants of the vehicle.

Data Sampling and Aggregation

Included in the data collected in the NDS are GPS location, the outcome of the alcohol trigger (alcohol presence), yaw rate, and steering and speed variability.

Drivers tend to stay on familiar routes when traveling between home, work, and other routine destinations. Capturing driving during segments when no alcohol is detected on routine roadway links could be considered baseline (i.e., nonimpaired) driving. Aggregated baseline profiles for a particular roadway link would be compared with instances of positive alcohol sensing on the same link. When a driver is impaired, the profile would change based on differences in speed, steering and/or yaw rate. Positive alcohol triggers on curves and straight road segments will be matched within each route to segments with no alcohol detection.

Roadway, regional, and environmental characteristics (e.g., weather, day or night) will also be examined for each road segment and included in the model as covariates as appropriate. Information on roadway characteristics (e.g., road type, lane width, cross slope, and type and width of shoulder) will be provided by mobile mapping or will be available from existing state databases. These databases should be cross referenced with the vehicle GPS coordinates to identify feature-based epochs of data upstream of the point of curvature (Campbell et al. 2008). Regions can be classified as rural and urban according to the vehicle GPS coordinates and state or national standards. Weather and other environmental conditions will most likely be extracted from the forward video.

Comment: Other data sets may also be needed depending on available information (e.g., aerial images), and the proposer will need to identify where such information will be obtained.

Model Formulation

Sampling Approach

Epochs for each event will be collected for straight and curved segments with and without the detection of alcohol. Data for this specific research question will be reduced to 30-second blocks and aggregated across a road segment, depending on the length of the segment.

Database Structure

The database will be set up so that it can be shared with other researchers. Shared information will include a description of data extraction, reduction, and processing methods, as well as a data dictionary with an operational definition for each term or variable used. Based on the sampling approach and specified data, a processed database will be derived from the integration of the vehicle, roadway, and environmental data elements (see above). This processed database will have columns to represent the data shown below each epoch:

- Trip information: date, trip number, and segment number;
- Driver information: driver ID, driver face video, and eye point of gaze;
- Vehicle information:
  - Alcohol presence or absence,
  - Speed variation on road link when alcohol is and is not detected,
  - Speed and steering variation on road link when alcohol is and is not detected,
  - Yaw rate when alcohol is and is not detected,
  - TTEC when alcohol is and is not detected,
  - Vehicle speed at curve averaged between 5 meters before and 5 meters after the point of curvature, and
  - Vehicle speed on roadway averaged between a distance 60 and 50 meters before the curve entrance;
- Roadway information:
  - Road type,
  - Lanes (number, marking type, width),
  - Speed limit (posted and roadway),
  - Road curvature (horizontal, vertical),
  - Indicator for roadway speed >9 mph above the posted speed limit,
  - Indicator for curve entrance speed >9 mph above the posted speed limit; and
- Regional information: urban or rural based on GPS.

Statistical Analysis

The central focus of this analysis is on the quantification of steering behavior and speed associated with situations in which alcohol is detected. These steering patterns can be defined in various ways. One approach is to describe the steering behavior in the time domain with traditional measures of steering performance, such as standard deviation or the frequency of steering reversals greater than some threshold. Another approach is to use a frequency domain description that describes the steering behavior in terms of a power spectrum using Fourier analysis or techniques such as wavelet analysis that are more robust to the characteristics of naturalistic driving data. Parameters extracted from the time and frequency domain analysis could then be evaluated with a cluster analysis to identify distinct types of steering behavior for alcohol and no-alcohol cases. Risk ratios applied to event counts (e.g., alcohol detected) and other forms of event-based analysis such as logistic regression are an appropriate statistical method to test the association of alcohol with cluster membership (types of steering behavior) and cluster membership with crash and near-crash ROR events.

Pitfalls or Limitations That May Be Encountered and How to Address Them

Perfumes and other substances could falsely be identified as alcohol by the current NDS alcohol-detection system. Additional data coding resources may be needed to separate single- and multiple-occupant situations. Even though the proposed scenario is constrained to one occupant (i.e., the driver), it would still be difficult to determine whether the driver is under the influence of alcohol. Thus, video data will also be examined to assess whether the driver appears to have been drinking in the moments leading up to the episode being examined or whether he or she was using some other alcohol-based substance that was not ingested.

Eliminating situations that might cause inaccurate indications of alcohol presence might bias the data (few drivers will have their windows open in northern states in the winter), consume substantial effort, and diminish the sample size. However, according to current reports in the literature, there will be many instances of drivers drinking alcohol (NHTSA 2001); thus, a large-enough sample size to achieve adequate statistical power may be possible to mitigate these biases.

Documentation of Results

Project outcomes will be presented in a final report that will include a description of the data, data reduction, model formulation, analysis, results, and conclusions.

Expected Impact or Outcome of Research on Countermeasures or Policy Implications

The research is important because a large number of fatal alcohol-related crashes occur, with the highest rate of alcohol use and fatal crashes occurring in rural areas. This research will provide results that could further aid agencies in understanding the relationship between alcohol consumption and driving safety. However, without BAC data, providing additional support for alcohol policies that relate to the BAC level considered impaired and the potential methods for detecting impaired drivers from their driving performance measures is not possible.

The profiles of behavior that significantly correlate with driver impairment can provide valuable information (1) to support methods for officers to detect impaired drivers from observed actions of vehicles and (2) to develop vehicle-based systems to monitor vehicle control and diagnose inferred impairment states. For example, real-time measures of vehicle speed in relation to posted speed limits can be used with intelligent speed adaptation systems that can automatically warn drivers and control speed for alcohol-impaired drivers. This study could, therefore, demonstrate the value of controlling the speed of cars that are being driven by alcohol-impaired drivers.

CHAPTER 7

Recommendations for Project S08

Additional Data Reduction

The current plan is to provide Project S08 researchers with data at the continuous and trip level, with the expectation that S08 researchers will be able to parse the data in a reasonable time frame to conduct their analyses. Some researchers may have more experience with naturalistic or other aggregated data sets than others. However, these same researchers may not necessarily be familiar with more complex analytical techniques. Alternatively, those who are familiar with more sophisticated data analysis techniques may not recognize the magnitude of work required to reduce video or parse vehicle kinematics data. Given these limitations and the immense quantity of data that will be collected for the NDS, the S02 team recommends that SHRP 2 consider additional data reduction that would benefit many researchers. Event-based data, which can be exceedingly useful, is a common requirement for many studies. Even though there is clearly a cost involved in obtaining these data, the additional cost of event-based data reduction might be much less if it is performed by a single entity and distributed rather than performed redundantly by different teams. More generally, it could be useful to require each S08 proposer to provide a data-sharing plan so that the effort in data reduction in SHRP 2 can benefit researchers in the future.

Timing of Release of Work Plans and Expected Outcomes

The first round of Project S08 RFPs were released in December 2010. Given the availability of data, the team recommends that the first call for proposals be delayed until an adequate data quality check has been completed and an adequate amount of data is available for each S08 researcher to conduct temporal and spatial analysis, if desired. It is anticipated that each of the outcomes of the S08 studies will lead to implementable safety interventions that can ultimately reduce fatalities. Such policy-relevant outcomes demand a sufficient amount of exceptionally high-quality data.

Considerations for Project Costs

To date, there is approximately $3 million to spend on S08 studies. Therefore, the S02 team recommends that the funds be distributed across the projects to (1) address project ideas with high yield and (2) account for the needs of the stakeholders. Funds will more likely be directed toward research questions related to driver behavior rather than roadway features. For example, it may be reasonable to allocate 60% of funds for questions related to driver behavior and 40% for roadway-related questions. However, S08 proposers should recognize the intrinsic link between the two areas and account for it in their proposals. The final determination related to allocation of funds will ultimately reside with the Expert Task Group and will be based on scientific merit and contribution to the field.

The S08 projects will address complex problems that will require a multidisciplinary approach. Hence, small grants to individual faculty members are not likely to have the greatest effects. Alternatively, if the team is too large, project management can be difficult. Costs associated with S08 projects will most likely need to account for a research team that consists of a human factors specialist with expertise in driver behavior, a traffic safety engineer knowledgeable in the particular roadway of interest, and a person with a strong background in the analytic tool being used. When necessary, the project team might also need an individual with expertise in GIS or spatial data manipulation. Specific research questions may require other areas of expertise, including team members who are knowledgeable in more than one field would be entirely reasonable. An individual could demonstrate his or her expertise in more than one area through relevant publications, membership on expert panels, or some other recognized record of accomplishment. It will be up to the bidder to ensure that funds are allocated for each person and to justify each area of expertise.

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APPENDIX A

Summary of Phase I of SHRP 2 Project S02

Introduction

Advances in data collection techniques, such as instrumentation suites that capture naturalistic driving behavior, allow problems relating to transportation and driving behavior to be examined in a way that was not previously possible. In recent years, capturing naturalistic driving behavior has become more feasible and cost-effective. Naturalistic refers to a method of observation that captures driver behavior in a way that does not interfere with the various influences that govern those behaviors. This in-vehicle method allows for the observation of drivers in their own environment and can provide deeper insight into the factors affecting driving safety.

Naturalistic driving studies provide data that are most likely to generalize to actual driving situations; however, such studies provide the least control, making it difficult to identify causal mechanisms without ambiguity. Naturalistic driving studies by their nature collect a large amount of data and have the potential to produce some of the world's largest databases. The size and challenge of identifying mechanisms underlying driving safety from these databases complicate the data analysis techniques used to address research questions related to driver safety. The spatial, dynamic, and temporal nature of driver behavior adds to the complexity of such analyses. Sifting through the plethora of data collected in such studies can be extremely demanding and will provide little insight if data are improperly sampled, integrated, and analyzed.

Reviews of Safety Projects S01 and S05

The outcomes of Safety Project S01, Development of Analysis Methods Using Recent Data, and Safety Project S05, Design of the In-Vehicle Driving Behavior and Crash Risk Study, were reviewed in this phase. The S01 contractors included the University of Minnesota Center for Transportation Studies, the Pennsylvania Transportation Institute, the University of Michigan Transportation Research Institute, and the Iowa State University Center for Transportation Research and Education. From these reports, 56 specific research questions were extracted. In addition, 392 questions were extracted from the S05 report from the Virginia Tech Transportation Institute (VTTI).

These research questions were initially compiled into separate matrices. Each specific question (described in Appendices B and C) was separated into categories for classifying the variables corresponding to those factors identified in Figure A.1: environmental, driver, vehicle, roadway, and nondriving activities. This systems-based perspective frames the specific research questions to identify how multiple factors influence the risk of collisions.

These factors are not independent of each other but may actually have different contributions depending on the interactions of different factors (Donmez et al. 2006; Neyens and Boyle 2006). Categories are functionally defined below.

Driver characteristics include attention, perception, situation assessment, and motor control (Lee 2006). These characteristics vary among people and are influenced by individual differences such as age and driving experience. Drivers' psychological functioning also varies across time as a function of fatigue and alcohol or drug impairment (which are identified as the driver state in Figure A.1). In addition, nondriving-related activities, especially driver distraction, also influence driver attention, perception, situation assessment, and motor control. Technology, such as cell phones, MP3 players, and Internet connectivity, makes possible a wide range of nondriving activities that can distract drivers. The effect of such technology on crash risk depends on more than the vehicle characteristics alone. It is very dependent on how drivers engage the technology relative to the roadway characteristics (Lee 2006). Crash risk often depends on the interaction of driver and roadway characteristics, as demonstrated by the overrepresentation of older drivers in intersection crashes.

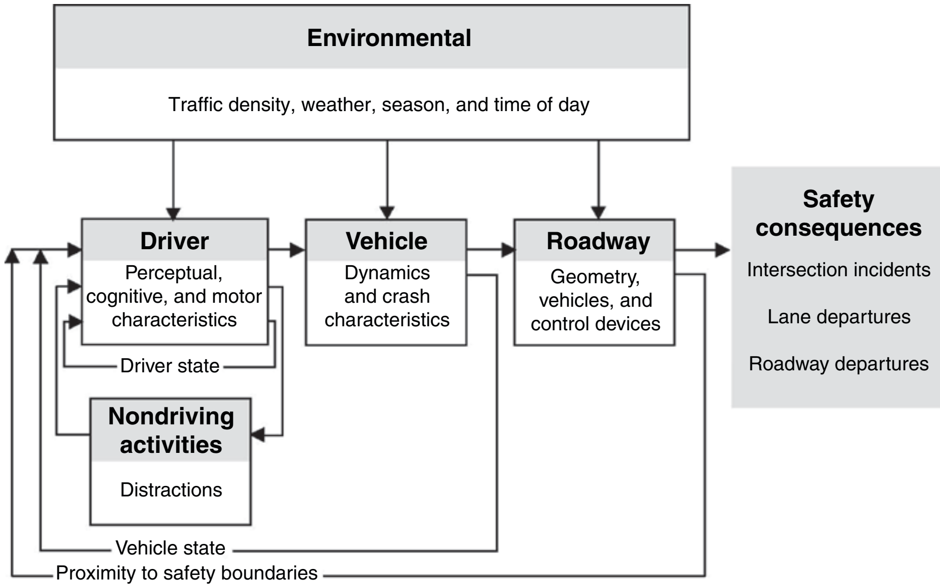


Figure A.1. The dynamic relationships between driver, vehicle, roadway, and environment and the resulting safety consequences.

Vehicle characteristics influence driver behavior; for example, advanced braking systems influence the braking effectiveness of the driver. Rear-end collision avoidance systems have been shown to have a safety effect in reducing crash frequency (Lee et al. 2002). Other technologies, such as adaptive cruise control or crash-warning systems, change the driving task more fundamentally and may lead drivers to disengage from the driving task and lose situation awareness (Stanton and Young 2005; Young and Stanton 2004). The interaction between the driver and the vehicle is a critical aspect of the safety of the driver–vehicle system.

Roadway characteristics influence the safety consequences associated with changes of vehicle state. A narrow lane or shoulder magnifies the safety consequences of a deviation from the center of the lane. Isolated road characteristics such as shoulder width and curve geometry can influence crash risk, but the interaction of these factors with driver characteristics may have a more powerful influence on risk. Lane width and shoulder treatment influence lane-keeping behavior, and drivers' ability to anticipate curves based on signage and topography, as well as other factors, influence road-departure crashes.

Environmental characteristics influence the safety consequences of driver characteristics, vehicle dynamics, demands of nondriving tasks, and roadway characteristics (Lunenfeld and Alexander 1990). The environment includes traffic density, ambient lighting, weather conditions, and pavement surface condition. These elements not only represent situational factors considered (or ignored) by the driver in planning behavior (or triggering errors), but they also define boundaries for the operation of the vehicle for a particular roadway (e.g., ice reduces the speed at which a vehicle can negotiate a curve without sliding). Thus, research questions must be framed to consider the relevant context of the driving environment.

Feedback loops in Figure A.1 show the influence of past events on a driver's response to future events. One example is how drivers' awareness of their own state can influence their behavior—people adapt and drive more conservatively if they perceive themselves to be impaired. Likewise drivers' attention and perception are strongly influenced by expectations, such as typical cues that indicate horizontal curves (Lunenfeld and Alexander 1990). These expectations reflect both very recent experiences that may have occurred only seconds before and long-term exposure to similar situations (driver expectation) over months or years. It is therefore important to consider research questions that relate these human factors to driver behavior and crash risk.

Safety consequences can be viewed from two perspectives: inside-out and outside-in. Inside-out refers to a driver-centric perspective and focuses on driver-related data relative to safety critical events. For example, an increase in visual attention demand (e.g., eyes-off-road time, complexity of the environment, or driving task) has been associated with diminished vehicle control. The outside-in perspective focuses on environment-related data relative to safety critical events.

Crash migration is a consideration because traffic improvement projects tend to improve the acute problem (an inside-out perspective) without attending to changes that may occur in surrounding areas (an outside-in perspective). This consideration has been examined by Griffith (1999), Shen and Gan (2003), and Smith and Ivan (2005). Their studies have typically centered on rumble strips and as such have not seen definitive effects. However, the benefit of the naturalistic driving study is the ability to observe whether changes in travel patterns and behavior result from changes in the system (e.g., the implementation of speed bumps, traffic signals, new roadway networks, and construction zones). Most studies on traffic improvements focus on before and after interventions of the acute area, but such micro examination does not provide insights into any larger safety problem that may have occurred due to changing travel patterns. The outside-in perspective is analogous to a bird's-eye-view of the vehicle in that it can allow observation of the contributions to crashes that arise from factors beyond the driver's control.

The data collected from this study can be aggregated to different levels (e.g., event, trip, or driver levels). For example, if the data are aggregated to the trip level, questions regarding trip-specific research questions can be addressed. At each level of data reduction some variables are consistent across the whole trip (e.g., the driver's gender), and other variables are not consistent across the trip (e.g., distraction). The categorization of the factors addressed in each question (from Figure A.1) was refined further to identify *static* and *dynamic* characteristics within each category of variables.

Dynamic characteristics are variables that can vary during the time period of interest (e.g., a trip or an event). For example, a driver can be distracted for only a portion of the trip; hence distraction is a dynamic variable. The curvature of the road, the type of pavement markings, and the average vehicle speed would also change within a trip.

Static characteristics are variables that are relatively constant across the time period of interest. For example, at the trip level, driver's age, the vehicle's make and model, and the environment (e.g., region or state) are static characteristics. At the event level, the driver's age and gender and the vehicle's make and model, as well as the road type, pavement markings, and visibility, are static.

Using the dynamic–static perspective identifies a combination of driver factors and nondriving activities that can be collapsed into a single category that represents both dynamic and static influences at the trip and event levels (see Figure A.2). Cells in Figure A.2 noted as N/A (not applicable) have no static or dynamic variables at the specified level of aggregation. At the trip level, there are no static roadway variables because, from the driver's perspective, the roadway is expected to change continuously within a trip. However, at the event level (e.g., lane departure) the roadway variables are static (e.g., road curvature, pavement markings) during the event. Likewise, at the event level, there are no dynamic environmental variables. In this context an event is a 5- to 15-second period surrounding a notable state change. The distinction of dynamic and static is based on the time constant of the variables relative to the time period over which the data are aggregated. As an example, visibility can change on the order of minutes, making it a dynamic variable at the trip level. But at the event

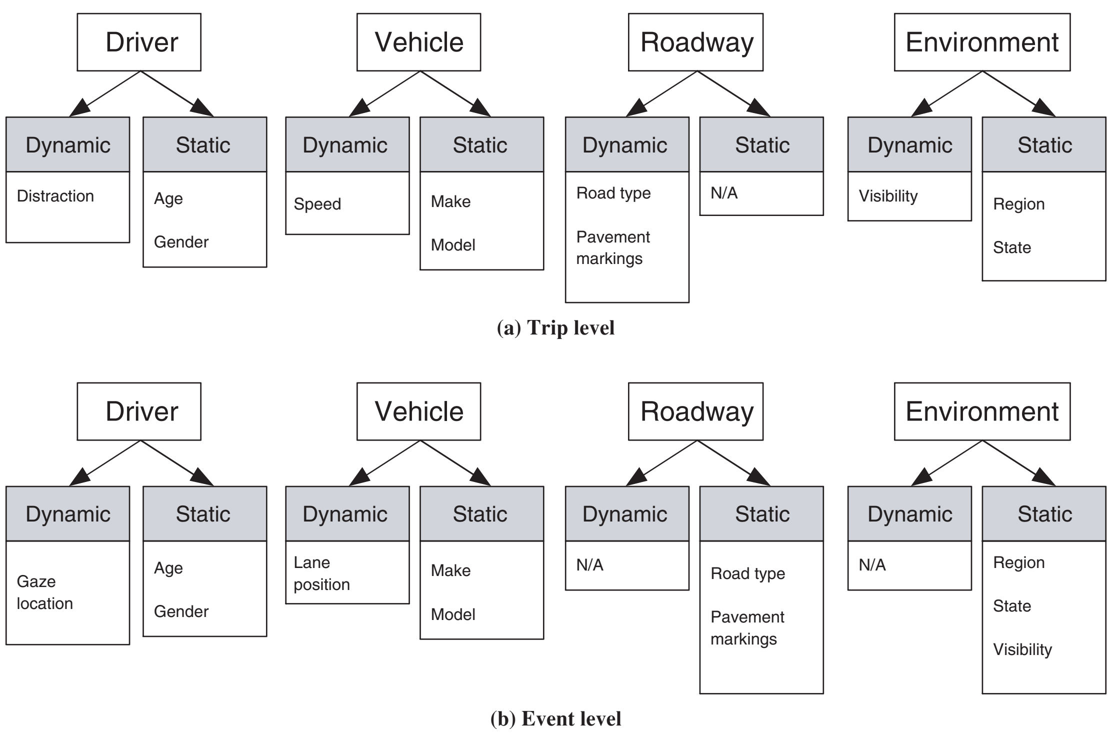


Figure A.2. Examples of dynamic and static factors that relate to driver, vehicle, roadway, and environmental variables at the trip level and event level.

level, visibility is considered static because it changes very slowly within the time period of the event.

Development of Global Research Questions

Research questions from the S01 and S05 projects were independently organized into five groups based on common themes related to

- Similar safety outcomes;
- Similar explanatory variables;
- Relationship to crash surrogate measures;
- Dynamic and static characteristics; and
- Combinations of these four subjects.

Based on the commonalities within each group of research questions, a broader set of global research questions (GRQs) was generated that represents the summation of the individual specific research questions (Figure A.3). All original S01 or S05 questions were unchanged, except to correct typographical errors. The S01 and S05 questions were combined to form one matrix that represented all of the research questions.

The outcome of this task was 27 GRQs (see list in Table A.1 on p. 52). Several S01 contractors also provided feedback on the categorization and wording of the global questions. Because the GRQs were developed based on the specific S01 and S05 questions in each grouping, some of the global questions may not actually be as broad as one might expect. For example, one global question ("How does the turn-lane configuration influence behavior and crash risks?") is specific to turn lanes as a result of the nature of the seven site-specific questions from the S05 contractors that did not seem to fit in other global questions but were inclusive of turn lanes (e.g., protected and unprotected phases, turn lanes, and bays).

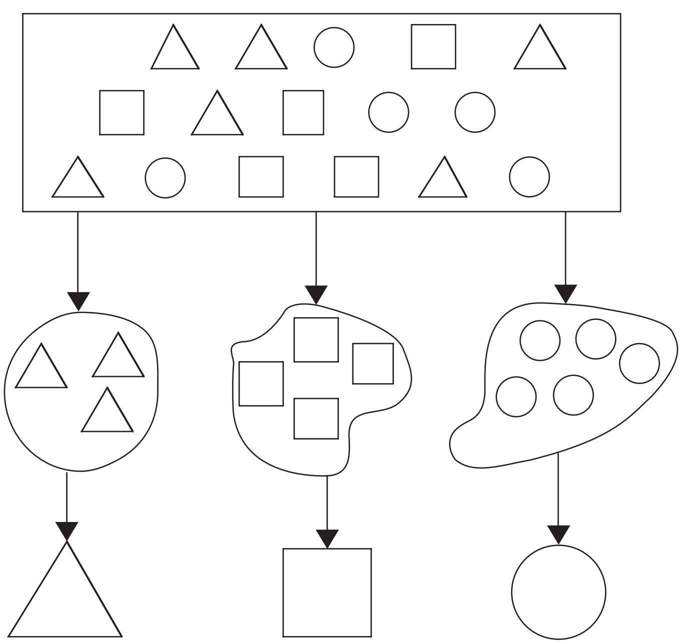


Figure A.3. Process of generating representative research questions through identifying similarities between research questions.

During this process, the wording of the GRQs and the classification of the original research questions were revised to ensure proper grouping and representation of the variables included in each S01 and S05 question. For example, at one point the specific questions related to GRQ 18 all began with "What is the relative risk of. . . ." However, after further examination of each question in this group, the team recognized that the major issue being addressed relates to the relationship of various factors. Thus, the global question changed from "What is the relative risk of specific factors given the driver's involvement in nondriving-related activities?" to "What are the interrelationships of environmental, road, and driver factors with nondriving-related activities?"

Decision Tree for Prioritization

These research questions can be addressed from many broad perspectives, and they capture several analytical approaches so that researchers who enter the process at a later date will be able to dive right in. For this project, a decision tree was used to filter the global questions from a safety perspective, which is the most relevant consideration for this overall research program. Several prioritization schemes or sets of criteria based on one of three perspectives (applied, basic, or methodological) are possible for ranking research questions:

1. Applied—Questions focused on countermeasure development or evaluation, such as GRQ 2, which relates to roadway features and lane keeping. This perspective will provide immediate results that are of greatest interest to policy makers and state and federal departments of transportation.
2. Basic—Questions leading to new information on driver behavior, such as GRQ 1, which relates to the effects of dynamic driver characteristics on crashes. This perspective may well lead to better understanding of important issues about which little is known currently, such as the role of driver behavior on the likelihood of engaging in distractions. While at the core of the whole project, answers to questions from the basic perspective may not lead to immediate countermeasures, but they will be of greatest interest to researchers and policy makers.
3. Methodological—Questions relating to surrogate development and data reduction needs. This perspective will also consider whether stand-alone data sets can be developed that will address a range of analytical needs or whether each detailed analysis requires separate data reduction. Questions from the methodological perspective are vital for addressing both applied and basic questions as there is currently no

consensus regarding the most effective analytical techniques for extracting information from naturalistic data.

The goal was to prioritize the GRQs with an emphasis on safety and the application of mitigation strategies. The decision tree (Figure A.4) emphasizes questions that require data about drivers, those that have the potential to support safety interventions, and those that address large-scale morbidity and mortality consequences. Each GRQ is evaluated using the questions in this decision tree to determine a priority ranking. The priorities range from lowest priority (ranking of 8) to highest priority (ranking of 1). This decision tree will retain all questions regardless of ranking as it relates to both the basic science and analytical perspectives.

This decision tree is designed to account for any questions that can be addressed in a naturalistic study regardless of questions developed as part of S01 and S05. That is, it is designed to account for any safety-related future questions that may be generated as the SHRP 2 project progresses and as additional research questions are developed. The following sections discuss the questions that are represented as nodes in the decision tree.

Decision Node A: Is the Question Safety Relevant and Focused?

Questions that are not safety relevant or are too broad to address are unranked because they are out of the scope this project. The question progresses to the next node in the decision tree if the unit of analysis or outcomes relate to crash risk or driver behavior (which can then be related to some safety consequence).

Some of the research questions raised were too broad to be ranked with the remaining questions in this decision tree. Others have an indirect relationship to safety or are not directly linked to the goal of the SHRP 2 Safety effort: quantifying crash risk as a function of driver, vehicle, roadway, or environmental factors. These questions have been included in an unranked priority listing and should be reviewed by possible users since they do contain ideas for future research using the SHRP 2 naturalistic driving study data.

Decision Node B: Does the Question Relate to a Potentially High Number of Fatalities?

If the question does not relate to a high number of fatal crashes, it is given a priority of 7. The criterion for determining high numbers of fatalities is whether the issue is known to relate to a specific crash type that encompasses a high number of fatalities or to one of the following factors related to morbidity and mortality in motor vehicle crashes (Evans 2004):

- Speeding;
- Alcohol;
- Safety belt usage (which relates to injury severity);
- Driver inattention; and
- Fatigue.

Factors related to high numbers of fatalities but that are not driver behavior–related will progress to the next node of the decision tree for consideration. None of the GRQs included in this report filtered out at this level. However, the goal is to use this decision tree as a future theoretical framework, and number of fatalities would be an important factor to consider.

Decision Node C: Does the Question Require Data Beyond What Are Currently Available?

If the research question can be addressed using existing data sources (e.g., crash data, existing simulator data, or road studies), then it is given a priority of 6. However, if the question is related to factors that have not yet been captured (e.g., aggressiveness), are underreported or inaccurately reported in the current crash databases as a result of judgments made by the officials reporting (e.g., presence of driver distraction factors), or cannot be examined in controlled studies (e.g., changes in weather conditions), then the question progresses to the next node in the decision tree.

Decision Node D: Does the Question Require Data About Driver Behavior?

The value of naturalistic studies is their ability to capture information about the driver. Thus, if the question relates to information about the driver's behavior (e.g., scan behavior, steering wheel movements), then the question progresses to Node E and is given a higher priority. Otherwise, it stops here and is given a priority of 5.

Factors related to the driver can include driver action (e.g., braking, scanning behavior, speeding, drinking, not wearing a restraint) or cognitive state (e.g., inattention, alcohol impairment, fatigue). Driver behaviors like these are not accurately measured in most crash investigations in that they are based on after-the-fact judgments rather than direct observations. In addition, since a driver's performance and behavior can change over time, there is a need for longer-term measurements.

Decision Node E: Are Naturalistic Data the Best Way to Address This Question?

There are many ways to capture information on crashes, including test tracks, simulators, and observational data (e.g., crash databases). If a naturalistic study is not the best alternative, then the question stops here and is given a priority of 4. If the question is best addressed using naturalistic data, then it progresses to Node F and is given a higher priority. This node is included to ensure that time- and evidence-based

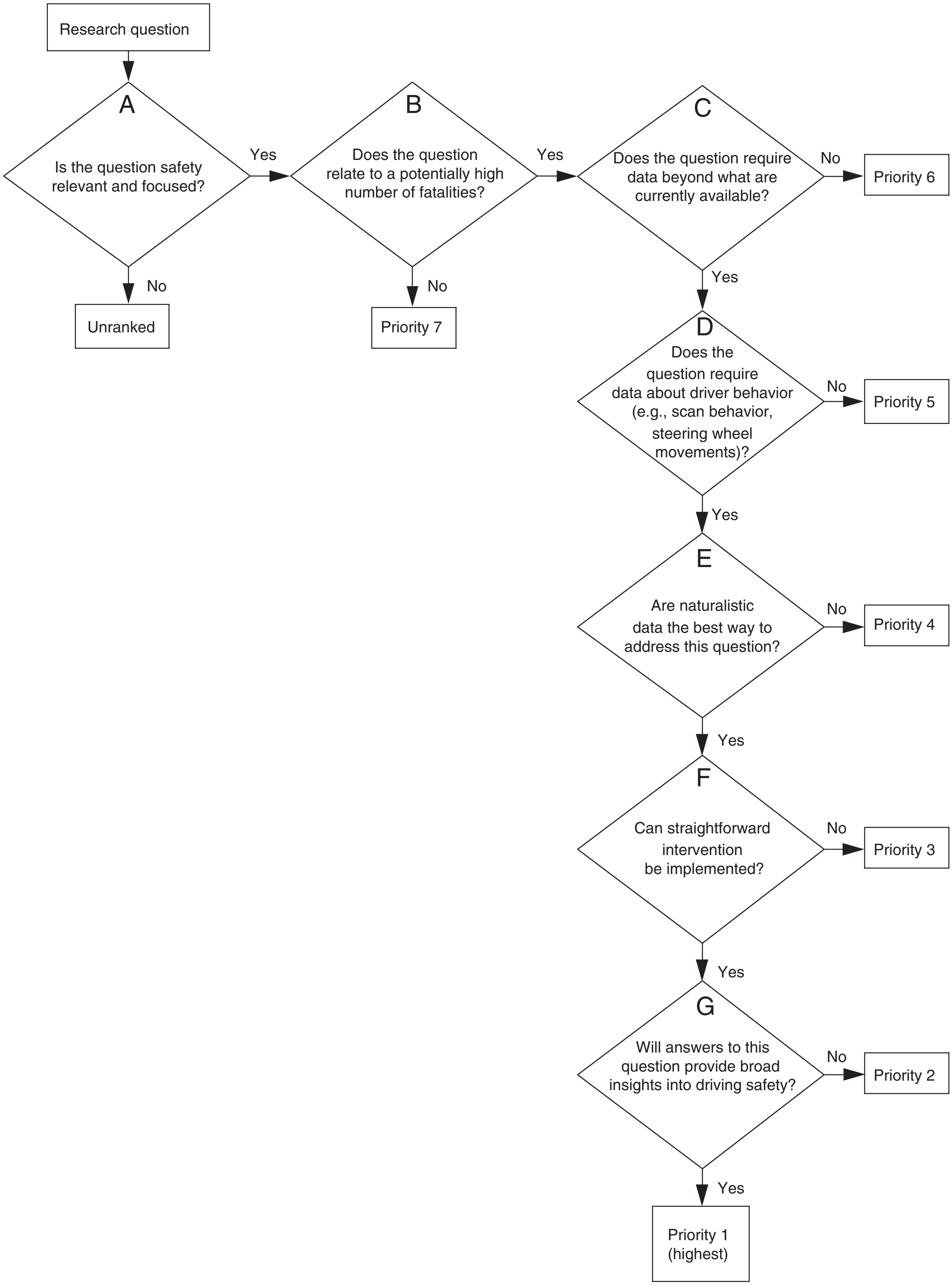


Figure A.4. Decision tree for prioritization of the research questions based on a safety perspective.

data (which can only be captured in a naturalistic study) are elevated in priority.

Decision Node F: Can a Straightforward Intervention Be Implemented?

If the GRQ can be addressed with a straightforward intervention, then it progresses to Node G. A straightforward intervention is defined here as an intervention for which a solution is (more or less) known, even though the actual implementation may be easy or difficult. Potential interventions can include infrastructure improvements, in-vehicle system enhancements, educational programs, and policy implications (e.g., installing rumble strips, enhancing an in-vehicle technology, or developing training programs). However, if no interventions could be developed based on the GRQ, then it is given a priority of 3.

Decision Node G: Will Answers to This Question Provide Broad Insights into Driving Safety?

If the GRQ provides some fundamental understanding of the basic mechanisms of motor vehicle crashes and driving behavior that can be generalized to other situations beyond the specific question addressed in the study, then it is given a priority of 1 (the highest priority); otherwise it is given a priority of 2.

Prioritized Global Research Questions

Table A.1 prioritizes the GRQs listed above by using the decision tree. Thus, the nonsafety-relevant questions are located in the lowest portion of the table. Those questions that can be answered using means outside of the SHRP 2 project are located in the lower half of the table. Full GRQs can be found in Appendix B and Appendix C.

The priority summary shows how each of the global questions filtered through the decision tree. Since the decision tree was designed to address a broad set of research questions, there were several priority levels (Priorities 6 to 8) that were not represented from this sample. This was a result of the largely infrastructure-based questions from S01 and S05. Future questions will likely emerge as part of the S02 refinement. If those new questions fit into the existing global questions, then the priority will already be set. If a new question is outside of the current set of global questions, a new high-level question would be created and run through the decision tree.

Some of the GRQs provide insights to driver behavior or driving performance but were left unranked because they are not directly related to safety. These questions are as follows:

- How does the speed that a driver selects influence the driver's other behaviors or actions?
- How do roadway features influence driver performance and behavior?
- How does driver fatigue affect driving performance?
- How do the number and type of passengers influence the driver's behavior?
- How does inattention affect driving behavior?

Although some readers may feel that these questions deserve a higher priority, other similar questions directly related to safety were ranked more highly based on the decision tree. These include the following:

- How does driver fatigue influence the likelihood and type of crashes? (Ranked Priority 1.)
- How does driver distraction influence crash likelihood? (Ranked Priority 1.)
- How do roadway features influence crash likelihood? (Ranked Priority 2).

In addition, one GRQ (Question 9) consists of two questions:

- GRQ 9a: What variables or pre-event factors are the most effective crash surrogate measures?
- GRQ 9b: What explanatory factors are associated with crashes or crash surrogates and what analytical models can be developed to predict crash or crash surrogates?

These questions are related to crash surrogate measures, effective associations between variables, and to analytical models based on these associations. Thus GRQ 9a and 9b are grouped such that this connectivity is salient.

Challenges and Limitations: Verification of Research Themes with a Lexical Analysis

Accurately capturing the central themes of the research questions represented a major challenge that arose when developing the GRQs from the diversity of questions from the S01 and S05 contractors. The questions from the S01 contractors were developed from an analytical perspective, while the S05 contractors used a data-user perspective. In both cases, a large number of specific research questions were reviewed to identify representative GRQs. The resulting global questions reflect the subjective judgment of several researchers and thus may reflect cognitive biases and limits. At the least,

Table A.1. Initial Prioritization of the Global Research Questions Based on a Safety Perspective

Question	General Rating	Initial Priority	Global Research Question
1		1*	How do dynamic driver characteristics, as observed through driver performance measures, influence crash likelihood?
2		1*	What impacts do roadway countermeasures have on lane-keeping performance?
3		1*	How does driver distraction influence crash likelihood?
4		1*	How do aggressive driving behaviors influence crash likelihood?
5		1*	How does driver fatigue influence the likelihood and type of crashes?
6		1*	How do advanced driver support systems influence crash likelihood?
7		1*	What is the influence of driver impairment on crashes and driver errors?
8		1*	How does the turn-lane configuration influence behavior and crash risks?
9a		1*	What variables or pre-event factors are the most effective crash surrogate measures?
9b		1*	What explanatory factors are associated with crashes or crash surrogates, and what analytical models can be developed to predict crashes or crash surrogates?
10	No broad insights	2*	How do roadway features influence crash likelihood?
11		2*	How do signage, lighting conditions, and other traffic control–related countermeasures influence crash likelihood and driver performance?
12	No straightforward intervention	3*	How do static driver characteristics influence crash likelihood?
13	Naturalistic data not the best	4*	How do static driver characteristics, as observed through driver performance measures, influence crash likelihood?
14		4*	What are the relationships between driver behavior, performance, crash types, crash likelihood, and population-attributable risk for each factor contributing to crashes?
15		4*	How do individual differences (e.g., age, gender, or speed selection) influence lane-keeping performance?
16		4*	How do traffic and traffic volume influence intersection negotiation, lane-keeping performance, and crashes?
17	Crash or simulation sufficient	6	Do vehicle characteristics influence crash likelihoods or driver behaviors?
18		6	What are the interrelationships of environmental, road, and driver factors with nondriving-related activities (e.g., technology, OEM, or nomadic devices)?
19		6	How does seatbelt use vary with different levels of enforcement and in different jurisdictions?
20	Nonsafety related	Unranked	General or very high-level questions.
21		Unranked	How else can naturalistic driving data be used?
22		Unranked	How does the speed that drivers select influence other driver behaviors or actions?
23		Unranked	How do roadway features influence driver performance and behavior?
24		Unranked	How do the number and type of passengers influence the driver's behavior?
25		Unranked	How does driver fatigue affect driver performance?
26		Unranked	How does inattention affect driver behavior and performance?
27		Unranked	What nonsafety-related but useful information can be obtained from these data?

*Indicates relevance to goals of SHRP 2.

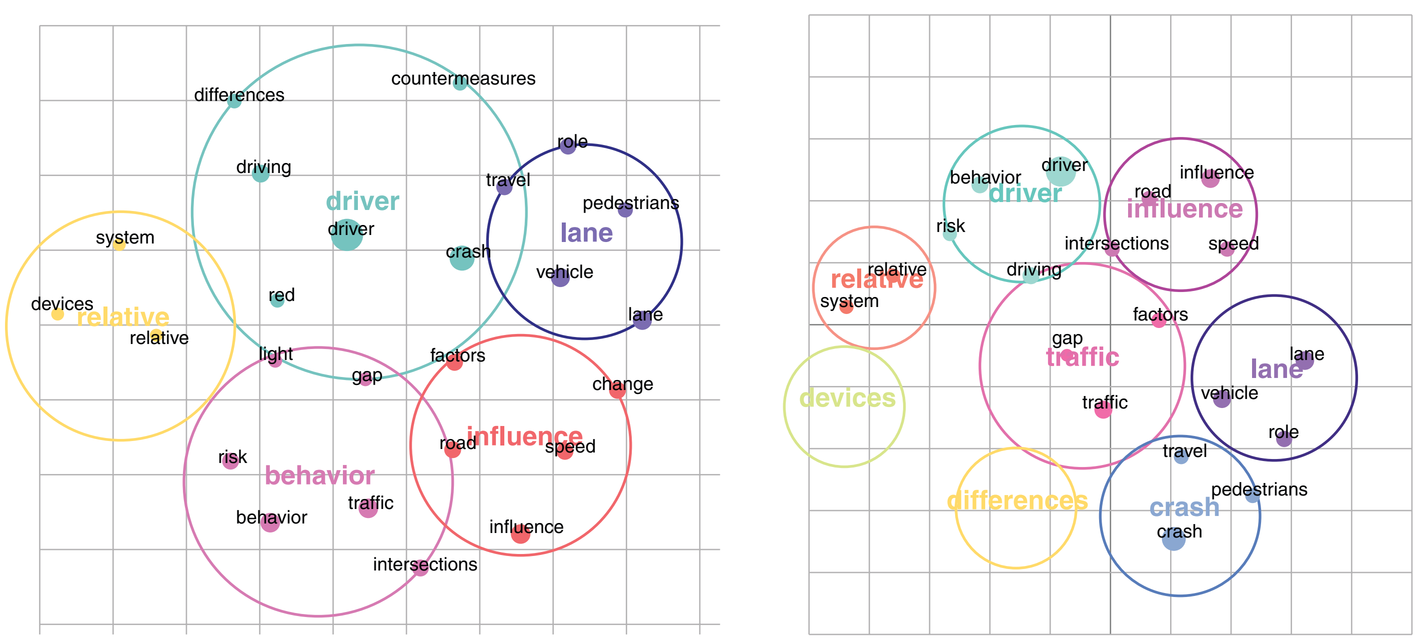
these questions reflect one of several perspectives that might be used to aggregate the questions.

Lexical analysis techniques provide a computational approach to understanding the content of the research questions provided by the S01 contractors and Virginia Tech Transportation Institute. Word frequency and word co-occurrence can identify key themes, concepts, and their connections. Because lexical analysis identifies central themes of the research questions independently of the subjective method used to identify the global questions, it offers a means of verifying the relevance of the GRQs.

This analysis used Leximancer, a software tool that employs a two-stage approach to lexical analysis (Smith and Humphreys 2006). The first stage is a semantic analysis and the second is a relational analysis. The semantic analysis uses a Bayesian co-occurrence metric to consider how frequently words occur together and how frequently they occur apart. The relational analysis uses the results of the semantic analysis and a naïve Bayesian algorithm to code segments of text. The result of this two-stage analysis is a statistical description of the co-occurrence of concepts and the related text. This information provides the basis for identifying themes, which are labeled by a highly connected word that dominates the region. The number of themes is a parameter that can be adjusted in the analysis.

The input to the analysis was a file containing only the research questions without any labeling or grouping. Co-occurrence and proximity of concepts reflect how frequently particular words occur within each research question. Figures A.5 and A.6 are the outcomes of the analysis for the S01 and S05 questions, respectively. The S05 contract questions are shown separately with six and eight themes as a comparison. The general themes are represented as circles (e.g., animals, lane, behavior) and concepts (e.g., vehicle, gap, driving) as points within the circles. More frequently occurring themes and concepts are shown as darker words and circles. The proximity of concepts and themes represents how similar they are, as determined by how often they co-occur. For example, *driver* and *behavior* are similar themes by virtue of their spatial proximity, whereas *influence, lane,* and *behavior* are not.

The five-theme grouping has four major themes (driver, behavior, influence, and lane) and one minor theme (relative). Concepts are identified from sets of words that tend to occur in similar contexts. For example, in the five-theme grouping on the left side of Figure A.5, the concept of *lane* reflects association of words such as vehicle, pedestrian, and travel. Map B, featuring eight themes for the same S05 questions, shows a generally similar pattern. In both Map A and B, the themes *driver, influence,* and *lane* dominate. The prominence of *lane* is somewhat surprising and reflects a substantial focus on the key activity of lane keeping in the development of these questions. These spaces show the centrality of the driver in the questions, with road, traffic influences, and behavior playing important roles. The themes in the high-priority research questions are generally consistent with the themes in Figure A.5, particularly the themes of lane keeping, support systems, and driver behavior. Missing from the global questions is the general theme of traffic and drivers' management of their position relative to other vehicles (e.g., gap acceptance and following distance).



Map A　　Map B

Figure A.5. Relationships among S05 contractor questions (five and eight themes).

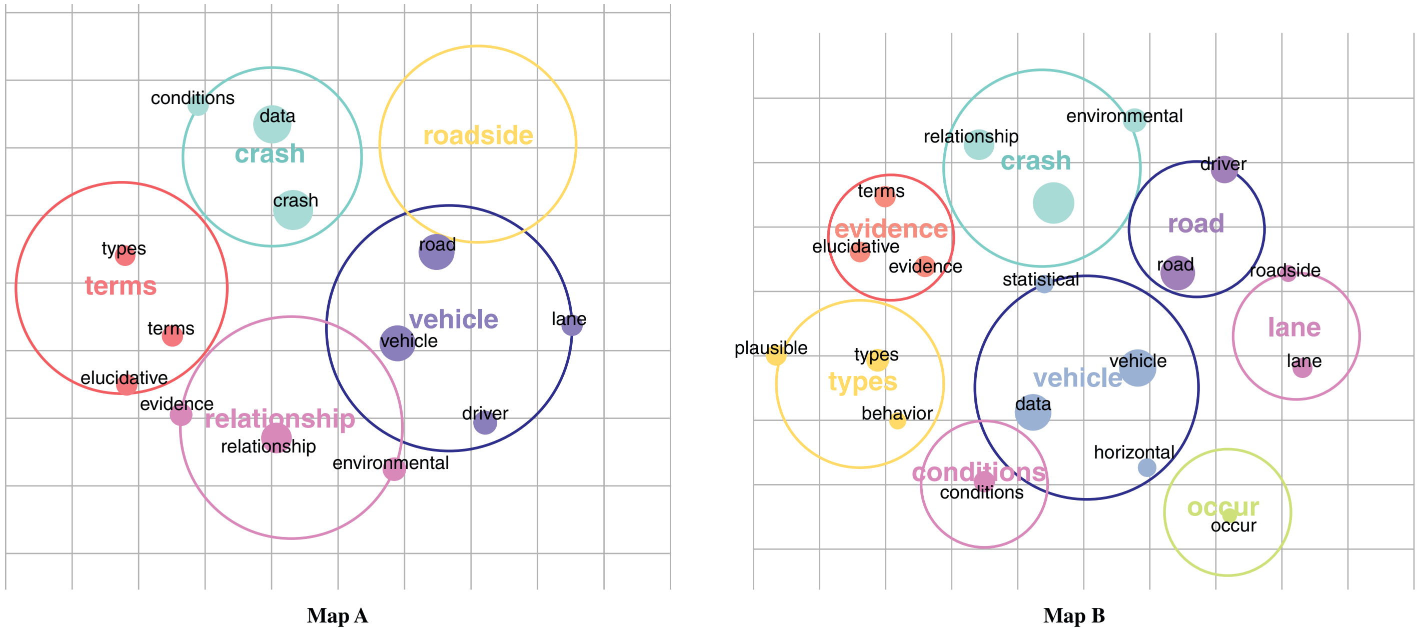


Figure A.6. Relationships among S01 contractor questions (five and eight themes).

Figure A.6 shows maps of the five and eight themes associated with the S01 questions. Map A is a set of five themes dominated by *crash, terms, relationship,* and *vehicle.* Map B shows eight themes dominated by similar themes of *crash, evidence, vehicle,* and *road.* In both maps, the space defined by these themes roughly separates into an area on the left of associated data and extracting meaning from data, as indicated by the concepts of *elucidative, data,* and *relationship,* and on the right of factors affecting safety, including *vehicle, lane,* and *road.* Many of the themes in Figure A.6 are not directly reflected in the global questions, as these themes reflect the basis for answering the questions. These themes may play a greater role in Phase 2 of this project, when the emphasis will shift to identifying promising analytic techniques that can provide *evidence* regarding the *conditions* and *relationships* that contribute to crashes.

The themes, concepts, and their relationships are strikingly different for the two sets of questions. With the S05 questions, the driver and driver behavior hold a central position, whereas themes associated with understanding relationships play a dominant role in the S01 questions. The S01 questions also focus on road and roadway infrastructure to a much greater extent than do the S05 questions. The two sources of questions provide complementary perspectives on issues to be addressed in a naturalistic study. Any study should address questions from both sources. The two perspectives also demonstrate how perspectives from different constituencies can be radically different. In this case, the difference may reflect the requirements of the particular contracts the S01 and S05 contractors were aiming to satisfy. A broader survey of stakeholders might produce important questions and perspectives not represented in the current set of questions.

The lexical analysis only provides one alternate perspective and does not support any firm conclusions. In some cases, the themes reflect idiosyncratic word choices of the authors, such as the repeated use of a particular word (e.g., *elucidative*). In addition, some words have quite different meanings depending on their context, such as *terms* as used in the phrase *in terms of.* The co-occurrence algorithms that underlie the lexical analysis do not always produce a meaningful interpretation of such phrases when they are used to label themes. These limits demonstrate the need for subject matter experts to create GRQs. At the same time, the lexical analysis suggests several themes, such as *traffic* and the broad analytic issue of identifying relationships from data, which should be considered in the next phase of this project. Specifically, the general groupings of behavior, crashes, and relationships/influences suggest a central theme of identifying surrogate measures that effectively relate contributors to driving safety to safety-relevant changes in driver behavior.

Conclusions

The GRQs generated in this report were based on the specific questions posed by the S01 and S05 contractors, questions that arose from very different focuses. As the tables in Appendices B and C show, the S01 questions were more focused on transportation and infrastructure questions. The S01 questions did include some driver-related questions, but not to the specificity provided by the S05 contractors. The systems-based approach used to classify the research questions by driver, vehicle, roadway, and environment factors as described in the introduction to this report (Figure A.1) provides a means to illustrate these gaps. For example, no GRQs consider the feedback loops in Figure A.1. That is, no question addressed how driving behavior changes over time and how drivers adapt to changing conditions. Other research questions that may also be meaningful based on this analysis are the following:

- How do advanced driver support systems mitigate crash likelihood when a driver is impaired? (Estimated priority of 1.)
- How does inattention interact with fatigue to influence crash likelihood? (Estimated priority of 1.)
- How do surrounding vehicles adapt to the impairment of the driver? (Estimated priority of 1.)
- How do drivers adapt their behaviors (and engagement) with driver support systems over time? (Estimated priority of 3.)

While it is unclear how many participants in the naturalistic driving study will have driver support systems in their vehicles, these drivers can still provide important insights.

Using the systems-based approach to aggregate the specific research questions posed by the S01 and S05 contractors offers insights into the commonalities and differences in the types of research questions that potentially can be addressed in a naturalistic study. The initial prioritization provides a means to rank these questions within the scope of this study. Questions that were considered too broad for ranking or not directly related to the goals of this effort are considered out of scope of the project. However, they may be useful in guiding future research that uses the SHRP 2 naturalistic driving data.

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APPENDIX B

Global Research Question Priorities

Priority 1

Global Research Question 1: How Do Dynamic Driver Characteristics, as Observed Through Driver Performance Measures, Influence Crash Likelihood?

These questions relate to how driver states (e.g., aggressiveness, drowsiness, willingness to engage in distracting activities) influence specific driver performance measures and subsequent crash likelihoods. This global research question represents 12 individual research questions:

- Can driving control performance for various states be categorized more simply (i.e., good and bad, or risky and nonrisky)?
- Can various driver states (e.g., drowsy, aggressive, distracted, engaged) be identified from naturalistic driving data?
- How do driver behavior and response influence subsequent events and outcomes after a vehicle initially leaves the roadway?
- What is the relationship between measures obtained from pretest assessment batteries (e.g., a life stress test) and the frequency of engagement in distracting behaviors while driving?
- Does there appear to be any correlation between willingness to engage in distracting behaviors and life stress sources, personality characteristics, or ability to focus attention?
- How often and under what circumstances do drivers drive while fatigued?
- What are the individual differences, both between and within drivers, related to fatigue? Fatigue sensors?
- How often and under what circumstances do drivers drive while under the influence of alcohol?
- What are the individual differences, both between and within drivers, related to alcohol use? Passive alcohol sensors?
- What are the differences in demographic data, test battery results, and performance-based measures between attentive and inattentive drivers?
- How might knowledge of demographic differences in attentive and inattentive drivers be used to mitigate the potential negative consequences of inattentive driving behaviors?
- Could information concerning demographic differences in attentive and inattentive drivers be used to improve driver education courses or traffic schools?

Global Research Question 2: What Impacts Do Roadway Countermeasures Have on Lane-Keeping Performance?

These questions relate to the effectiveness of roadway-based crash countermeasures on lane maintenance. This global research question represents 13 individual research questions:

- Are drivers more likely to lane keep on roadways with edge-line rumble strips?
- How do lane-edge markings affect lane keeping?
- What is the influence of rumble strips in measured lane-keeping performance?
- Are centerline rumble strips beneficial in improving lane-keeping performance?
- Would centerline rumble strips be effective in preventing head-on collisions?
- What is the influence of special curve warning markings (e.g., on-pavement markings)?
- What are the potential impacts of rumble strips on non-freeways?
- Would rumble strips be effective without the paved shoulder?
- Does rumble strip noise reduce the deviation from the lane, or does it function as an alarm to improve subsequent alertness and lane keeping after encountering the rumble strip?
- Do rumble strips reduce the frequency and duration of lane deviations, making successful recovery more likely,

and/or does a lane departure over a rumble strip improve subsequent lane keeping and decrease the frequency of lane departures?
- How does the driver's positioning of the vehicle affect lane keeping, and how is this related to the efficacy of edge marking and rumble strips?
- Are drivers less likely to pass with centerline rumble strips?
- How likely are drivers to overcorrect or countersteer away from edge rumble strips so that they avoid a road departure but encroach into an adjacent lane?

Global Research Question 3: How Does Driver Distraction Influence Crash Likelihood?

These questions relate to how driver distraction influences the likelihood of a driver being involved in a specific crash type (e.g., run-off-road (ROR), pedestrian, object, animal, and head-on crashes). This global research question represents nine individual research questions:

- Is driving-control-performance pattern different for the same driver when distracted or not distracted (e.g., on cell phone or not on cell phone)?
- How do driver distractions affect involvement in ROR collisions?
- What is the role of inattention in collision risk at intersections?
- What is the role of driver inattention in rear-end crashes (i.e., striking a vehicle in the travel lane)?
- To what degree does the lead vehicle driver (i.e., the driver in the instrumented vehicle) contribute to the crash as a result of driver inattention?
- What is the role of driver inattention as it relates to crashes involving pedestrians, objects, or animals in the travel lane?
- What is the role of inattention (i.e., as a result of focusing on a secondary task) in lane-change or merge crashes?
- What is the role of inattention in head-on crashes?
- What is the role of inattention (i.e., as a result of focusing on a secondary task) in backing crashes?

Global Research Question 4: How Do Aggressive Driving Behaviors Influence Crash Likelihood?

These questions relate to the specific driver state of aggression and how this state leads to crash likelihood for specific crash types (e.g., ROR, backing, or rear-end crashes). This global research question represents 13 individual research questions:

- What is the relative contribution of aggressive driving to inappropriate gap acceptance?
- What is the relative contribution of aggressive driving to red light running?
- What is the role of aggressive driving in rear-end crashes (i.e., striking a vehicle in the travel lane)?
- To what degree does the lead vehicle driver (i.e., the driver in the instrumented vehicle) contribute to the crash as a result of aggressive driving?
- What is the role of aggressive driving as it relates to crashes involving pedestrians, objects, or animals in the travel lane?
- What is the role of aggressive driving (e.g., approach speed, gap with lead vehicle when change is initiated) in lane-change or merge crashes?
- What is the role of aggressive driving (e.g., speeding, being in a hurry) in backing crashes?
- What is the influence of aggression or aggressive driving on lane keeping?
- What is the influence of aggression or aggressive driving on ROR events?
- How does aggressive driving behavior affect crash risks?
- What is the role of aggressive driving in passing-maneuver errors?
- How does aggressive driving behavior affect near-crash risks?
- Why do aggressive driving behaviors occur, and how do they relate to ROR crashes and near crashes?

Global Research Question 5: How Does Driver Fatigue Influence the Likelihood and Type of Crashes?

This global research question represents six individual research questions related to fatigued drivers:

- What is the role of driver fatigue in rear-end crashes (i.e., striking a vehicle in the travel lane)?
- To what degree does the lead vehicle driver (i.e., the driver in the instrumented vehicle) contribute to the crash as a result of driver fatigue?
- What is the role of driver fatigue as it relates to crashes involving pedestrians, objects, or animals in the travel lane?
- What is the role of driver fatigue in head-on crashes?
- What is the role of driver fatigue in lane-change or merge crashes?
- What is the role of driver fatigue in backing crashes?

Global Research Question 6: How Do Advanced Driver Support Systems Influence Crash Likelihood?

These questions relate to how advanced driver support systems (e.g., antilock braking system [ABS], adaptive cruise control [ACC], and collision-warning system [CWS]) influence the likelihood of crash surrogate events. This global research question represents 23 individual research questions:

- Are drivers less likely to lose control with antilock braking systems?
- How do drivers react in a ROR crash or near crash in terms of precrash maneuvers (with or without a crash-warning system)?
- How do crash-avoidance systems, including electronic stability control ESC, affect driver behavior in ROR or rear-end crash scenarios?
- Can ACC help reduce ROR crashes?
- What are the benefits of a CWS deployed in the fleet when a striking vehicle is in the travel lane?
- What are the benefits of other vehicle countermeasures (e.g., brake assist) in the fleet?
- Does vehicle CWS contribute to crashes?
- Do other types of vehicle countermeasures, such as brake assist, lead to struck secondary crashes?
- Given that most objects, pedestrians, and animals produce no radar signature, is there any indication that reliance on a CWS is a detriment?
- Are there benefits to enhanced vision systems at night (e.g., infrared headlamps or differing types of head lighting) in determining the presence of pedestrians or objects in the travel lane?
- Are there any forward CWS benefits related to head-on crashes?
- What are the potential benefits of other vehicle countermeasures (e.g., brake assist) in the fleet related to head-on crashes?
- What are the benefits of lane-change aids and a CWS?
- How does ACC use (compared with cruise control) affect speed compliance?
- How does ACC use affect eyes-off-the-road time (i.e., drivers allowing themselves to be more distracted)?
- Where do drivers look when they receive these alerts or activate these systems?
- How and how fast do drivers respond when they receive these alerts or activate these systems?
- Do these alerts and/or systems offer a safety benefit for impaired or drowsy drivers?
- What are the potential benefits of radar and ABS in reducing the incidence and severity of automobile accidents?
- How do crash-avoidance systems, including ESC, affect driver behavior in ROR or rear-end crash scenarios?
- How can the effectiveness of back-up warning algorithms be tested?
- Are back-up warning systems of different types (e.g., cameras) beneficial? What aspects make them beneficial or detrimental?
- What is the driver response, in terms of immediate control input and subsequent speed selection, to in-vehicle CWS warnings?

Global Research Question 7: What Is the Influence of Driver Impairment on Crashes and Driver Errors?

These questions focus on the effect of the driver being in an impaired state on crash types and driving errors. This global research question represents eight individual research questions:

- What is the relative contribution of impairment to inappropriate gap acceptance?
- What is the relative contribution of impairment to red light running?
- What is the role of driver impairment in rear-end crashes (i.e., striking a vehicle in the travel lane)?
- To what degree does the lead vehicle driver (i.e., the driver in the instrumented vehicle) contribute to the crash as a result of other driver impairment?
- What is the role of other driver impairment as it relates to crashes involving pedestrians, objects, or animals in the travel lane?
- What is the role of other driver impairment in head-on crashes?
- What is the role of other driver impairment in lane-change or merge crashes?
- What is the role of other driver impairment in backing crashes?

Global Research Question 8: How Does the Turn-Lane Configuration Influence Behavior and Crash Risks?

These questions relate to how intersection negotiation performance is influenced by roadway (specifically intersection) traits. This global research question represents seven individual research questions:

- What are the safety effects of protected and unprotected turn lanes?
- How do turn lanes change the pattern of conflict at intersections?
- Do offset left-turn lanes (bays) affect turn behavior (e.g., gap acceptance and the decision to turn)?
- How much do left-turn lanes and/or signal phases reduce collision risk?
- How much do left-turn lanes reduce collision risk, with and without left-turn signal phases?
- How much do right-turn lanes reduce collision risk, with and without right-turn signal phases?
- How much do right-turn lanes and/or signal phases reduce collision risk?

Global Research Question 9a: What Variables or Pre-Event Factors Are the Most Effective Crash Surrogate Measures?

These questions relate to different factors or events that can be used as crash surrogate measures most effectively. This global research question represents eight individual research questions:

- For a given crash type, are any conflicts directly informative about crashes in the sense that they are generated from similar sets of background conditions?
- Which noncrash incidents can be used as crash surrogates to assess risk for road-departure crashes?
- Do naturalistic driving data contain measurable episodes of disturbed control? (Broad research question.)
- Do objective measures of disturbed control from naturalistic driving data, together with highway geometric factors, off-highway factors, and environmental factors, satisfy criteria for crash surrogates, that is, are they related to actual crashes? (Broad research question.)
- If so, are these conflicts more frequent, as frequent, or less frequent than actual crashes?
- Once a road departure occurs, what is the next most common sequence of incidents and outcomes (e.g., safe recovery and return to roadway, minor conflict with safe return, near miss with safe return, property damage accident, or injury accident)?
- Once a road departure occurs, what kinematic variables can be used to define the different outcomes (e.g., road-departure crash, near crash, conflict, or incident)?
- What measures exist in naturalistic driving data that directly measure disturbed control?

Global Research Question 9b: What Explanatory Factors Are Associated with Crashes or Crash Surrogates, and What Analytical Models Can Be Developed to Predict Crashes or Crash Surrogates?

These questions relate to different factors that can be effectively associated with crashes and crash surrogates. This global research question represents 14 individual research questions:

- What kinematic measures of driving control performance are available in the naturalistic driving data, and what are the levels of accuracy in those measures?
- What kinematic variables can be used to determine when a road departure is likely or imminent?
- How can severity-related factors conditioned on an event having occurred be most effectively examined?
- Are other driving control metrics necessary (in addition to vehicle kinematic measures) to identify disturbed control?
- Are there measures of driving control performance in existing FOT data that depend on highway factors in a way that is consistent with single-vehicle road-departure crash frequencies?
- What factors are associated with unconditional event occurrences?
- What is the nature of the relationship between crashes, near crashes, incidents, and pre-event maneuvers and precipitating factors, driver factors, contributing factors, and environmental factors?
- For a given crash type and data source, is it possible to identify a plausible structural model? If so, is the data source sufficiently rich to support estimation of the values taken on by the model variables for crashes and interesting noncrashes?
- If it is not possible to identify and validate plausible models, what additional data would be needed to support the estimation of values for crashes and interesting noncrashes?
- What hierarchical structure (statistically speaking), if any, exists in the manner in which these relationships need to be explored?
- Do single-vehicle road-departure crashes occur only under conditions of disturbed control? (Broad research question.)
- Can satisfactory crash risk predictions be made based on vehicle, driver, and highway factors available from naturalistic driving data (e.g., via extreme value theory), or do additional roadside and environmental factors need to be introduced?
- Does coupling roadside factors to naturalistic driving data improve correlation with actual crashes?
- What kinds of elucidative evidence emerge from the analysis of roadway departure crashes in terms of the relationship between crashes, near crashes, and incidents with situational factors, and what (statistical) hierarchical structure exists within these relationships?

Priority 2

Global Research Question 10: How Do Roadway Features Influence Crash Likelihood?

These questions are similar to those in Question 14, except that this set of questions relates roadway features to crash surrogates. This global research question represents 15 individual research questions:

- What statistical tests are available to determine if measures of driving control performance in naturalistic data and single-vehicle crashes depend on geometric features in a consistent way?

- What key driver, roadway, and environmental factors affect lane keeping that may result in a road departure?
- What is the influence of life events and factors on ROR events?
- What combination of driver, vehicle, traffic, environmental, and roadway factors leads to rear-end crashes (i.e., striking a vehicle in the travel lane)?
- What environmental factors influence whether a vehicle actually departs the roadway once a road departure is precipitated?
- To what extent do roadway features influence whether a vehicle actually departs the roadway once a roadway departure is precipitated?
- How frequently do road departures occur given a specific set of roadway variables?
- Are any specific highway features (e.g., isolated horizontal curves, sharp horizontal curves, sequences of horizontal curves, and combinations of horizontal and vertical curves) associated with single-vehicle road-departure crashes and specific driving control performance measures?
- How is the occurrence of ROR events under different driving conditions and roadway geometries related to ROR causal factors and driver inputs during ROR maneuvers?
- How are ROR crashes affected by different roadway geometries (e.g., shoulder width)?
- How are ROR crashes and near crashes affected by different roadway features (e.g., shoulder width, signage, and delineators)?
- What is the influence of roundabouts on pedestrian crashes?
- Are there methods of identifying potentially dangerous intersections before the occurrence of high collision rates?
- What is the role of curves and grades in lane-change or merge crashes?
- What is the role of length and type of ramps (e.g., weave) in lane-change or merge crashes?

Global Research Question 11: How Do Signage, Lighting Conditions, and Other Traffic Control–Related Countermeasures Influence Crash Likelihood and Driver Performance?

These questions relate to the effect that pavement markings, signage, reflectors, and other traffic control devices have on both driver performance variables and on the likelihood of crash surrogate events. This global research question represents 26 research questions.

Traffic Control Signal–Related Questions

- Would there be any safety benefits of alternative signal-control strategies? Adaptive signal-control timing? Alternative signal timing?
- How do traffic control variables influence braking behavior at intersections?
- How do traffic control variables influence speed behavior at intersections?
- How do traffic control variables influence compliance with traffic controls at intersections?
- What is the influence of closed-loop signal systems?
- What is the safety effect of offset, split, and cycle time for fixed-time signals?
- What is the safety effect of detector placement and signal-timing parameters for semiactuated signals?
- What are the safety effects of different-sized signal heads (8 in. versus 12 in.), number of signals per approach lane (is one necessary for each lane?), and signal placement (overhead versus nearside)?
- How does operating speed affect deceleration for traffic signals?
- How do drivers react to different intersection signal installations (phasing and timing operations)? Do certain types appear better?
- What are the effects of protected left-turn phasing at high-speed rural intersections?
- What is the prevalence of straight crossing path traffic signal violations?
- Do traffic control devices countermeasures (e.g., signal phase related) lead to struck secondary crashes?

Other Questions

- How does signage influence braking behavior at intersections?
- Are road departures less likely when pavement markings are more visible?
- Does roadway lighting result in fewer nighttime road departures?
- Does signage have any impact on frequency of road departures (e.g., large chevrons may alert drivers to an adverse horizontal curve)?
- What are the effects of in-pavement warning lights at pedestrian crossings?
- What is the effectiveness of various countermeasures (e.g., strobe lights to red lights) to reduce intersection-related crashes?
- Could new technology, such as automated all-red signal extension systems, infrastructure to inform drivers of acceptable gaps in traffic, or dilemma-zone detection at high-speed intersections, reduce intersection crashes?
- How do traffic control variables influence gap acceptance at intersections?
- How does signage influence gap acceptance at intersections?
- What are the benefits of roadway lighting, and under what circumstances does roadway lighting increase drivers'

ability to see pedestrians, animals, or objects in the travel lane?
- What are the benefits of reflectors and reflective clothing, and under what circumstances do these items improve drivers' ability to see pedestrians, animals, or objects in the travel lane?
- How long does it take for drivers to respond to speed limit reductions?
- Are drivers influenced by speed reduction signs, and if so, how? Do drivers travel at higher speeds on secondary streets and highways after long-distance travel on freeways?

Priority 3

Global Research Question 12: How Do Static Driver Characteristics Influence Crash Likelihood?

These questions relate to individual driver traits (e.g., age, gender, and personality) and how they influence crash likelihoods. They also address the ability to distinguish between safe and unsafe drivers. This global research question represents seven individual research questions:

- What can be done to reduce the number of crashes and fatalities for older drivers?
- What is the influence of gender on ROR crashes?
- What is the influence of age on ROR crashes?
- What is the influence of personality (as measured by Myers–Briggs or other assessment) on ROR crashes?
- What is the influence of driving confidence (self-report) on ROR crashes?
- What is the influence of useful field of view on ROR crashes?
- Do demographics play a role in ROR crashes?

Priority 4

Global Research Question 13: How Do Static Driver Characteristics, as Observed Through Driver Performance Measures, Influence Crash Likelihood?

These questions relate to individual driver traits (e.g., age, gender, and personality) and how they influence specific driver performance measures and subsequent crash likelihoods. These questions also address the ability to distinguish between safe and unsafe drivers. This global research question represents 41 individual research questions:

Age and Gender

- Does the relative risk of different intersection maneuvers vary with driver age and gender?
- Do older drivers make fewer left turns or accept larger gaps?
- Do older drivers make fewer right turns or accept larger gaps?
- How do drivers of various age categories judge and select a gap in traffic flow to enter or cross a street or highway?
- How do differences in age, gender, and other driver traits influence variations in driving behavior?
- How do drivers of various age categories use the available acceleration lanes when entering freeways?
- What is the level of compliance by drivers of various age categories to stop signs, traffic signals, advisory speeds on curves, speed limits, and stopping for pedestrians?
- What is the relationship between drivers' involvement in crashes, near crashes, and incidents and drivers' age, driving knowledge, vision, driving experience, and vehicle familiarity?
- What are exposure differences in terms of road types, speed selection, and miles traveled across driver age and gender subgroups?
- What are the behavioral characteristics, especially in terms of driving style and visual search, which distinguish the youngest and oldest drivers from drivers aged 25 to 65 years?
- What is the influence of gender on lane keeping?
- What is the influence of age on lane keeping?

Other Questions

- In terms of elucidative evidence, what types of behavioral correlates emerge? For example, are attitudinal measurements indicative of revealed behavior in terms of headway maintenance and speed reductions?
- Are attitudinal (e.g., predisposing) measurements indicative of revealed behavior in terms of headway distance and speed reduction?
- Is there a difference in the driving control performance of good and bad drivers (or risky and nonrisky drivers) at locations with geometric features associated with high single-vehicle crash frequency?
- How does within- and between-subject variation in lane keeping compare (i.e., to what extent does one driver consistently perform better than another driver)?
- How can performance differences be quantified (e.g., as differences in the frequency and amplitude of steering and braking actions; or in terms of the frequency, duration, or amount of lane departure, time to departure, or other measures)?
- Are all drivers equally exposed to road departures?
- How do driver testing scores serve as predictors to driving performance, in particular, to lane keeping?
- What is the role of driver factors in the risk associated with inappropriate gap acceptance with crossing traffic?
- What is the role of driver factors in the risk associated with red light running and inappropriate gap acceptance situations?

- What are the intra- and interindividual differences in braking and crash-avoidance skill?
- What are the intra- and interindividual differences in willingness to pass and skill in passing?
- What are the intra- and interindividual differences in lane-change or merge behavior and skill?
- What are the intra- and interindividual differences in backing behavior and skill?
- What is the influence of personality (as measured by Myers–Briggs or other assessment) on lane keeping?
- What is the influence of driving confidence (self report) on lane keeping?
- What is the influence of risk-taking propensity on lane keeping?
- What is the influence of experience and previous motor vehicle accidents on lane keeping?
- What is the influence of life events and factors on lane keeping?
- What is the influence of experience and previous motor vehicle accidents on ROR crashes?
- Do demographics influence lane keeping?
- How do drivers adjust their behavior (relative to expected adjustments) in response to high-risk situations? Such situations may be environmental (e.g., night, slick roads from rain and snow, or fog) or personal (e.g., fatigue or alcohol intoxication).
- How do exposure differences across subgroups vary in terms of amount of travel and environment?
- How does the driving experience vary in different regions of the country and for different drivers?
- What driving styles exist across the country and within different driving conditions?
- How often, for what length of time, and in what pattern do drivers look away from the forward roadway? What are the individual differences among and between drivers?
- Can attitudes toward risk taking (or other behaviors or beliefs) versus driving style (i.e., errors, inattention, or distraction) be characterized demographically?
- How are a specific driving behavior and crash risk affected by both permanent descriptors (e.g., age, gender, driving experience, and crash record) and transitory descriptors (e.g., fatigue, other impairment, and distraction)?
- How do safe and unsafe drivers differ in demographic data, test battery results, and performance-based measures? What are the crash rate and history of violations before the study for these safe and unsafe drivers? (Some drivers may not be honest in reporting this driving history information.)
- What is the relationship between various risky driving behaviors and combinations of risky driving behaviors between low-risk and high-risk drivers?

Global Research Question 14: What Are the Relationships Between Driver Behavior, Performance, Crash Types, Crash Likelihood, and Population-Attributable Risk for Each Factor Contributing to Crashes?

These questions relate to how driver behavior, driving performance, and population-attributable risk contribute to crashes and crash likelihoods. This global research question represents 62 individual research questions:

- In order to use conflict data to predict crash probability, it is necessary to know how the selected evasive action varies as a function of background conditions. For a given crash type and data set, is it possible to identify and validate plausible models for this relationship?
- In terms of elucidative evidence, what types of behavioral correlates emerge?
- What exposure variables are available and which are the best measures to use in the analytical models? Possible exposure variables include traffic volume, traffic density, driver subpopulations (i.e., crash risk for teenage drivers compared with older drivers), and miles of travel.
- What driver actions and behaviors are present in the seconds preceding and during ROR crashes?
- Can ROR countermeasures be effectively designed to reduce crashes?
- At what point can the intersection safety effectiveness of automated speed enforcement on roads with posted speed limits be considered credible?
- What is the role of illegal maneuvers in collision risk at intersections?
- What driver actions occur in the seconds preceding and during intersection crashes and near crashes?
- What is drivers' situational awareness just before crashes (e.g., at multiple-vehicle accidents at intersections)?
- What is the role of driver factors in the risk associated with red light running and inappropriate gap acceptance situations?
- What is the relative risk of different maneuvers at intersections?
- Having defined appropriate exposure measures for each intersection maneuver, what is the relative risk of the different maneuvers?
- How does risk assessment vary based on driver behavior and intersection design?
- What effect does the intersection environment have on the driver's decision-making processes?
- How does the public perception of the attitude of law enforcement on highway safety affect intersection crashes?
- Is there greater risk for left turns?

- What is the role of driver factors in the risk associated with inappropriate gap acceptance with opposing traffic on left turns?
- What is the role of driver factors in the risk associated with inappropriate gap acceptance with opposing traffic on right turns?
- What is the relative contribution of decision errors to inappropriate gap acceptance?
- What is the relative contribution of illegal maneuvers to inappropriate gap acceptance?
- What is the relative contribution of decision errors to red light running?
- What is the role of driver factors in the risk associated with red light running?
- What is the relative contribution of illegal maneuvers to red light running?
- For willful straight crossing path signal violations, what is the nature (e.g., position and speed) of the crossing traffic?
- What is the role of following distance in rear-end crashes (i.e., striking a vehicle in the travel lane)?
- To what degree does the lead vehicle driver (i.e., the driver in the instrumented vehicle) contribute to the crash as a result of the following distance?
- What is the role of following distance as it relates to crashes involving pedestrians, objects, or animals in the travel lane?
- What is the role of sight distance in passing maneuver errors?
- How many times do drivers pass against road markings (e.g., double yellow)?
- How many times do drivers misjudge the speed or gap of approaching vehicles?
- How many times do drivers misjudge car acceleration or time available?
- What is the role of inadequate mirror check in lane-change or merge crashes?
- What is the role of no blind-spot check in lane-change or merge crashes?
- What is the role of inadequate gap in lane-change or merge crashes?
- What is the role of failure to match speed in lane-change or merge crashes?
- What is the role of failure to recognize speed differential in lane-change or merge crashes?
- What is the role of sight distance in lane-change or merge crashes?
- What is the role of failure to visually verify (i.e., over-the-shoulder check)?
- What is the role of inadequate mirror check in backing crashes?
- What is the role of failure to clear windows or improve visibility in backing crashes?
- What is the influence of factors such as backing while turning?
- What mechanisms of occupant injury exist that have been unrecognized or underemphasized?
- What baselines can be measured in frequencies, risk exposure, or behaviors against which design improvements can be compared?
- How does driver interaction with vehicle systems change over extended periods (e.g., 1 year)?
- What steering and brake inputs occur in the seconds preceding collisions?
- What is the influence of useful field of view on lane keeping?
- What is the driver reaction time and control input selection for safety-critical events?
- What is the error/accident involvement in crashes, near crashes, and incidents, and how can the driver behavior that contributed to the involvement be assessed?
- What are the response times, deceleration, braking behavior, and turn-signal use of following drivers in response to vehicles that enter the forward driving path?
- How can braking and signaling behaviors with respect to striking and struck drivers be assessed and analyzed?
- How can potential patterns in the driving performance–based measures (e.g., high longitudinal decelerations, high lateral accelerations) be assessed and analyzed?
- What new methodologies for assessing the role of human factors in accident causation can be developed?
- What driver behaviors (e.g., bracing, postural adjustments) arise immediately before a crash?
- What is the role of following distance in lane-change or merge crashes?
- What types of accidents occur when drivers are paying attention?
- In what circumstances do distracted drivers have accidents (e.g., are these more likely within the influence area of intersections or in stop-and-go traffic, but less likely on freeways)?
- How can differences between struck and striking vehicles with regard to sampling behavior for rear-view and side-view mirrors be assessed and analyzed?
- Does a driver's familiarity with a road influence his or her driving behavior?
- How do differences in vehicle types influence variations in driving behavior?
- What factors initiate or influence the sequence of events resulting in a motor vehicle accident?
- How does the availability or lack of sight distance affect how a driver travels over a crest, around a horizontal curve, or through an intersection?
- In a crash or near crash did the driver perceive but misjudge the available gap, or did the driver not perceive the oncoming vehicle?

Global Research Question 15: How Do Individual Differences (e.g., Age, Gender, or Speed Selection) Influence Lane-Keeping Performance?

These questions relate to the influence of individual differences on lane maintenance. This global research question represents five individual research questions:

- What are the individual differences in lane-keeping performance?
- What is the role of speed relative to the posted speed limit in lane-keeping performance?
- Does lane keeping vary with vehicle type or driver age and gender?
- How do driver age and gender, grade, curve, speed, rumble strips, and other factors relate to lane-keeping performance?
- How does driver behavior (speeding) affect lane keeping?

Global Research Question 16: How Do Traffic and Traffic Volume Influence Intersection Negotiation, Lane-Keeping Performance, and Crashes?

These questions relate to how different crash surrogate events and driving maneuvers are influenced by the traffic volume and specific vehicles (potentially conflict vehicles) within proximity of the instrumented vehicle. This global research question represents 16 individual research questions:

- Is the illustrative hierarchy of relationships generalizable to other nonintersection crash types such as leading vehicle crashes?
- Does risk of lane departure vary by road type and traffic volume?
- How will increased traffic volume on U.S. roadways affect driver involvement in ROR crashes?
- What is the influence of surrounding traffic on lane keeping?
- Does opposing traffic affect lane position or lane-keeping performance?
- What is the influence of adjacent traffic or opposing traffic on lane keeping?
- What is the influence of leading vehicles on lane keeping?
- What lane-changing behavior of nearby vehicles may contribute to crash and near-crash events?
- How can a consideration of traffic volume for each of the turning maneuvers, which may play a role in all aspects of intersection risk, be incorporated into the analysis?
- What is the relationship of traffic density and type of traffic-control devices to crash occurrence at intersections?
- How does the pattern of conflicts and collision risk vary with traffic volume?
- How does traffic volume influence left-turn maneuvers at intersections?
- How does traffic volume influence right-turn maneuvers at intersections?
- What is the role of the amount and location of traffic in lane-change or merge crashes?
- What combinations of factors (including closure speed) affect left-turn risk?
- What combinations of factors (including closure speed) affect right-turn risk?

Priority 6

Global Research Question 17: Do Vehicle Characteristics Influence Crash Likelihoods or Driver Behaviors?

These questions relate to specific vehicle factors (e.g., size, center of gravity, and kinematic measures) and how they influence crash likelihoods and driver behaviors. This global research question represents eight individual research questions:

- Are sport utility vehicles more likely to be involved in an overturn than other passenger vehicles?
- Are vehicle kinematic measures sufficient to identify disturbed control for risk measures in single-vehicle departure crashes?
- How do vehicle characteristics (e.g., size, braking capabilities, and center of gravity) affect subsequent events and outcome after a vehicle initially leaves the roadway?
- How do circumstances of low friction (e.g., OBD II, traction control, and wheel slip) affect driver behavior and crash or near-crash risk at intersections?
- Does driver behavior or performance relate to vehicle design (e.g., weight, center of mass, greenhouse geometry, and instrument panel design)?
- What lifestyle or driving behaviors (e.g., gas use, brake behavior, and trip distances) reveal opportunities for fuel economy or alternative-fuel vehicle designs?
- What are the kinematic conditions, in terms of range, range rate, vehicle speed, and deceleration, at the onset of a hard braking maneuver?
- How does driver behavior change by vehicle type (e.g., truck or SUV)?

Global Research Question 18: What Are the Interrelationships of Environmental, Road, and Driver Factors with Nondriving-Related Activities (e.g., Technology, OEM, or Nomadic Devices)?

These questions relate to relative risk of specific driving situations or behaviors when drivers are engaged in nondriving-related tasks (e.g., original equipment manufacturer [OEM], technology, or nomadic devices). This global research question represents 19 individual research questions:

- What is the relative risk of an activity's duration on driver behavior when using technology-related tasks?
- What is the relative risk of an activity's duration on driver behavior when using OEM system tasks?
- What is the relative risk of an activity's duration on driver behavior when using nomadic devices?
- What is the relative risk of the road geometry (e.g., curves, straightaways, and hills) on driver behavior when using technology-related tasks?
- What is the relative risk of the road geometry on driver behavior when using OEM system tasks?
- What is the relative risk of the road geometry on driver behavior when using nomadic devices?
- What is the relative risk of time of day on driver behavior when using technology-related tasks?
- What is the relative risk of time of day on driver behavior when using OEM system tasks?
- What is the relative risk of time of day on driver behavior when using nomadic devices?
- What is the relative risk of traffic density on driver behavior when using technology-related tasks?
- What is the relative risk of traffic density on driver behavior when using OEM system tasks?
- What is the relative risk of traffic density on driver behavior when using nomadic devices?
- What is the relative risk of pedestrian or cyclist density on driver behavior when using technology-related tasks?
- What is the relative risk of pedestrian or cyclist density on driver behavior when using OEM system tasks?
- What is the relative risk of pedestrian or cyclist density on driver behavior when using nomadic devices?
- What is the relative risk of weather conditions on driver behavior when using technology-related tasks?
- What is the relative risk of weather conditions on driver behavior when using OEM system tasks?
- What is the relative risk of weather conditions on driver behavior when using nomadic devices?
- What is the relative risk of various sources of currently available and future devices (e.g., nomadic or in-vehicle devices such as iPhones or mobile offices)?

Global Research Question 19: How Does Seatbelt Use Vary with Different Levels of Enforcement and in Different Jurisdictions?

These questions are specifically related to the use of seatbelts across jurisdictions and how such use changes as the laws related to seatbelt usage change. This global research question represents two individual research questions:

- How does seatbelt use vary between states with and without primary seatbelt laws? For example, do different types of seatbelt laws result in variations of seatbelt use in the presence of passengers or during day and night hours?
- What is the effect on seatbelt use of a change in seatbelt law from a secondary to a primary source?

Priority Unranked

Global Research Question 20: General or Very High-Level Questions

This category of questions represents very high-level (nonspecific) research questions. This global research question represents 23 individual research questions:

- What driver, vehicle, operational, roadway, and environmental factors increase inadvertent lane departures? Specific factors of interest (*denotes highest-priority factors): driver fatigue, speed limit, alcohol level, driver distraction, driver gender, shoulder width, shoulder type (paved or unpaved) clear zone cross slope, weather, day or night, *driver age, *vehicle speed, *lane width, edge drop presence, *lane line presence and nighttime visibility, *rumble strip presence, *curvature.
- What percentage of roadway-departure crashes start as rear-end crash scenarios?
- What combination of driver, vehicle, traffic, environmental, and roadway factors leads to rear-end crashes in which there is a struck vehicle in the same travel lane?
- What combination of driver, vehicle, traffic, environmental, and roadway factors leads to crashes involving pedestrians, animals, or objects in the travel lane?
- What combination of driver, vehicle, traffic, environmental, and roadway factors leads to head-on crashes?
- What combination of driver, vehicle, traffic, environmental, and roadway factors leads to lane-change or merge crashes?
- What combination of driver, vehicle, traffic, environmental, and roadway factors leads to backing crashes?
- How do various factors work together to affect collisions, and how do exposure data for noncrash populations and accurate precrash data weigh into this scenario?
- How are a specific driving behavior and crash risk affected by both permanent descriptors (e.g., curvature, road surface, lane width, and sight distance) and transitory descriptors (e.g., weather, light conditions, traffic flow, and adjacent vehicles)?
- What effect do various countermeasures have on crash and near-crash incidents?

- Where do drivers position their vehicles in the travel lane on two-lane and two-way roads (using a simply painted centerline and gravel shoulders as baseline), and is this position influenced by factors such as opposing traffic volumes, centerline rumble strips, shoulder treatments, curbs, and weather?
- What is the interrelationship of driver factors and behavior with roadway design and traffic conditions on the risk of collision and causalities?
- How cost effective are various countermeasures?
- What is the relative frequency of these driver factors and their causal contribution within a defined accident and driving population?
- What is the feasibility and research potential of linking GIS and GPS data to investigate ROR crashes?
- What defined events may be recorded through naturalistic driving studies so that these events may be understood?
- For the purpose of accident prediction modeling, how can drivers' failures to perceive oncoming vehicles be classified, and what are the baseline estimates of the frequency of such events?
- What opportunities for crash countermeasures exist that have been unrecognized or underemphasized?
- How can crash data from the 100-car naturalistic driving study be used to investigate the potential role of specific crash-avoidance systems in preventing near crashes and actual crashes?
- How do drivers process multiple sources of information?
- How do drivers make decisions?
- What types of driver distraction episodes can be identified and understood?
- What problems emerge from an examination of naturalistic driving data that would be amendable to countermeasures?

Global Research Question 21: How Else Can Naturalistic Driving Data Be Used?

These questions relate to how naturalistic driving data can be used to address other questions, including how roadside factors can be integrated with the naturalistic driving data. This global research question represents 10 individual research questions:

- Can the analysis of data in southeast Michigan be applied or recreated in another region, such as Virginia?
- Can roadside factors (e.g., locations of poles, trees, bridge abutments, and side slopes) be coupled to naturalistic driving data?
- Can general descriptors of roadside environments be used in this coupling (e.g., tree density or proportion of side slope steeper than 4:1), or does the location of roadside obstacles need to be more specified?
- Could naturalistic driving data be used to validate simulators?
- Can a cognitive model be developed that could assess how specific factors influence specific driving tasks or events (e.g., gap acceptance or ROR events)?
- How can human factors design standards be implemented in roadway design to minimize errors associated with gap acceptance or other driving behaviors?
- What is the incidence of drowsiness and conditions under which drowsiness arises?
- How can lane-change events be classified according to subject vehicle, role, event severity, precrash or event maneuvers, causal or contributing factors, evasive maneuvers, and state variables?
- How can taxonomy development and group identification concepts be used to define and identify problem driver types and actions (specifically, alcohol-impaired drivers and the driving performance mistakes made by particular types of alcohol-impaired drivers under certain conditions), and how can this process lead to recommendations for dealing with particular classes of drivers?
- Can a *design driver* be defined, and relative to that concept can crash causes be identified?

Global Research Question 22: How Does the Speed That Drivers Select Influence Other Driver Behaviors or Actions?

These questions relate to speed selection and how a driver's speed selection is guided by other factors and behaviors and vice versa. This global research question represents nine individual research questions:

- Do drivers adjust their headway distance in response to level of operating speed, traffic volumes, weather conditions, road conditions, and visibility?
- How does pavement roughness affect speed (i.e., how much will milled pavement slow drivers down)?
- Do drivers drive faster and/or wander less in the lane on curves with better delineation (e.g., brighter lane markings, RPMs, chevrons, post-mounted delineators) than on curves with poorer delineation?
- How do drivers select speed?
- Is a subset of drivers responsible for the majority of speeding, or do all drivers speed occasionally?
- Do drivers travel at slower speeds and with longer headways, and to what degree, in rain, snow, or fog?
- Does speed increase with cell phone usage?
- Do drivers travel at slower speeds and within what range when pedestrians (especially children) and bicyclists are present?
- What factors (e.g., roadway geometry, roadside features, intersections, driveways, weather, traffic volume, or day versus night) influence a driver's choice of operating speed, and how does the speed change?

Global Research Question 23: How Do Roadway Features Influence Driver Performance and Behavior?

These questions relate to the effect that specific roadway features (e.g., rumble strips or glare from lighting) have on driver performance and behavior. This global research question represents 21 individual research questions:

- How much impact does pavement surface condition have on drivers' ability to safely recover within their own lane once a road departure is likely?
- What is the influence of superelevation on lane keeping and departure?
- How do lane keeping and road departure on curves and grades compare with straight and flat road segments?
- What are the effects of closely associated versus isolated curves with the same geometric characteristics, such as spirals, and other compound curves on lane keeping?
- What are the potential effects of improved roadway delineation?
- How do rumble strips change driver behavior?
- Are current design guidelines for roadway design (e.g., curvature of roadway) appropriate for the aging population?
- How does risk assessment vary based on driver performance and highway design or other features in roadway departure?
- How does roadway design influence compliance with traffic controls at intersections?
- What is the effect of removing access (e.g., commercial driveways) near high-volume signalized intersections?
- What effect do access points near the intersection have?
- How does sight distance affect safety at intersections? At roundabouts? Of pedestrians?
- How does roadway design influence speed behavior at intersections?
- How does roadway design influence braking behavior at intersections?
- How does roadway design influence gap acceptance at intersections?
- What is the influence of factors such as backing on a slope?
- How do differences in roadway geometry influence variations in driving behavior?
- What road features (e.g., generally gentle curvature with the exception of one curve) and curve features (e.g., tight radius but high posted speed, wide shoulders) result in high lateral acceleration?
- What is the effect of glare from opposing vehicles and roadway lighting of differing levels on driver behavior and performance?
- How does the length of an acceleration lane and traffic volume affect how long drivers take to merge or change lanes?
- At what point on the ramp do drivers typically merge?

Global Research Question 24: How Do the Number and Type of Passengers Influence the Driver's Behavior?

These questions relate to investigating how passengers influence driving behavior and the effect of multiple passengers. This global research question represents three individual research questions:

- How do driving behavior and crash and near-crash risk change when one or more passengers are present?
- How does a driver's behavior change with and without particular passengers, such as peers, parents, and children, in the vehicle?
- Does teen driver behavior change based on the presence of other teens in the vehicle?

Global Research Question 25: How Does Driver Fatigue Affect Driver Performance?

These questions relate to investigating how driver fatigue affects driving performance. This global research question represents four individual research questions:

- How does fatigue influence speed behavior at intersections?
- How does fatigue influence braking behavior at intersections?
- How does fatigue influence compliance with traffic controls at intersections?
- How does fatigue influence gap acceptance at intersections?

Global Research Question 26: How Does Inattention Affect Driver Behavior and Performance?

These questions relate to the specific driver state of being inattentive and how it affects driving behavior, as well as how roadway and environmental factors influence driver inattention. This global research question represents 51 individual research questions:

- How do driver factors such as inattention or fatigue affect lane keeping?
- How does signage influence inattention at intersections?
- How do traffic control variables influence inattention at intersections?
- How does roadway design influence inattention at intersections?
- How does fatigue influence inattention at intersections?
- What is the role of inattention in intersection errors and conflicts?
- How does distraction influence braking behavior at intersections?

- How does distraction influence speed behavior at intersections?
- Does driver distraction influence compliance with traffic controls at intersections?
- How does distraction influence compliance with traffic controls at intersections?
- To what degree do different types of distractions influence inattention at intersections?
- What is the relative contribution of inattention to inappropriate gap acceptance?
- How does distraction influence gap acceptance at intersections?
- What is the relative contribution of inattention to red light running?
- How do drivers come to use and understand advanced in-vehicle safety systems, and are the full benefits of the system being realized by individual drivers?
- What is the frequency and type of in-vehicle activity related to the use of OEM system tasks?
- What is the level of exposure for OEM system tasks?
- What types of technology-related tasks do drivers engage in while driving, and at what frequency?
- What nontechnology-related tasks do drivers engage in while driving?
- What in-vehicle activities do drivers engage in using nomadic or non-OEM devices?
- What external distractions (e.g., billboards, variable messaging signs, pedestrians, animals, objects, and other traffic) influence driving behavior?
- What is the level of exposure for technology-related tasks?
- What is the level of exposure for nomadic devices?
- What is the level of exposure for external distractions?
- How frequently do drivers interact with infotainment or nomadic devices (e.g., iPod)?
- Is the frequency of use for infotainment or nomadic devices affected by road type and/or traffic volume?
- Is the frequency of use for infotainment or nomadic devices affected by lead vehicles?
- How long are the interactions of use for infotainment or nomadic devices?
- What are the eyeglance patterns before, during, and after interactions of use for infotainment or nomadic devices?
- Is there a difference in frequency or duration of the interactions across different infotainment units?
- How often are these interactions associated with crash or near-crash events? Is this association dependent on the duration of the interaction?
- Does the use of nomadic devices outside of the vehicle's infotainment system (e.g., iPod or MP3 player) degrade driving performance more than typical vehicle infotainment system use? If such degradation exists, is it alleviated by integration of the nomadic device with the infotainment system?
- To what extent does the use of vehicle-based or nomadic devices reduce drowsy driving (e.g., listening to music versus listening to talk radio versus driving without listening to anything; or talking on a cell phone versus talking with a passenger versus driving without conversation)?
- What are the effects of learning to use new infotainment devices on driving performance?
- What percentage of time do drivers look at mirrors, in-vehicle or nomadic devices, signs, and external distractions?
- What factors (e.g., age, trying circumstances, traffic volume, or controlled access versus arterial) determine the amount of distracted driving that people engage in?
- What types of driver distraction lead to serious consequences?
- How well are drivers able to divert their attention from nondriving voluntary distractions (e.g., cell phones, use of the sound system, eating, or conversing with passengers)?
- Does driving performance differ between drivers who are engaged in a distraction task and drivers who are attending to driving? Are some safety surrogate measures more sensitive to driving performance differences when driving distracted than other safety surrogate measures?
- What percentage of time do drivers spend engaged in distracted behavior, traveling specified speeds over the speed limit, traveling through stop-controlled or signalized intersections, driving in various lighting conditions, driving in rain, and driving through construction zones?
- What do drivers do to cause distraction and when do they do it?
- Do drivers reserve technology-related tasks (e.g., speaking on a cell phone or tuning a radio) for times when the driving situation is relatively simple?
- How often and in what circumstances do drivers check speedometer and rearview mirrors?
- What is the relative risk of eyes off the forward roadway?
- Do eyes off the forward roadway significantly affect safety and/or driving performance?
- How do drivers adapt their level of attention and direction of gaze in response to expected and unexpected changes in driving demands?
- How can normative driver inattention be characterized?
- What is the relative risk of driving while engaging in a task that results in inattention?
- Is the relative risk different for different types of secondary tasks?
- What are the environmental conditions associated with driver choice of engagement in secondary tasks or driving while fatigued?
- What are the relative risks of driving inattention while encountering these environmental conditions?

Global Research Question 27: What Nonsafety-Related but Useful Information Can Be Obtained from These Data?

These questions relate to other useful information (e.g., how often alerts occur and how drivers respond to them). This global research question represents 18 individual research questions:

- What spatially referenced crash and highway data exist in the regions where the driving took place, and what gaps exist in the data?
- Can closure data or oncoming vehicle presence (with estimate of speed) be obtained?
- Can driver interfaces be compared?
- Are OnStar data task dependent—e.g., phone vs. wayfinding?
- What useful data could be obtained from studies that track driver use and interaction with a given system?
- What new infotainment devices are being used in vehicles?
- Can new or novel uses for existing (or traditional) infotainment devices be detected?
- How often do drivers activate the antilock braking system (ABS)?
- How often do drivers activate predictive brake assist (PBA)?
- How often do drivers activate electronic stability control (ESC)?
- How often do drivers receive forward collision warning (FCW) alerts? How often are these alerts a nuisance?
- How often do drivers receive lane-keeping alerts? How often are those alerts a nuisance?
- What are the traffic and environmental characteristics for activation of these systems and alerts?
- How often are different alerts presented for the same situation?
- What is the driver response to these multiple alerts?
- How effective is less-expensive methodology in answering research questions? For example, does showing photographs or videos of curves to drivers and asking them to estimate an appropriate speed effectively predict the speed selected by drivers in the naturalistic study?
- How do drivers look but not see?
- What are the prevalence, types, and frequency of driver inattention in which drivers engage during their daily commuting?

APPENDIX C

Research Question Analyses

Table C.1. How Do Dynamic Driver Characteristics, as Observed Through Driver Performance Measures, Influence Crash Likelihood?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
Can driving control performance for various states be categorized more simply (i.e., good and bad, or risky and nonrisky)?	UMTRI	Driving control performance measures								
Can various driver states (e.g., drowsy, aggressive, distracted, engaged) be identified from naturalistic driving data?	UMTRI	Driver state								
How do driver behavior and response influence subsequent events and outcomes after a vehicle initially leaves the roadway?	CTRE	Driver distraction, aggressiveness, driver status								
What is the relationship between measures obtained from pretest assessment batteries (e.g., a life stress test) and the frequency of engagement in distracting behaviors while driving?	VTTI									
Does there appear to be any correlation between willingness to engage in distracting behaviors and life stress sources, personality characteristics, or ability to focus attention?	VTTI	Pretest batteries (life stress test)								Willingness to engage in distracting activities
How often and under what circumstances do drivers drive while fatigued?	VTTI									Fatigued driving
What are the individual differences, both between and within drivers, related to fatigue? Fatigue sensors?	VTTI	Driver fatigue	Age							
How often and under what circumstances do drivers drive while under the influence of alcohol?	VTTI	Alcohol use								
What are the individual differences, both between and within drivers, related to alcohol use? Passive alcohol sensors?	VTTI	Alcohol use	Individual differences							Crash
What are the differences in demographic data, test battery results, and performance-based measures between attentive and inattentive drivers?	VTTI		Many							
How might knowledge of demographic differences in attentive and inattentive drivers be used to mitigate the potential negative consequences of inattentive driving behaviors?	VTTI									
Could information concerning demographic differences in attentive and inattentive drivers be used to improve driver education courses or traffic schools?	VTTI									

Table C.2. What Impacts Do Roadway Countermeasures Have on Lane-Keeping Performance?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
Are drivers more likely to lane keep on roadways with edge-line rumble strips?	CTRE						Roadway attributes, number of lanes, type of pavement surface, lane width, shoulder type and width			Lane position (lane departures)
How do lane-edge markings affect lane keeping?	VTTI						Lane-edge markings			Lane departure
What is the influence of rumble strips in measured lane-keeping performance?	VTTI						Rumble strips			Lane departure
Are centerline rumble strips beneficial in improving lane-keeping performance?	VTTI						Rumble strips			Lane departure
Would centerline rumble strips be effective in preventing head-on collisions?	VTTI						Centerline rumble strips			Head-on collisions
What is the influence of special curve warning markings (e.g., on-pavement markings)?	VTTI						Curve warning markers			Lane departure
What are the potential impacts of rumble strips on nonfreeways?	VTTI						Rumble strips			Lane departure
Would rumble strips be effective without the paved shoulder?	VTTI						Rumble strips, paved shoulder			Lane departure

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Table C.2. What Impacts Do Roadway Countermeasures Have on Lane-Keeping Performance? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	Source	Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	Outcome
Does rumble strip noise reduce the deviation from the lane, or does it function as an alarm to improve subsequent alertness and lane keeping after encountering the rumble strip?	VTTI	Alertness					Noise from rumble strips			Lane departure
Do rumble strips reduce the frequency and duration of lane deviations, making successful recovery more likely, and/or does a lane departure over a rumble strip improve subsequent lane keeping and decrease the frequency of lane departures?	VTTI						Rumble strips			Lane departure
How does the driver's positioning of the vehicle affect lane keeping, and how is this related to the efficacy of edge marking and rumble strips?	VTTI	Driver lane position maintained					Edge markings and rumble strips			Lane departure
Are drivers less likely to pass with centerline rumble strips?	VTTI						Centerline rumble strips			Lane departure
How likely are drivers to overcorrect or countersteer away from edge rumble strips so that they avoid a road departure but encroach into an adjacent lane?	CTRE			Vehicle heading; lateral and longitudinal acceleration; pitch, yaw, and roll rates; speed			Roadway attributes, number of lanes, type of pavement surface, lane width, shoulder type, shoulder width			Lane position (lane departures)

Table C.3. How Does Driver Distraction Influence Crash Likelihood?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
Is driving-control-performance pattern different for the same driver when distracted or not distracted (e.g., on cell phone or not on cell phone)?	UMTRI									
How do driver distractions affect involvement in ROR collisions?	VTTI	Distraction								
What is the role of inattention in collision risk at intersections?	VTTI	Inattention								Crash risks in intersections
What is the role of driver inattention in rear-end crashes (i.e., striking a vehicle in the travel lane)?	VTTI	Inattention								Rear-end crashes
To what degree does the lead vehicle driver (i.e., the driver in the instrumented vehicle) contribute to the crash as a result of driver inattention?	VTTI	Inattention for lead vehicle driver								Crashes
What is the role of driver inattention as it relates to crashes involving pedestrians, objects, or animals in the travel lane?	VTTI	Inattention								Crashes with pedestrians, objects, or animals
What is the role of inattention (i.e., as a result of secondary task) in lane-change or merge crashes?	VTTI	Secondary tasks, inattention								Lane-change or merge crashes
What is the role of inattention in head-on crashes?	VTTI	Inattention								Head-on collisions
What is the role of inattention (i.e., as a result of focusing on a secondary task) in backing crashes?	VTTI	Secondary tasks, inattention								Backing crashes

Table C.4. How Do Aggressive Driving Behaviors Influence Crash Likelihood?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What is the relative contribution of aggressive driving to inappropriate gap acceptance?	VTTI	Aggressive driving								Inappropriate gap acceptance
What is the relative contribution of aggressive driving to red light running?	VTTI	Aggressive driving								Red light running
What is the role of aggressive driving in rear-end crashes (i.e., striking a vehicle in the travel lane)?	VTTI	Aggressive driving								Rear-end crashes
To what degree does the lead vehicle driver (i.e., the driver in the instrumented vehicle) contribute to the crash as a result of aggressive driving?	VTTI	Aggressive driving								Lead vehicle contribution to crashes
What is the role of aggressive driving as it relates to crashes involving pedestrians, objects, or animals in the travel lane?	VTTI	Aggressive driving								Crashes with pedestrians, objects, or animals
What is the role of aggressive driving (e.g., approach speed, gap with lead vehicle when change is initiated) in lane-change or merge crashes?	VTTI	Aggressive driving								Lane-change or merge crashes
What is the role of aggressive driving (e.g., speeding, being in a hurry) to backing crashes?	VTTI	Aggressive driving								Backing crashes
What is the influence of aggression or aggressive driving on lane keeping?	VTTI	Aggressive driving								Lane departure
What is the influence of aggression or aggressive driving on ROR events?	VTTI	Aggressive driving								ROR crashes
How does aggressive driving behavior affect crash risks?	VTTI	Aggressive driving								Crash risks
What is the role of aggressive driving in passing-maneuver errors?	VTTI	Aggressive driving								Passing maneuver crashes
How does aggressive driving behavior affect near-crash risks?	VTTI	Aggressive driving								Near crash, crash
Why do aggressive driving behaviors occur, and how do they relate to ROR crashes and near crashes?	VTTI	Aggressive driving								ROR crashes, near crashes

Table C.5. How Does Driver Fatigue Influence the Likelihood and Type of Crashes?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What is the role of driver fatigue in rear-end crashes (i.e., striking a vehicle in the travel lane)?	VTTI	Fatigue								Rear-end crashes
To what degree does the lead vehicle driver (i.e., the driver in the instrumented vehicle) contribute to the crash as a result of driver fatigue?	VTTI	Fatigue								Lead vehicle contribution to crash
What is the role of driver fatigue as it relates to crashes involving pedestrians, objects, or animals in the travel lane?	VTTI	Fatigue								Crashes with pedestrians, objects, or animals
What is the role of driver fatigue in head-on crashes?	VTTI	Fatigue								Head-on crashes
What is the role of driver fatigue in lane-change or merge crashes?	VTTI	Fatigue								Lane-change or merge crashes
What is the role of driver fatigue in backing crashes?	VTTI	Fatigue								Backing crashes

Table C.6. How Do Advanced Driver Support Systems Influence Crash Likelihood?

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
Are drivers less likely to lose control with antilock braking systems?	CTRE				Make and model, any known deficiencies					
How do drivers react in a ROR crash or near crash in terms of precrash maneuvers (with or without a crash-warning system)?	VTTI				Warning system					Driver behavior response time
How do crash-avoidance systems, including electronic stability control (ESC), affect driver behavior in ROR or rear-end crash scenarios?	VTTI				Crash-avoidance systems					Driver behavior in ROR or rear-end crashes
Can ACC help reduce ROR crashes?	VTTI				ACC					ROR crashes
What are the benefits of CWS deployed in the fleet when a striking vehicle is in the travel lane?	VTTI				CWS					Safety benefits
What are the benefits of other vehicle countermeasures (e.g., brake assist) in the fleet?	VTTI				Other vehicle countermeasures					Safety benefits
Do vehicle CWS contribute to crashes?	VTTI				CWS					Crashes
Do other types of vehicle countermeasures, such as brake assist, lead to struck secondary crashes?	VTTI				Vehicle countermeasures					Secondary crashes
Given that most objects, pedestrians, and animals produce no radar signature, is there any indication that reliance on CWS is a detriment?	VTTI	Reliance on CWS			CWS					Detriment on safety
Are there benefits to enhanced vision systems at night (e.g., infrared headlamps or differing types of head lighting) in determining the presence of pedestrians or objects in the travel lane?	VTTI				Enhanced vision systems					Ability to see pedestrians or objects in lane
Are there any forward CWS benefits related to head-on crashes?	VTTI				Forward CWS					Head-on crashes
What are the potential benefits of other vehicle countermeasures (e.g., brake assist) in the fleet related to head-on crashes?	VTTI				Other vehicle countermeasures					Head-on crashes

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Table C.6. How Do Advanced Driver Support Systems Influence Crash Likelihood? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
What are the benefits of lane-change aids and CWS?	VTTI				Lane-change aids					Benefits to safety
How does ACC use (compared with cruise control) affect speed compliance?	VTTI				ACC					Driver speed compliance
How does ACC use affect eyes-off-the-road time (i.e., drivers allowing themselves to be more distracted)?	VTTI				ACC					Eyes-off-the-road time
Where do drivers look when they receive these alerts or activate these systems?	VTTI	Glance behavior			Warning system					None
How and how fast do drivers respond when they receive these alerts or activate these systems?	VTTI				Warning system					Response time
Do these alerts and/or systems offer a safety benefit for impaired or drowsy drivers?	VTTI	Impaired/ fatigued		Alerts						Safety benefits
What are the potential benefits of radar and ABS in reducing the incidence and severity of automobile accidents?	VTTI				Radar and ABS					Reducing crash severity and incidents
How do crash-avoidance systems, including ESC, affect driver behavior in ROR or rear-end crash scenarios?	VTTI				ESC					Driver behavior in ROR or rear-end crashes
How can the effectiveness of back-up warning algorithms be tested?	VTTI									
Are back-up warning systems of different types (e.g., cameras) beneficial? What aspects make them beneficial or detrimental?	VTTI				Back-up warning systems					Beneficial
What is the driver response, in terms of immediate control input and subsequent speed selection, to in-vehicle CWS warnings?	VTTI				CWS warning					Driver response

Table C.7. What Is the Influence of Driver Impairment on Crashes and Driver Errors?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What is the relative contribution of impairment to inappropriate gap acceptance?	VTTI	Impairment								Inappropriate gap acceptance
What is the relative contribution of impairment to red light running?	VTTI	Impairment								Red light running
What is the role of driver impairment in rear-end crashes (i.e., striking a vehicle in the travel lane)?	VTTI	Impairment								Rear-end crashes
To what degree does the lead vehicle driver (i.e., the driver in the instrumented vehicle) contribute to the crash as a result of other driver impairment?	VTTI	Impairment								Lead vehicle contribution
What is the role of other driver impairment as it relates to crashes involving pedestrians, objects, or animals in the travel lane?	VTTI	Impairment								Crashes with pedestrians, objects, or animals
What is the role of other driver impairment in head-on crashes?	VTTI	Impairment								Head-on crashes
What is the role of other driver impairment in lane-change or merge crashes?	VTTI	Impairment								Lane-change or merge crashes
What is the role of other driver impairment in backing crashes?	VTTI	Impairment								Backing crashes

Table C.8. How Does the Turn-Lane Configuration Influence Behavior and Crash Risks?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What are the safety effects of protected and unprotected turn lanes?	VTTI						Protected turn lanes			Lane departure
How do turn lanes change the pattern of conflict at intersections?	VTTI						Turn lanes			Pattern of conflicts
Do offset left-turn lanes (bays) affect turn behavior (e.g., gap acceptance and the decision to turn)?	VTTI						Offset turn lanes			Driver turn behavior (e.g., gap acceptance and decision to turn)
How much do left-turn lanes and/or signal phases reduce collision risk?	VTTI						Turn lanes or signal phases			Crash risks
How much do left-turn lanes reduce collision risk, with and without left-turn signal phases?	VTTI						Left-turn lanes with and without signal phases			Crash risks
How much do right-turn lanes reduce collision risk, with and without right-turn signal phases?	VTTI						Right-turn lanes			Crash risks
How much do right-turn lanes and/or signal phases reduce collision risk?	VTTI						Right-turn lanes with and without signal phases			Crash risks

Table C.9a. What Variables or Pre-Event Factors Are the Most Effective Crash Surrogate Measures?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
For a given crash type, are any conflicts directly informative about crashes in the sense that they are generated from similar sets of background conditions?	UofMN	Gap-selection events				Conflict types, back-ground variables		Back-ground variables		Crash type
Which noncrash incidents can be used as crash surrogates to assess risk for road-departure crashes?	CTRE			Pitch and roll angle rates, lateral and longitudinal acceleration, speed, distance vehicle encroaches into adja-cent lane or shoulder						Road-departure crashes
Do naturalistic driving data con-tain measurable episodes of disturbed control? **(Broad research question.)**	UMTRI	Disturbed control								
Do objective measures of dis-turbed control from naturalistic driving data, together with high-way geometric factors, off-highway factors, and environ-mental factors, satisfy the criteria for crash surrogates, i.e., are they related to actual crashes? **(Broad research question.)**	UMTRI	Disturbed control					Highway features	Environ-mental factors		
If so, are these conflicts more frequent, as frequent, or less frequent than actual crashes?	UofMN	Gap-selection events								Crash types and con-flict types
Once a road departure occurs, what is the next most common sequence of incidents and out-comes (e.g., safe recovery and return to roadway, minor conflict with safe return, near miss with safe return, property damage accident, or injury accident)?	CTRE			Lateral and longitudinal acceleration, speed, distance vehicle encroaches into adja-cent lane or shoulder			Pitch and roll angles and rates			
Once a road departure occurs, what kinematic variables can be used to define the different outcomes (e.g., road-departure crash, near crash, conflict, or incident)?	CTRE			Longitudinal and lateral acceleration, speed, distance vehicle encroaches into adja-cent lane or shoulder			Pitch and roll angles and rates			
What measures exist in natural-istic driving data that directly measure disturbed control?	UMTRI	Disturbed control								

Table C.9b. What Explanatory Factors Are Associated with Crashes or Crash Surrogates, and What Analytical Models Can Be Developed to Predict Crashes or Crash Surrogates?

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
What kinematic measures of driving control performance are available in the naturalistic driving data, and what are the levels of accuracy in those measures?	UMTRI									
What kinematic variables can be used to determine when a road departure is likely or imminent?	CTRE			Lateral and longitudinal acceleration, vehicle heading			Lane width	Position of other vehicles		Lane position (lane departures)
How can severity-related factors conditioned on an event having occurred be most effectively examined?	PSU	Conversing with passengers, internal distractions, wireless devices, talking, eating, distractions from the vehicle, loss of control, aggressive, risky driving, life stressors, improper speed behavior	Number of years driving, driving experience, miles driven, history of violations and crashes, education, gender, annual mileage, and other predisposing factors		Vehicle age	Congested flow	Over road edge, curve	Dawn/dusk; lighting conditions; wet, icy, or snowy		Severity level: crashes, near crashes, incidents
Are other driving control metrics necessary (in addition to vehicle kinematic measures) to identify disturbed control?	UMTRI			Vehicle kinematics						
Are there measures of driving control performance in existing FOT data that depend on highway factors in a way that is consistent with single-vehicle road-departure crash frequencies?	UMTRI	Driving control performance measures								

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Table C.9b. What Explanatory Factors Are Associated with Crashes or Crash Surrogates, and What Analytical Models Can Be Developed to Predict Crashes or Crash Surrogates? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
What factors are associated with unconditional event occurrences?	PSU	Aggression, risky driving, life stress	Gender, driving experience, miles driven, education, history of driving violations, past crashes		Vehicle age					Crashes
What is the nature of the relationship between crashes, near crashes, incidents, and pre-event maneuvers and precipitating factors, driver factors, contributing factors, and environmental factors?	PSU	Pre-event maneuvers	Driver factors					Environmental factors		Crashes, near crashes, incidents (and their surrogates)
For a given crash type and data source, is it possible to identify a plausible structural model? If so is the data source sufficiently rich to support estimation of the values taken on by the model variables for crashes and interesting noncrashes?	UofMN	Speed, reaction times, evasive actions		Vehicle speed, acceleration (longitudinal and lateral)		Opposing traffic				Vehicle trajectory
If it is not possible to identify and validate plausible models, what additional data would be needed to support the estimation of the values for crashes and interesting noncrashes?	UofMN	Gap-selection events				Opposing driver's evasive actions (braking, steering, or a combination)				

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Table C.9b. What Explanatory Factors Are Associated with Crashes or Crash Surrogates, and What Analytical Models Can Be Developed to Predict Crashes or Crash Surrogates? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
What hierarchical structure (statistically speaking), if any, exists in the manner in which these relationships need to be explored?	PSU	Dula Dangerous Driving Inventory component score (e.g., aggressive or reckless driving, negative emotion), life stress inventory score, driving experience, improper speed, driver distraction (e.g., wireless devices, vehicle related, passenger related, talking, singing, daydreaming, internal distraction, dining, other)				Surface conditions (wet, snowy, or icy), traffic density not free flowing, alignment or curve, lighting (dusk/dawn)		Environmental conditions		
Do single-vehicle road-departure crashes occur only under conditions of disturbed control? **(Broad research question.)**	UMTRI	Disturbed control								ROR crashes

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Table C.9b. What Explanatory Factors Are Associated with Crashes or Crash Surrogates, and What Analytical Models Can Be Developed to Predict Crashes or Crash Surrogates? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
Can satisfactory crash risk predictions be made based on vehicle, driver, and highway factors available from naturalistic driving data (e.g., via extreme value theory), or do additional roadside and environmental factors need to be introduced?	UMTRI									
Does coupling roadside factors to naturalistic driving data improve correlation with actual crashes?	UMTRI									
What kinds of elucidative evidence emerge from the analysis of roadway departure crashes in terms of the relationship between crashes, near crashes, and incidents with situational factors, and what (statistical) hierarchical structure exists within these relationships?										

Table C.10. How Do Roadway Features Influence Crash Likelihood?

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
What statistical tests are available to determine if measures of driving control performance in naturalistic data and single-vehicle crashes depend on geometric features in a consistent way?	UMTRI	Driving control performance measures					Roadway geometric features			Single-vehicle crashes (ROR, lane departure)
What key driver, roadway, and environmental factors affect lane keeping that may result in a road departure?	CTRE			Lateral and longitudinal acceleration, vehicle heading			Lane width	Position of other vehicles		Lane position (lane departures)
What is the influence of life events and factors on ROR events?	VTTI		Life events							ROR crashes
What combination of driver, vehicle, traffic, environmental, and roadway factors leads to rear-end crashes (i.e., striking a vehicle in the travel lane)?	VTTI		Driver factors				Roadway factors	Environmental conditions		
What environmental factors influence whether a vehicle actually departs the roadway once a road departure is precipitated?	CTRE	Wiper use						Weather conditions, outside temperature		Lane position (lane departures)
To what extent do roadway features influence whether a vehicle actually departs the roadway once a roadway departure is precipitated?	CTRE			Vehicle heading; lateral and longitudinal acceleration; pitch, yaw, and roll rates; speed			GIMS database (roadway attributes: number of lanes, type of pavement surface, lane width, shoulder type, shoulder width)			Lane position (lane departures)
How frequently do road departures occur given a specific set of roadway variables?	CTRE			Vehicle heading; lateral and longitudinal acceleration; pitch, yaw, and roll rates; speed			GIMS database (roadway attributes: number of lanes, type of pavement surface, lane width, shoulder type, shoulder width)			Lane position (lane departures)

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Table C.10. How Do Roadway Features Influence Crash Likelihood? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
Are any specific highway features (e.g., isolated horizontal curves, sharp horizontal curves, sequences of horizontal curves, combinations of horizontal and vertical curves) associated with single-vehicle road-departure crashes and specific driving control performance measures?	UMTRI	Driving control performance measures					Isolated, sharp, and the sequence of curves; combinations of horizontal and vertical curves			Single-vehicle crashes (ROR, lane departures)
How is the occurrence of ROR events under different driving conditions and roadway geometries related to ROR causal factors and driver inputs during ROR maneuvers?	VTTI						Roadway geometries	Driving conditions		Rate of ROR crashes
How are ROR crashes affected by different roadway geometries (e.g., shoulder width and speed limits)?	VTTI						Roadway geometries			ROR crashes
How are ROR crashes and near crashes affected by different roadway features (e.g., shoulder width, signage, and delineators)?	VTTI						Roadway features			ROR crashes
What is the influence of roundabouts on pedestrian crashes?	VTTI						Roundabouts			Pedestrian crashes
Are there methods of identifying potentially dangerous intersections before the occurrence of high collision rates?	VTTI						Intersections			
What is the role of curves and grades in lane-change or merge crashes?	VTTI						Curves or grades			Lane-change or merge crashes
What is the role of length and type of ramps (e.g., weave) in lane-change or merge crashes?	VTTI						Length of ramps			Lane-change or merge crashes

Table C.11. How Do Signage, Lighting Conditions, and Other Traffic Control–Related Countermeasures Influence Crash Likelihood and Driver Performance?

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
Are road departures less likely when pavement markings are more visible?	CTRE			Vehicle heading; lateral and longitudinal acceleration; Pitch, yaw, and roll rates; speed			GIMS database (roadway attributes: number of lanes, pavement types, shoulder width)			Lane position (lane departures)
Does roadway lighting result in fewer nighttime road departures?	CTRE					Lighting conditions		Lighting conditions, time of day		Lane position (lane departures)
Does signage have any impact on frequency of road departures (e.g., large chevrons may alert drivers to an adverse horizontal curve)?	CTRE			Vehicle heading; lateral and longitudinal acceleration; pitch, yaw, and roll rates; speed			GIMS database (roadway attributes: number of lanes, type of pavement surface, lane width, shoulder type, shoulder width)			Lane position (lane departures)
How does signage influence braking behavior at intersections?	VTTI						Signage			Excessive braking
Would there be any safety benefits of alternative signal-control strategies? Adaptive signal-control timing? Alternative signal timing?	VTTI						Alternative signal control strategies			Safety benefits
How do traffic control variables influence braking behavior at intersections?	VTTI						Traffic control variables			Excessive braking
How do traffic control variables influence speed behavior at intersections?	VTTI						Traffic control variables			Speeding
How do traffic control variables influence compliance with traffic controls at intersections?	VTTI						Traffic control variables			Compliance with traffic controls
What are the effects of in-pavement warning lights at pedestrian crossings?	VTTI						In-pavement warning lights			Pedestrian safety

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Table C.11. How Do Signage, Lighting Conditions, and Other Traffic Control–Related Countermeasures Influence Crash Likelihood and Driver Performance? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What is the influence of closed-loop signal systems?	VTTI						Closed loop signal system			
What is the safety effect of offset, split, and cycle time for fixed-time signals?	VTTI						Offset, split, and cycle time			Safety effect (crash reduction)
What is the safety effect of detector placement and signal-timing parameters for semiactuated signals?	VTTI						Detector placement and signal timing			Safety effect (crash reduction)
What are the safety effects of different-sized signal heads (8 in. versus 12 in.), number of signals per approach lane (is one necessary for each lane?), and signal placement (overhead versus nearside)?	VTTI						Different-sized signal heads			Safety effect (crash reduction)
How does operating speed affect deceleration for traffic signals?	VTTI			Operating speed						Deceleration
How do drivers react to different intersection signal installations (phasing and timing operations)? Do certain types appear better?	VTTI						Signalized intersections			Drivers' reactions
What is the effectiveness of various countermeasures (e.g., strobe lights to red lights) to reduce intersection-related crashes?	VTTI									Intersection-related crashes
Could new technology, such as automated all-red signal extension systems, infrastructure to inform drivers of acceptable gaps in traffic, or dilemma-zone detection at high speed intersections, reduce intersection crashes?	VTTI									
What are the effects of protected left-turn phasing at high-speed rural intersections?	VTTI						Protected left-turn phasing			
How do traffic control variables influence gap acceptance at intersections?	VTTI						Traffic control variables			Gap acceptance

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Table C.11. How Do Signage, Lighting Conditions, and Other Traffic Control–Related Countermeasures Influence Crash Likelihood and Driver Performance? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
How does signage influence gap acceptance at intersections?	VTTI						Signage			Gap acceptance
What is the prevalence of straight crossing path traffic signal violations?	VTTI									Prevalence of signal violations
Do traffic control device counter-measures (e.g., signal phase related) lead to struck secondary crashes?	VTTI						TCD counter-measures			Secondary crashes
What are the benefits of roadway light-ing, and under what circumstances does roadway lighting increase drivers' ability to see pedestrians, animals, or objects in the travel lane?	VTTI							Roadway lighting		Ability to see pedestrians, animals, and objects
What are the benefits of reflectors and reflective clothing, and under what circumstances do these items improve drivers' ability to see pedestrians, animals, or objects in the travel lane?	VTTI							Reflectors and reflective clothing		Ability to see pedestrians, animals, and objects
How long does it take for drivers to respond to speed limit reductions?	VTTI						Speed limit reductions			Response times
Are drivers influenced by speed reduc-tion signs and if so, how? Do drivers travel at higher speeds on secondary streets and highways after long-distance travel on freeways?	VTTI						Speed reductions signs			Driver behavior

Table C.12. How Do Static Driver Characteristics Influence Driver Performance and Crash Likelihood?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What can be done to reduce the number of crashes and fatalities for older drivers?	VTTI		Age							Crashes
What is the influence of gender on ROR crashes?	VTTI		Gender							ROR crashes
What is the influence of age on ROR crashes?	VTTI		Age							ROR crashes
What is the influence of personality (as measured by Myers–Briggs or other assessment) on ROR crashes?	VTTI		Personality factors							ROR crashes
What is the influence of driving confidence (self-report) on ROR crashes?	VTTI	Driving confidence								ROR crashes
What is the influence of useful field of view on ROR crashes?	VTTI			Useful field of view						ROR crashes
Do demographics play a role in ROR crashes?	VTTI		Demographic data							ROR crashes

Table C.13. How Do Static Driver Characteristics, as Observed Through Driver Performance Measures, Influence Crash Likelihood?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
In terms of elucidative evidence, what types of behavioral correlates emerge? For example, are attitudinal measurements indicative of revealed behavior in terms of head-way maintenance and speed reductions?	PSU	Behavioral correlates, headway maintenance, speed								
Are attitudinal (e.g., predis-posing) measurements indicative of revealed behavior in terms of head-way distance and speed reduction?	PSU	Attitudinal (e.g., predisposing) measurements								Headway distance, speed reduction
Is there a difference in the driving control performance of good and bad drivers (or risky and nonrisky drivers) at locations with geometric features associated with high single-vehicle crash frequency?	UMTRI									
How does within- and between-subject variation in lane keeping compare (i.e., to what extent does one driver consistently perform better than another driver)?	VTTI		Within- and between-subject variability							Lane departures
How can performance dif-ferences be quantified (e.g., as differences in the frequency and amplitude of steering and braking actions; or in terms of frequency, duration, or amount of lane departure, time to departure, or other measures)?	VTTI									Performance differences
Are all drivers equally exposed to road departures?	VTTI		Driver exposure							Road departures

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Table C.13. How Do Static Driver Characteristics, as Observed Through Driver Performance Measures, Influence Crash Likelihood? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
How do driver testing scores serve as predictors to driving performance, in particular, to lane keeping?	VTTI		Driver test scores							Driving performance
Does the relative risk of different intersection maneuvers vary with driver age and gender?	VTTI		Age, gender							Intersection maneuvers
Do older drivers make fewer left turns or accept larger gaps?	VTTI		Age							Gap acceptance, left-turn frequencies
Do older drivers make fewer right turns or accept larger gaps?	VTTI		Age, gender							Right turn or larger gap frequencies
What is the role of driver factors in the risk associated with inappropriate gap acceptance with crossing traffic?	VTTI		Driver factors							Gap acceptance
What is the role of driver factors in the risk associated with red light running and inappropriate gap acceptance situations?	VTTI		Driver factors							Red light running, gap acceptance
How do drivers of various age categories judge and select a gap in traffic flow to enter or cross a street or highway?	VTTI		Driver age							Judgment of gaps in traffic
What are the intra- and inter-individual differences in braking and crash-avoidance skill?	VTTI		Individual differences							Crash-avoidance skills
What are the intra- and inter-individual differences in willingness to pass and skill in passing?	VTTI		Individual differences							Willingness to pass and skill in passing
What are the intra- and interindividual differences in lane-change or merge behavior and skill?	VTTI		Individual differences							Lane-change or merge behavior and skill

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Table C.13. How Do Static Driver Characteristics, as Observed Through Driver Performance Measures, Influence Crash Likelihood? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What are the intra- and inter-individual differences in backing behavior and skill?	VTTI		Individual differences							Backing behavior and skill
What is the influence of gender on lane keeping?	VTTI		Gender							Lane departure
What is the influence of age on lane keeping?	VTTI		Age							Lane departure
What is the influence of personality (as measured by Myers–Briggs or other assessment) on lane keeping?	VTTI		Personality factors							Lane departure
What is the influence of driving confidence (self report) on lane keeping?	VTTI	Driving confidence								Lane departure
What is the influence of risk-taking propensity on lane keeping?	VTTI		Risk-taking propensity							Lane departure, ROR crashes
What is the influence of experience and previous motor vehicle accidents on lane keeping?	VTTI		Experience and previous crashes							Lane departure
What is the influence of life events and factors on lane keeping?	VTTI		Life events							Lane departure
What is the influence of experience and previous motor vehicle accidents on ROR crashes?	VTTI									ROR crashes
Do demographics influence lane keeping?	VTTI		Demographic data							Lane departure
How do differences in age, gender, and other driver traits influence variations in driving behavior?	VTTI		Age gender							Driving behavior
How do drivers of various age categories use the available acceleration lanes when entering freeways?	VTTI		Age							Use of acceleration lanes

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Table C.13. How Do Static Driver Characteristics, as Observed Through Driver Performance Measures, Influence Crash Likelihood? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What is the level of compliance by drivers of various age categories to stop signs, traffic signals, advisory speeds on curves, speed limits, and stopping for pedestrians?	VTTI		Age							Compliance to traffic signals and signs
How do drivers adjust their behavior (relative to expected adjustments) in response to high-risk situations? Such situations may be environmental (e.g., night, slick roads from rain and snow, or fog) or personal (e.g., fatigue or alcohol intoxication).	VTTI		High-risk personal factors					High-risk environmental factors		Behavior adjustments
What is the relationship between drivers' involvement in crashes, near crashes, and incidents and drivers' age, driving knowledge, vision, driving experience, and vehicle familiarity?	VTTI	Vehicle familiarity	Age, knowledge, vision, experience							Crash involvement
How do exposure differences across subgroups vary in terms of amount of travel and environment?	VTTI	Amount of travel								
How does the driving experience vary in different regions of the country and for different drivers?	VTTI		Different drivers						Regions of the country	Driving experience
What driving styles exist across the country and within different driving conditions?	VTTI							Driving conditions	Regions of the country	Driving styles
What are exposure differences in terms of road types, speed selection, and miles traveled across driver age and gender subgroups?	VTTI	Speed selection	Miles traveled				Road types			Exposure differences

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Table C.13. How Do Static Driver Characteristics, as Observed Through Driver Performance Measures, Influence Crash Likelihood? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
How often, for what length of time, and in what pattern do drivers look away from the forward roadway? What are the individual differences among and between drivers?	VTTI		Individual differences							Visual scan patterns
Can attitudes toward risk taking (or other behaviors or beliefs) versus driving style (i.e., errors, inattention, or distraction) be characterized demographically?	VTTI		Demographic data							Characterization of attitudes toward risk taking, beliefs versus driving style, distractions
What are the behavioral characteristics, especially in terms of driving style and visual search, which distinguish the youngest and oldest drivers from drivers aged 25–65 years?	VTTI		Age							Driving behavior characteristics
How are a specific driving behavior and crash risk affected by both permanent descriptors (e.g., age, gender, driving experience, and crash record) and transitory descriptors (e.g., fatigue, other impairment, and distraction)?	VTTI		Many							Crash
How do safe and unsafe drivers differ in demographic data, test battery results, and performance-based measures? What are the crash rate and history of violations before the study for these safe and unsafe drivers? (Some drivers may not be honest in reporting this driving history information.)	VTTI		Demographic data							Categorization of safe and unsafe drivers
What is the relationship between various risky driving behaviors and combinations of risky driving behaviors between low-risk and high-risk drivers?	VTTI	Risky driving behaviors								Categorization of low- and high-risk drivers

Table C.14. What Are the Relationships Between Driver Behavior, Performance, Crash Types, Crash Likelihood, and Population-Attributable Risk for Each Factor Contributing to Crashes?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
In order to use conflict data to predict crash probability, it is necessary to know how the selected evasive action varies as a function of background conditions. For a given crash type and data set, is it possible to identify and validate plausible models for this relationship?	UofMN	Driver gap selection						Opposing driver's evasive actions		
In terms of elucidative evidence, what types of behavioral correlates emerge?	PSU									
What exposure variables are available and which are the best measures to use in the analytical models? Possible exposure variables include traffic volume, traffic density, driver subpopulations (i.e., crash risk for teenage drivers compared with older drivers), and miles of travel.	CTRE		Driver age				AADT	Number of licensed drivers in state	Number of licensed drivers in state	
What driver actions and behaviors are present in the seconds preceding and during ROR crashes?	VTTI	Driver actions and behaviors								ROR crashes
Can ROR countermeasures be effectively designed to reduce crashes?	VTTI						ROR crash counter-measures			Reduction in crashes
At what point can the intersection safety effectiveness of automated speed enforcement on roads with posted speed limits be considered credible?	VTTI									

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Table C.14. What Are the Relationships Between Driver Behavior, Performance, Crash Types, Crash Likelihood, and Population-Attributable Risk for Each Factor Contributing to Crashes? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What is the role of illegal maneuvers in collision risk at intersections?	VTTI	Illegal maneuvers								Gap acceptance
What driver actions occur in the seconds preceding and during intersection crashes and near crashes?	VTTI									Driver actions
What is drivers' situational awareness just before crashes (e.g., at multiple-vehicle accidents at intersections)?	VTTI									Drivers' situational awareness
What is the role of driver factors in the risk associated with red light running and inappropriate gap acceptance situations?	VTTI	Driver factors								Red light running
What is the relative risk of different maneuvers at intersections?	VTTI	Driving maneuvers								Relative risks in intersections
Having defined appropriate exposure measures for each intersection maneuver, what is the relative risk of the different maneuvers?	VTTI									Relative risks of driving maneuvers
How does risk assessment vary based on driver behavior and intersection design?	VTTI	Driver behavior					Intersection design			Risk assessment
What effect does the intersection environment have on drivers' decision-making processes?	VTTI						Intersection design			Decision-making process
How does the public perception of the attitude of law enforcement on highway safety affect intersection crashes?	VTTI	Public perception								Intersection crashes
Is there greater risk for left turns?	VTTI									Risk of left turns

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Table C.14. What Are the Relationships Between Driver Behavior, Performance, Crash Types, Crash Likelihood, and Population-Attributable Risk for Each Factor Contributing to Crashes? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
What is the role of driver factors in the risk associated with inappropriate gap acceptance with opposing traffic on left turns?	VTTI		Driver factors							Gap acceptance
What is the role of driver factors in the risk associated with inappropriate gap acceptance with opposing traffic on right turns?	VTTI		Driver factors							Gap acceptance
What is the relative contribution of decision errors to inappropriate gap acceptance?	VTTI	Decision errors								Gap acceptance
What is the relative contribution of illegal maneuvers to inappropriate gap acceptance?	VTTI	Illegal maneuvers								Gap acceptance
What is the relative contribution of decision errors to red light running?	VTTI	Decision errors								Red light running
What is the role of driver factors in the risk associated with red light running?	VTTI		Driver factors							Risk of red light running
What is the relative contribution of illegal maneuvers to red light running?	VTTI	Illegal maneuvers								Red light running
For willful straight crossing path signal violations, what is the nature (e.g., position and speed) of the crossing traffic?	VTTI					Crossing traffic				Signal violations
What is the role of following distance in rear-end crashes (i.e., striking a vehicle in the travel lane)?	VTTI	Following distance								Rear-end crashes

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Table C.14. What Are the Relationships Between Driver Behavior, Performance, Crash Types, Crash Likelihood, and Population-Attributable Risk for Each Factor Contributing to Crashes? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
To what degree does the lead vehicle driver (i.e., the driver in the instrumented vehicle) contribute to the crash as a result of the following distance?	VTTI	Following distance				Lead vehicle				Crash
What is the role of following distance as it relates to crashes involving pedestri-ans, objects, or animals in the travel lane?	VTTI	Following distance								Crashes with pedestrians, objects, or animals
What is the role of sight dis-tance in passing maneuver errors?	VTTI					Sight distance		Sight distance		Passing maneuver errors
How many times do drivers pass against road markings (e.g., double yellow)?	VTTI	Driver behavior					Road markings			Passing against road markings
How many times do drivers misjudge the speed or gap of approaching vehicles?	VTTI	Driver mis-judgment								Gap acceptance
How many times do drivers misjudge car acceleration or time available?	VTTI	Driver mis-judgment								Frequency of misjudg-ments
What is the role of inadequate mirror check in lane-change or merge crashes?	VTTI	Inadequate mirror checking								Lane-change or merge crashes
What is the role of no blind spot check in lane-change or merge crashes?	VTTI	No blind spot checking								Lane-change or merge crashes
What is the role of inadequate gap in lane-change or merge crashes?	VTTI	Inadequate gaps								Lane-change or merge crashes
What is the role of failure to match speed in lane-change or merge crashes?	VTTI	Failure to match speed								Lane-change or merge crashes
What is the role of failure to recognize speed differential in lane-change or merge crashes?	VTTI	Failure to recognize speed differentials								Lane-change or merge crashes

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Table C.14. What Are the Relationships Between Driver Behavior, Performance, Crash Types, Crash Likelihood, and Population-Attributable Risk for Each Factor Contributing to Crashes? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What is the role of sight distance in lane-change or merge crashes?	VTTI					Sight distance		Sight distance		Lane-change or merge crashes
What is the role of failure to visually verify (i.e., over-the-shoulder check)?	VTTI	Failure to visually verify								
What is the role of inadequate mirror check to backing crashes?	VTTI	Inadequate mirror checking								Backing crashes
What is the role of failure to clear windows or improve visibility to backing crashes?	VTTI	Failure to clear windows, improve visibility								Backing crashes
What is the influence of factors such as backing while turning?	VTTI									Backing while turning
What mechanisms of occupant injury exist that have been unrecognized or underemphasized?	VTTI	Mechanism of occupant injury								
What baselines can be measured in frequencies, risk exposure, or behaviors against which design improvements can be compared?	VTTI						Design improvements			Frequencies, risk exposures, behaviors
How does driver interaction with vehicle systems change over extended periods (e.g., 1 year)?	VTTI	Driver interaction								Change over first year
What steering and brake inputs occur in the seconds preceding collisions?	VTTI	Actions and behavior								ROR crashes
What is the influence of useful field of view on lane keeping?	VTTI			Useful field of view						Lane departure
What is the driver reaction time and control input selection for safety-critical events?	VTTI	Driver reaction								Safety-critical events

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Table C.14. What Are the Relationships Between Driver Behavior, Performance, Crash Types, Crash Likelihood, and Population-Attributable Risk for Each Factor Contributing to Crashes? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What is the error/accident involvement in crashes, near crashes, and incidents, and how can the driver behavior that contributed to the involvement be assessed?	VTTI	Driver error/ accident involvement								Crashes, near crashes
What are the response times, deceleration, braking behavior, and turn-signal use of following drivers in response to vehicles that enter the forward driving path?	VTTI					Vehicle entering driving path				Response times
How can braking and signaling behaviors with respect to striking and struck drivers be assessed and analyzed?	VTTI					Striking, struck vehicles				Braking behavior and signaling behavior
How can potential patterns in driving performance–based measures (e.g., high longitudinal decelerations, high lateral accelerations) be assessed and analyzed?	VTTI									Driving patterns
What new methodologies for assessing the role of human factors in accident causation can be developed?	VTTI									
What driver behaviors (e.g., bracing, postural adjustments) arise immediately before a crash?	VTTI									Driver behavior (bracing)
What is the role of following distance in lane-change or merge crashes?	VTTI	Following distance								Lane-change or merge crashes

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Table C.14. What Are the Relationships Between Driver Behavior, Performance, Crash Types, Crash Likelihood, and Population-Attributable Risk for Each Factor Contributing to Crashes? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What types of accidents occur when drivers are paying attention?	VTTI	Paying attention								Crashes
In what circumstances do distracted drivers have accidents (e.g., are these more likely within the influence area of intersections or in stop-and-go traffic, but less likely on freeways)?	VTTI					Circumstances				Crashes
How can differences between struck and striking vehicles with regard to sampling behavior for rear-view and side-view mirrors be assessed and analyzed?	VTTI			Struck, striking vehicles	Struck, striking vehicles					Rear- and side-view mirror sampling behavior
Does a driver's familiarity with a road influence his or her driving behavior?	VTTI	Familiarity with road								Driving behavior
How do differences in vehicle types influence variations in driving behavior?	VTTI				Vehicle types					Driving behavior
What factors initiate or influence the sequence of events resulting in a motor vehicle accident?	VTTI		Driver factors							Sequence of errors
How does the availability or lack of sight distance affect how a driver travels over a crest, around a horizontal curve, or through an intersection?	VTTI					Sight distance		Sight distance		Driver performance
In a crash or near crash did the driver perceive but misjudge the available gap, or did the driver not perceive the oncoming vehicle?	VTTI									

Table C.15. How Do Individual Differences (e.g., Age, Gender, or Speed Selection) Influence Lane-Keeping Performance?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What are the individual differences in lane-keeping performance?	VTTI		Individual differences							Lane departure
What is the role of speed relative to the posted speed limit in lane-keeping performance?	VTTI	Speed selection					Posted speed limit			Lane departure
Does lane keeping vary with vehicle type or driver age and gender?	VTTI		Driver age		Vehicle type					Lane departure
How do driver age and gender, grade, curve, speed, rumble strips, and other factors relate to lane-keeping performance?	VTTI		Driver age, gender				Grade, curve, rumble strips			Lane departure
How does driver behavior (speeding) affect lane keeping?	VTTI	Driver behavior								Lane departure

Table C.16. How Do Traffic and Traffic Volume Influence Intersection Negotiation, Lane-Keeping Performance, and Crashes?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
Is the illustrative hierarchy of relationships generalizable to other nonintersection crash types such as leading-vehicle crashes?	PSU									
Does risk of lane departure vary by road type and traffic volume?	VTTI					Road type and traffic volume				Lane departure
How will increased traffic volume on U.S. roadways affect driver involvement in ROR crashes?	VTTI					Traffic volume				ROR crashes
What is the influence of surrounding traffic on lane keeping?	VTTI					Surrounding traffic				Lane departure
Does opposing traffic affect lane position or lane-keeping performance?	VTTI					Opposing traffic				Lane departure
What is the influence of adjacent traffic or opposing traffic on lane keeping?	VTTI					Adjacent traffic				Lane departure
What is the influence of leading vehicles on lane keeping?	VTTI					Leading vehicles				Lane departure
What lane-changing behavior of nearby vehicles may contribute to crash and near-crash events?	VTTI					Lane changing of other vehicles				Crash and near-crash events
How can a consideration of traffic volume for each of the turning maneuvers, which may play a role in all aspects of intersection risk, be incorporated into the analysis?	VTTI					Traffic volume				Intersection crashes
What is the relationship of traffic density and type of traffic-control devices to crash occurrence at intersections?	VTTI					Traffic density	Traffic control devices			Intersection crashes
How does the pattern of conflicts and collision risk vary with traffic volume?	VTTI					Traffic volume				Pattern of conflicts
How does traffic volume influence left-turn maneuvers at intersections?	VTTI					Traffic volume				Left maneuvers
How does traffic volume influence right-turn maneuvers at intersections?	VTTI					Traffic volume				Left-hand turn crashes
What is the role of the amount and location of traffic in lane-change or merge crashes?	VTTI					Traffic amount and location				Lane-change or merge crash risks
What combinations of factors (including closure speed) affect left-turn risk?	VTTI					Oncoming vehicles				Left-turn crashes
What combinations of factors (including closure speed) affect right-turn risk?	VTTI					Oncoming vehicles				Right-turn crashes

Table C.17. Do Vehicle Characteristics Influence Crash Likelihoods or Driver Behaviors?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
Are sport utility vehicles more likely to be involved in an overturn than other passenger vehicles?	CTRE				Make and model, any known deficiencies					
Are vehicle kinematic measures sufficient to identify disturbed control for risk measures in single-vehicle departure crashes?	UMTRI									
How do vehicle characteristics (e.g., size, braking capabilities, and center of gravity) affect subsequent events and outcome after a vehicle initially leaves the roadway?	CTRE				Make and model, any known deficiencies					
How do circumstances of low friction (e.g., OBD II, traction control, and wheel slip) affect driver behavior and crash or near-crash risk at intersections?	VTTI			Low friction						Driver behavior
Does driver behavior or performance relate to vehicle design (e.g., weight, center of mass, greenhouse geometry, and instrument panel design)?	VTTI	Driver behavior								Vehicle design
What lifestyle or driving behaviors (e.g., gas use, brake behavior, and trip distances) reveal opportunities for fuel economy or alternative-fuel vehicle designs?	VTTI	Driving behavior	Lifestyle							Fuel economy or alternative vehicle designs
What are the kinematic conditions, in terms of range, range rate, vehicle speed, and deceleration, at the onset of a hard braking maneuver?	VTTI			Kinematic conditions						Hard braking maneuver
How does driver behavior change by vehicle type (e.g., truck or SUV)?	VTTI				Vehicle type					Driver behavior

Table C.18. What Are the Interrelationships of Environmental, Road, and Driver Factors with Nondriving-Related Activities (i.e., Technology, OEM, or Nomadic Devices)?

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	
What is the relative risk of an activity's duration on driver behavior when using technology-related tasks?	VTTI	Technology related								Relative risk of activities duration
What is the relative risk of an activity's duration on driver behavior when using OEM system tasks?	VTTI	OEM system tasks								Relative risk of activities duration
What is the relative risk of an activity's duration on driver behavior when using nomadic devices?	VTTI	Nomadic device								Relative risk of activities duration
What is the relative risk of the road geometry (e.g., curves, straightaways, and hills) on driver behavior when using technology-related tasks?	VTTI	Technology related								Relative risk of road geometry
What is the relative risk of the road geometry (e.g., curves, straightaways, and hills) on driver behavior when using OEM system tasks?	VTTI	OEM system tasks								Relative risk of road geometry
What is the relative risk of the road geometry (e.g., curves, straightaways, and hills) on driver behavior when using nomadic devices?	VTTI	Nomadic device								Relative risk of road geometry
What is the relative risk of time of day on driver behavior when using technology-related tasks?	VTTI	Technology related								Relative risk of time of day
What is the relative risk of time of day on driver behavior when using OEM system tasks?	VTTI	OEM system tasks								Relative risk of time of day
What is the relative risk of time of day on driver behavior when using nomadic devices?	VTTI	Nomadic device								Relative risk of time of day
What is the relative risk of traffic density on driver behavior when using technology-related tasks?	VTTI	Technology related								Relative risk of traffic density
What is the relative risk of traffic density on driver behavior when using OEM system tasks?	VTTI	OEM system tasks								Relative risk of traffic density
What is the relative risk of traffic density on driver behavior when using nomadic devices?	VTTI	Nomadic device								Relative risk of traffic density
What is the relative risk of pedestrian or cyclist density on driver behavior when using technology-related tasks?	VTTI	Technology related								Relative risk of pedestrian or cyclist density

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Table C.18. What Are the Interrelationships of Environmental, Road, and Driver Factors with Nondriving-Related Activities (i.e., Technology, OEM, or Nomadic Devices)? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
What is the relative risk of pedestrian or cyclist density on driver behavior when using OEM system tasks?	VTTI	OEM system tasks								Relative risk of pedestrian or cyclist density
What is the relative risk of pedestrian or cyclist density on driver behavior when using nomadic devices?	VTTI	Nomadic devices								Relative risk of pedestrian or cyclist density
What is the relative risk of weather conditions on driver behavior when using technology-related tasks?	VTTI	Technology related								Relative risk of weather conditions
What is the relative risk of weather conditions on driver behavior when using OEM system tasks?	VTTI	OEM system tasks								Relative risk of weather conditions
What is the relative risk of weather conditions on driver behavior when using nomadic devices?	VTTI	Nomadic devices								Relative risk of weather conditions
What is the relative risk of various sources of currently available and future devices (e.g., nomadic or in-vehicle devices such as iPhones or mobile offices)?	VTTI	Nomadic devices								Relative risk of new devices

Table C.19. How Does Seatbelt Use Vary with Different Levels of Enforcement and in Different Jurisdictions?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
How does seatbelt use vary between states with and without primary seatbelt laws? For example, do different types of seatbelt laws result in variations of seatbelt use in the presence of passengers or during day and night hours?	VTTI			Passengers				Time of day	Laws	Seatbelt use
What is the effect on seatbelt use of a change in seatbelt law from a secondary to a primary source?	VTTI								Laws	Seatbelt use

Table C.20. General or Very High-Level Questions

Actual Research Question	Source	Driver Factors: Dynamic	Driver Factors: Static	Vehicle Factors: Dynamic	Vehicle Factors: Static	Roadway Factors: Dynamic	Roadway Factors: Static	Environmental Factors: Dynamic	Environmental Factors: Static	Outcome
What driver, vehicle, operational, roadway, and environmental factors increase inadvertent lane departures? Specific factors of interest (* denotes highest-priority factors): driver fatigue, speed limit, alcohol level, driver distraction, driver gender, shoulder width, shoulder type (paved or unpaved), clear zone cross slope, weather, day or night, *driver age, *vehicle speed, *lane width, edge drop presence, *lane line presence and nighttime visibility, *rumble strip presence, *curvature.	VTTI	Distractions	Driver factors				Roadway factors	Environmental conditions		
What percentage of roadway-departure crashes start as rear-end crash scenarios?	VTTI									
What combination of driver, vehicle, traffic, environmental, and roadway factors leads to rear-end crashes in which there is a struck vehicle in the same travel lane?	VTTI		Driver factors		Vehicle factors		Roadway factors	Environmental conditions		Relationship between ROR crashes and lane departures
What combination of driver, vehicle, traffic, environmental, and roadway factors leads to crashes involving pedestrians, animals, or objects in the travel lane?	VTTI		Driver factors		Vehicle factors		Roadway factors	Environmental conditions		Rear-end crashes
What combination of driver, vehicle, traffic, environmental, and roadway factors leads to head-on crashes?	VTTI		Driver factors		Vehicle factors		Roadway factors	Environmental conditions		Crashes
What combination of driver, vehicle, traffic, environmental, and roadway factors leads to lane-change or merge crashes?	VTTI		Driver factors		Vehicle factors		Roadway factors	Environmental conditions		Crashes with pedestrians, animals, or objects
What combination of driver, vehicle, traffic, environmental, and roadway factors leads to backing crashes?	VTTI		Driver factors		Vehicle factors		Roadway factors	Environmental conditions		Head-on crashes
How do various factors work together to affect collisions, and how do exposure data for noncrash populations and accurate pre-crash data weigh into this scenario?	VTTI									

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Table C.20. General or Very High-Level Questions (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
How are a specific driving behavior and crash risk affected by both permanent descriptors (e.g., curvature, road surface, lane width, and sight distance) and transitory descriptors (e.g., weather, light conditions, traffic flow, and adjacent vehicles)?	VTTI									
What effect do various countermeasures have on crash and near-crash incidents?	VTTI									
Where do drivers position their vehicles in the travel lane on two-lane, two-way roads (using a simply painted centerline and gravel shoulders as baseline), and is this position influenced by factors such as opposing traffic volumes, centerline rumble strips, shoulder treatments, curbs, and weather?	VTTI					Opposing traffic	Centerline rumble strips, shoulders	Weather conditions		
What is the interrelationship of driver factors and behavior with roadway design and traffic conditions on the risk of collision and causalities?	VTTI		Driver factors				Roadway design and traffic conditions			
How cost-effective are various countermeasures?	VTTI									Position of vehicle in lane
What is the relative frequency of these factors and their causal contribution within a defined accident and driving population?	VTTI									Risk of crashes
What is the feasibility and research potential of linking GIS and GPS data to investigate ROR crashes?	VTTI									
What defined events may be recorded through naturalistic driving studies so that these events may be understood?	VTTI									Relative frequencies of crashes
For the purpose of accident prediction modeling, how can drivers' failures to perceive oncoming vehicles be classified, and what are the baseline estimates of the frequency of such events?	VTTI									
What opportunities for crash countermeasures exist that have been unrecognized or underemphasized?	VTTI									Defined naturalistic events

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Table C.20. General or Very High-Level Questions (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
How can crash data from the 100-car naturalistic driving study be used to investigate the potential role of specific crash-avoidance systems in preventing near crashes and actual crashes?	VTTI									
How do drivers process multiple sources of information?	VTTI									
How do drivers make decisions?	VTTI									
What types of driver distraction episodes can be identified and understood?	VTTI	Distractions								
What problems emerge from an examination of naturalistic driving data on driver distraction that would be amendable to countermeasures?	VTTI									

Table C.21. How Else Can Naturalistic Driving Data Be Used?

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
Can the analysis of data from southeast Michigan be applied or recreated in another region, such as Virginia?	UMTRI									
Can roadside factors (e.g., locations of poles, trees, bridge abutments, and side slopes) be coupled to naturalistic driving data?	UMTRI						Locations of poles, trees, bridge abutments, side slopes			
Can general descriptors of roadside environments be used in this coupling (e.g., tree density or proportion of side slope steeper than 4:1), or does the location of roadside obstacles need to be more specified?	UMTRI						Tree density, proportion of side slopes			
Could naturalistic driving data be used to validate simulators?	VTTI									Driving simulator validation
Can a cognitive model be developed that could assess how specific factors influence specific driving tasks or events (e.g., gap acceptance or ROR events)?	VTTI									
How can human factors design standards be implemented in roadway design to minimize errors associated with gap acceptance or other driving behaviors?	VTTI									

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Table C.21. How Else Can Naturalistic Driving Data Be Used? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
What is the incidence of drowsiness and the conditions under which drowsiness arises?	VTTI	Drowsiness conditions								Incidents of drowsiness
How can lane-change events be classified according to subject vehicle, role, event severity, precrash or event maneuvers, causal or contributing factors, evasive maneuvers, and state variables?	VTTI				Vehicle role					Lane-change events
How can taxonomy development and group identification concepts be used to define and identify problem driver types and actions (specifically, alcohol-impaired drivers and the driving performance mistakes made by particular types of alcohol-impaired drivers under certain conditions), and how can this process lead to recommendations for dealing with particular classes of drivers?	VTTI									
Can a *design driver* be defined, and relative to that concept can crash causes be identified?	VTTI									

Table C.22. How Does the Speed That Drivers Select Influence Other Driver Behaviors or Actions?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
Do drivers adjust their headway distance in response to level of operating speed, traffic volumes, weather conditions, road conditions, and visibility?	VTTI	Driving behavior				Traffic conditions		Weather conditions		Headway distance maintained
How does pavement roughness affect speed (i.e., how much will milled pavement slow drivers down)?	VTTI						Pavement roughness			Speed
Do drivers drive faster and/or wander less in the lane on curves with better delineation (brighter lane markings, RPMs, chevrons, post-mounted delineators) than on curves with poorer delineation?	VTTI						Lane markings, delineations			Driving behavior (drive faster, wander less)
How do drivers select speed?	VTTI									Speed selection
Is a subset of drivers responsible for the majority of speeding, or do all drivers speed occasionally?	VTTI		Individual differences							Responsibility for speeding
Do drivers travel at slower speeds and with longer headways, and to what degree, in rain, snow, or fog?	VTTI							Snow, fog		Headway distance and speed maintained
Does speed increase with cell phone usage?	VTTI	Cell phone usage								Speeding
Do drivers travel at slower speeds and within what range when pedestrians (especially children) and bicyclists are present?	VTTI							Pedestrians and bicyclists		Driver speed selection
What factors (e.g., roadway geometry, roadside features, intersections, driveways, weather, traffic volume, or day versus night) influence a driver's choice of operating speed, and how does the speed change?	VTTI		Driver factors		Vehicle factors		Roadway factors	Environmental conditions		Speed changes

Table C.23. How Do Roadway Features Influence Driver Performance and Behavior?

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
How much impact does pavement surface condition have on drivers' ability to safely recover within their own lane once a road departure is likely?	CTRE					Surface conditions				Lane position (lane departures)
What is the influence of super elevation on lane keeping and departure?	VTTI						Super elevations			Lane departure
How do lane keeping and road departure on curves and grades compare with straight and flat road segments?	VTTI						Curves versus straights			Lane departures
What are the effects of closely associated versus isolated curves with the same geometric characteristics, such as spirals, and other compound curves on lane keeping?	VTTI						Roadway geometries			Lane departures
What are the potential effects of improved roadway delineation?	VTTI						Roadway delineation			Crashes
How do rumble strips change driver behavior?	VTTI						Rumble strips			
Are current design guidelines for roadway design (e.g., curvature of roadway) appropriate for the aging population?	VTTI		Age							Roadway design guidelines
How does risk assessment vary based on driver performance and highway design or other features in roadway departure?	VTTI	Driver performance					Highway design			Risk assessment
How does roadway design influence compliance with traffic controls at intersections?	VTTI						Roadway design			Compliance with traffic signals
What is the effect of removing access (e.g., commercial driveways) near high-volume signalized intersections?	VTTI						Removing access roads near high-volume intersections			Crashes

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Table C.23. How Do Roadway Features Influence Driver Performance and Behavior? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
What effect do access points near the intersection have?	VTTI						Access points near intersections			Crashes
How does sight distance affect safety at intersections? At roundabouts? Of pedestrians?	VTTI			Sight distance			Sight distance			Safety at intersections, roundabouts, with pedestrians
How does roadway design influence speed behavior at intersections?	VTTI						Roadway design			Speeding
How does roadway design influence braking behavior at intersections?	VTTI						Roadway design			Excessive braking
How does roadway design influence gap acceptance at intersections?	VTTI						Roadway design			Gap acceptance
What is the influence of factors such as backing on a slope?	VTTI	Backing ability					Slope in road surface			Crashes
How do differences in roadway geometry influence variations in driving behavior?	VTTI						Roadway geometries			Driving behavior
What road features (e.g., generally gentle curvature with the exception of one curve) and curve features (e.g., tight radius but high posted speed, wide shoulders) result in high lateral acceleration?	VTTI						Geometric features, curve features			Large lateral accelerations
What is the effect of glare from opposing vehicles and roadway lighting of differing levels on driver behavior and performance?	VTTI			Glare			Roadway lighting			Driver behavior
How does the length of an acceleration lane and traffic volume affect how long drivers take to merge or change lanes?	VTTI						Traffic volume, length of acceleration lanes	Traffic volume		Time course of lane change or merge
At what point on the ramp do drivers typically merge?	VTTI									

Table C.24. How Do the Number and Type of Passengers Influence the Driver's Behavior?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
How do driving behavior and crash and near-crash risk change when one or more passengers are present?	VTTI			Passengers						Driver behavior
How does a driver's behavior change with and without particular passengers, such as peers, parents, or children, in the vehicle?	VTTI			Passengers						Driver behavior
Does teen driver behavior change based on the presence of other teens in the vehicle?	VTTI			Teen passengers						Teen driving behavior

Table C.25. How Does Driver Fatigue Affect Driver Performance?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
How does fatigue influence speed behavior at intersections?	VTTI	Fatigue								Speeding
How does fatigue influence braking behavior at intersections?	VTTI	Fatigue								Excessive braking
How does fatigue influence compliance with traffic controls at intersections?	VTTI	Fatigue								Compliance with controls
How does fatigue influence gap acceptance at intersections?	VTTI	Fatigue								Gap acceptance

Table C.26. How Does Inattention Affect Driver Behavior and Performance?

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
How do driver factors such as inattention or fatigue affect lane keeping?	VTTI	Inattention or fatigue								Lane keeping
How does signage influence inattention at intersections?	VTTI						Signage			Inattention at intersections
How do traffic control variables influence inattention at intersections?	VTTI						Traffic controls			Driver inattention
How does roadway design influence inattention at intersections?	VTTI						Roadway design			Inattention at intersections
How does fatigue influence inattention at intersections?	VTTI	Fatigue								Inattention at intersections
What is the role of inattention in intersection errors and conflicts?	VTTI	Inattention								Intersection errors or conflicts
How does distraction influence braking behavior at intersections?	VTTI	Distraction								Excessive braking
How does distraction influence speed behavior at intersections?	VTTI	Distraction								Speeding
Does driver distraction influence compliance with traffic controls at intersections?	VTTI	Distraction								
How does distraction influence compliance with traffic controls at intersections?	VTTI	Distraction								
To what degree do different types of distractions influence inattention at intersections?	VTTI	Distractions								Inattention at intersections
What is the relative contribution of inattention to inappropriate gap acceptance?	VTTI	Inattention								Inappropriate gap acceptance

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Table C.26. How Does Inattention Affect Driver Behavior and Performance? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
How does distraction influence gap acceptance at intersections?	VTTI	Distraction								
What is the relative contribution of inattention to red light running?	VTTI	Inattention								Red light running
How do drivers come to use and understand advanced in-vehicle safety systems, and are the full benefits of the system being realized by individual drivers?	VTTI			In-vehicle systems						
What is the frequency and type of in-vehicle activity related to the use of OEM system tasks?	VTTI				OEM systems					
What is the level of exposure for OEM system tasks?	VTTI				OEM systems					
What types of technology-related tasks do drivers engage in while driving, and at what frequency?	VTTI			Technology-related tasks						
What nontechnology-related tasks do drivers engage in while driving?	VTTI			Non-technology-related tasks						
What in-vehicle activities do drivers engage in using nomadic or non-OEM devices?	VTTI			Nomadic devices						
What external distractions (e.g., billboards, variable messaging signs, pedestrians, animals, objects, and other traffic) influence driving behavior?	VTTI	Distraction								

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Table C.26. How Does Inattention Affect Driver Behavior and Performance? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
What is the level of exposure for technology-related tasks?	VTTI			Technology-related tasks						
What is the level of exposure for nomadic devices?	VTTI			Nomadic devices						
What is the level of exposure for external distractions?	VTTI									
How frequently do drivers interact with infotainment or nomadic devices (e.g., iPod)?	VTTI			Nomadic devices						
Is the frequency of use for infotainment or nomadic devices affected by road type and/or traffic volume?	VTTI						Road type and traffic volume			
Is the frequency of use for infotainment or nomadic devices affected by lead vehicles?	VTTI			Nomadic devices		Lead vehicles				
How long are the interactions of use for infotainment or nomadic devices?	VTTI			Nomadic devices						
What are the eyeglance patterns before, during, and after interactions of use for infotainment or nomadic devices?	VTTI			Nomadic devices						
Is there a difference in frequency or duration of the interactions across different infotainment units?	VTTI			Nomadic devices						
How often are these interactions associated with crash or near-crash events? Is this association dependent on the duration of the interaction?	VTTI			Nomadic devices						

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Table C.26. How Does Inattention Affect Driver Behavior and Performance? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
Does the use of nomadic devices outside of the vehicle's infotainment system (e.g., iPod or MP3 player) degrade driving performance more than typical vehicle infotainment system use? If such degradation exists, is it alleviated by integration of the nomadic device with the infotainment system?	VTTI			Nomadic devices						
To what extent does the use of vehicle-based or nomadic devices reduce drowsy driving (e.g., listening to music versus listening to talk radio versus driving without listening to anything; or talking on a cell phone versus talking with a passenger versus driving without conversation)?	VTTI	Drowsy driving		Nomadic devices						
What are the effects of learning to use new infotainment devices on driving performance?	VTTI	Learning		Nomadic devices						
What percentage of time do drivers look at mirrors, in-vehicle or nomadic devices, signs, and external distractions?	VTTI	Gaze patterns								
What factors (e.g., age, trying circumstances, traffic volume, or controlled access versus arterial) determine the amount of distracted driving that people engage in?	VTTI	Distracted driving	Age							
What types of driver distraction lead to serious consequences?	VTTI	Distraction								

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Table C.26. How Does Inattention Affect Driver Behavior and Performance? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
How well are drivers able to divert their attention from nondriving voluntary distractions (e.g., cell phones, use of the sound system, eating, or conversing with passengers)?	VTTI	Distraction			In-vehicle systems					
Does driving performance differ between drivers who are engaged in a distraction task and drivers who are attending to driving? Are some safety surrogate measures more sensitive to driving performance differences when driving distracted than other safety surrogate measures?	VTTI	Distraction	Individual differences							
What percentage of the time do drivers spend engaged in distracted behavior, traveling specified speeds over the speed limit, traveling through stop-controlled or signalized intersections, driving in various lighting conditions, driving in rain, or driving through construction zones?	VTTI	Distraction		Speeding			Intersection, construction zones	Various lighting conditions, raining		Exposure to various driving conditions
What do drivers do to cause distraction and when do they do it?	VTTI	Behavioral causes of distractions, distractions								
Do drivers reserve technology-related tasks (e.g., speaking on a cell phone or tuning a radio) for times when the driving situation is relatively simple?	VTTI	Distractions								

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Table C.26. How Does Inattention Affect Driver Behavior and Performance? (continued)

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
How often and in what circumstances do drivers check the speedometer and rearview mirrors?	VTTI					Driving circumstances				
What is the relative risk of eyes off the forward roadway?	VTTI									
Do eyes off the forward roadway significantly affect safety and/or driving performance?	VTTI									
How do drivers adapt their level of attention and direction of gaze in response to expected and unexpected changes in driving demands?	VTTI					Expected and unexpected changes in driving demands				
How can normative driver inattention be characterized?	VTTI	Normative driver inattention								
What is the relative risk of driving while engaging in a task that results in inattention?	VTTI									
Is the relative risk different for different types of secondary tasks?	VTTI									
What are the environmental conditions associated with driver choice of engagement in secondary tasks or driving while fatigued?	VTTI	Secondary tasks, inattention, or fatigue						Environmental conditions		
What are the relative risks of driving inattention while encountering these environmental conditions?	VTTI									

Table C.27. What Nonsafety-Related but Useful Information Can Be Obtained from These Data?

Actual Research Question	Source	Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		Outcome
		Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	
What spatially referenced crash and highway data exist in the regions where the driving took place, and what gaps exist in the data?	UMTRI									
Can closure data or oncoming vehicle presence (with estimate of speed) be obtained?	VTTI					Oncoming vehicles				
Can driver interfaces be compared?	VTTI				Interfaces					
Are OnStar data task dependent—e.g., phone vs. wayfinding?	VTTI				OnStar					
What useful data could be obtained from studies that track driver use and interaction with a given system?	VTTI				System					
What new infotainment devices are being used in vehicles?	VTTI									
Can new or novel uses for existing (or traditional) infotainment devices be detected?	VTTI			Nomadic devices						
How often do drivers activate the antilock braking system (ABS)?	VTTI				ABS					
How often do drivers activate predictive brake assist (PBA)?	VTTI				PBA					
How often do drivers activate electronic stability control (ESC)?	VTTI				ESC					
How often do drivers receive forward collision warning (FCW) alerts? How often are these alerts a nuisance?	VTTI									

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Table C.27. What Nonsafety-Related but Useful Information Can Be Obtained from These Data? (continued)

		Driver Factors		Vehicle Factors		Roadway Factors		Environmental Factors		
Actual Research Question	**Source**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Dynamic**	**Static**	**Outcome**
How often do drivers receive lane-keeping alerts? How often are those alerts a nuisance?	VTTI			Lane-keeping alerts						
What are the traffic and environmental characteristics for activation of these systems and alerts?	VTTI					Traffic characteristics		Environmental conditions		
How often are different alerts presented for the same situation?	VTTI				Alert types					
What is the driver response to these multiple alerts?	VTTI				Alert types					
How effective is less-expensive methodology in answering research questions? For example, does showing photographs or videos of curves to drivers and asking them to estimate an appropriate speed effectively predict the speed selected by drivers in the naturalistic study?	VTTI									
How do drivers look but not see?	VTTI									
What are the prevalence, types, and frequency of driver inattention in which drivers engage during their daily commuting?	VTTI	Inattention								

Related SHRP 2 Research

Roadway Measurement System Evaluation (S03)
Roadway Information Database Developer, Technical Coordination, and Quality Assurance for Mobile Data Collection (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)