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Pilot Study of Instrumentation to Collect Behavioral Data to Identify On-Road Rider Behavior

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16. Abstract

Motorcycle-related research questions of interest to the National Highway Traffic Safety Administration (NHTSA) were reviewed. Instrumentation techniques and study procedures that have been used for light- and heavy-vehicle studies were adapted for use in answering the motorcycle-related questions. Three motorcyclists rode with instrumentation for a total of over 3,100 miles. The final data acquisition system and instrumentation recorded acceleration in three axes, yaw, pitch, roll, geographic location, rear-wheel speed, position in lane, turn-signal use, braking, range and closing speed to forward objects, and five video views. The sensor and video data were collected continuously while the bike was running. Development of helmet-mounted eye tracking and three dimensional head tracking instrumentation for use in naturalistic studies was attempted. Study components including recruiting, screening, questionnaires, and garage procedures were also tested. Analyses were conducted to illustrate possible uses of the data and to confirm the effectiveness of the adapted instrumentation. An independent evaluator reviewed the project, including the technical approach, instrumentation, data and questionnaires.

Demonstration of motorcycle instrumentation that will support the majority of NHTSA's motorcycle research questions was successful. Instrumentation for fine measurement of gaze location in naturalistic situations was not successful. Identification of coarse scan behavior and general areas where riders are looking (e.g., forward, left, right, down, rearward) was possible.

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EXECUTIVE SUMMARY

As fatalities from other vehicle crashes have been decreasing motorcycle crash deaths have been increasing. During the last 10 years, the proportion of deaths from motorcycle crashes rose from 5 percent to 15 percent of all traffic fatalities. Naturalistic data collection methods are being used to address a range of needs, particularly traffic safety, for drivers of cars, trucks, and other vehicles except motorcycles. A project was undertaken to evaluate the feasibility of using naturalistic data collection on motorcycles.

Research questions related to motorcycle research were reviewed. Instrumentation techniques and study procedures that have been used for light- and heavy-vehicle studies were adapted for use in answering the motorcycle-related questions. Instrumented motorcycles were ridden by three riders for a total of over 3,100 miles. The final data acquisition system and instrumentation recorded acceleration in three axes, yaw, pitch, roll, geographic location, rear-wheel speed, position in lane, turn-signal use, braking, range and closing speed to forward objects, and five video views. The sensor and video data were collected continuously while the bike was running. Development of helmet-mounted eye tracking and three dimensional head tracking instrumentation for use in naturalistic studies was attempted. Study components including recruiting, screening, questionnaires, and garage procedures were also tested. Analyses were conducted to illustrate possible uses of the data and to confirm the effectiveness of the adapted instrumentation.

Participants were recruited primarily through flyers and word of mouth. Flyers were placed on motorcycles. The flyers asked riders to answer a survey about their willingness to participate in such a study. Riders could fill in the survey using a paper version that was included with the flyer or by going to an online version of the survey.

Following data collection and demonstration, analyses were conducted, and a third-party researcher conducted an independent evaluation of the project. The independent evaluation included recommendations for future work and found that VTTI’s approach was technically sound.

Demonstration of motorcycle instrumentation that will support the majority of NHTSA’s motorcycle research questions was successful. Instrumentation for fine measurement of gaze location in naturalistic situations was not successful. Identification of coarse scan behavior and general areas where riders are looking (e.g., forward, left, right, down, rearward) was possible.

ACRONYMS

CB	Citizens Band radio
CCD	charged couple device
CMOS	complementary metal-oxide-semiconductor
DAS	data acquisition system
GIS	geographic information system
GPS	global positioning system
IMU	inertial measurement unit
IE	independent evaluator
IR	infrared
IRB	Institutional Review Board
NHTSA	National Highway Traffic Safety Administration
NSTSCE	National Surface Transportation Safety Center for Excellence
OEM	original equipment manufacturer
SMS	Smart Microsystems
TTC	time-to-collision
VDOT	Virginia Department of Transportation
VPET	ViewPoint Eye Tracker
VTTI	Virginia Tech Transportation Institute

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Introduction

The number of motorcyclist fatalities occurring on the nation's roads, and the trend in motorcyclist fatalities, is alarming. In 2009, almost one in seven motor vehicle fatalities were attributed to motorcycles (NHTSA, 2010). While motorcyclist fatalities decreased in 2009, they previously had increased each year since 1997. The proportion of deaths from motorcycle crashes rose from 7 percent to 13 percent of all traffic fatalities during the past 10 years.

Although a great deal is known about the characteristics of motorcycle crashes from crash databases, much less is known about the differences in rider behavior and exposure of those involved in fatal crashes versus those who are not involved. Naturalistic observation provides a unique mechanism for gleaning additional understanding of driver behavior, exposure, and subsequent crash risk. Understanding these relationships is key to developing effective countermeasures.

The National Highway Traffic Safety Administration (NHTSA) and others are using naturalistic data collection methods to address a broad range of needs. Data from naturalistic studies have been instrumental in describing behaviors as found in real-world driving. Findings from instrumented-vehicle studies have been of interest to Congress relative to legislating, to government agencies in identifying contributing factors in a range of crash types, to fleet operators working to improve operating procedures, and to vehicle manufacturers during systems development and testing.

Data describing the conditions within which motorcyclists ride, the interaction of other vehicles and motorcycles, the capabilities of riders, and simply how people ride, are needed to identify factors that are contributing to the motorcycle crashes. This document reports on instrumentation appropriate for collecting these types of data and a pilot test of the instrumentation and study procedures.

Two Funding Sources

Two funding sources were used during this project. NHTSA funding was used to support transition of sensors from automotive and truck application to motorcycles. The measures included in the NHTSA scope were geographic position, speed, surrounding environment (from cameras), eye-tracking, and measures of acceleration and rotation. A second funding source, from the National Surface Transportation Safety Center for Excellence (NSTSCE), was used to support work that complemented the objectives of the NHTSA project. This NSTSCE funding used a survey to collect rider information regarding how to configure instrumentation for motorcycles. NSTSCE funding was also used to acquire a test platform, integrate forward facing radar units into the instrumentation package, and explore the feasibility of collecting additional brake input measures. Findings obtained from these two funding sources will be included in this report.

Research Questions

The following initial set of research questions was provided by NHTSA:

- Where are riders looking when they have conflicts, near-crashes, and crashes? Do riders who have sufficient sight distance (i.e., looking 6+ seconds ahead of them) have fewer crashes and near-misses than riders who are overriding their sight distance?
- How does exposure among the study participants affect involvement in crashes or near-crashes? Does the number of conflicts, near-crashes and crashes increase with exposure, or is there an inverse relationship?
- What is the study participants' riding exposure over a riding season? Where do they ride most often and how does this compare to the fatality data?
- What is the interaction between experience and exposure?
- Are there differences between riders who have near-crashes and/or crashes and riders who experience none? What are they?
- How does lane placement affect a rider's ability to avoid crashes and detect hazards?
- Are riders who avoid crashes and near-crashes less likely to travel over the posted speed limit?
- How many instances occur in which the driver appears to fail to see the motorcycle rider (i.e., turning in front of the rider when there really isn't enough time to do so)?

During the early phase of the project, these initial research questions were combined with additional questions for consideration by NHTSA. Three respondents at NHTSA classified each of the full set of questions as low, medium, or high priority. These priority classifications were recast, with 1=low, 2=medium, and 3=high coding. Table 1 provides the questions that had an average value of 3.0. In other words, all respondents indicated they were high priority. A complete list of the questions with average priority values is provided in Appendix A. These ratings were used to support instrumentation decision making and specification development.

Table 1. High-priority research questions.

Questions
Where are riders looking when they have conflicts, near-crashes, and crashes? Is this the same between trained and untrained riders?
Do riders who have sufficient sight distance (i.e., looking 6+ seconds ahead of them) have fewer crashes and near-misses than riders who are overriding their sight distance?
How does exposure among the study participants affect involvement in crashes or near-crashes?
How does exposure affect where riders are looking?
Does the number of conflicts, near-crashes and crashes increase with exposure, or is there an inverse relationship?
What is the study participants' riding exposure over a riding season?
What is the interaction between experience and exposure?
Defensive riding - General
Do crashes and near-crashes arise during curve negotiation?

Questions
What are the trajectories (speed, direction, time-to-collision, etc.) of the subject motorcycle and other involved vehicles?
Evasive maneuvers - General
What is the relationship between riding style (braking, leaning, etc.) and pre-incident speed?
What is the relationship between riding style (braking, leaning, etc.) and rider experience?
What is the relationship between riding style (braking, leaning, etc.) and weight: power ratio?
How often do one or both wheels skid?
Lateral control - General
What is the sequence of events/precipitating factors in crashes and near-crashes?
What is the sequence of events/precipitating factors in crashes and near-crashes involving a second vehicle (leading, following, crossing, oblique crossing, adjacent)?
Is there a difference in riding characteristics (brake bias, braking force, countersteering, lean angle) between trained and untrained riders during crash or near-crash events? Does this correlate to the same differences above?
Are trained riders more effective in evasive maneuver choices? Execution?
What loss of control mode occurs leading up to the event (e.g., capsize, slide out, high side, wide on turn, end over, wobble, weave, lost wheelie)?
What is the timing and cause of rider separation from bike?

Instrumentation Adaptation

The prioritized research questions and a DAS design questionnaire were used to drive sensor selection as well as explore the feasibility of design alternatives. A specification was then developed for the instrumentation package using the strategy outlined in the following sections.

Specification Development

At the beginning of the project, a draft specification was developed based on the research question prioritization. The sections of the specification included bracketry, housings, wiring, fasteners, waterproofing, ventilation, sensor selection, and integration of components. As the bikes were instrumented, released to participants, returned, and data reviewed, the draft specification was revised. The complete specification table is provided in Appendix B.

DAS Design Questionnaire

In addition to sensor selection, the complete data acquisition system (DAS) must accommodate the usage requirements of potential participants. There were often questions regarding the needs and willingness of participants with respect to different design alternatives. A DAS design survey was created to provide a source of data to drive decision making in these areas. The survey was distributed through flyers placed on motorcycles (~60 flyers, mostly in Blacksburg, VA), through e-mail, and rider forums including a Motorcycle Safety Foundation list. Individuals were encouraged to forward the link to the online questionnaire on to others. The questionnaire asked a range of questions related to:

- Rider demographics
- Motorcycles owned
- Bike storage between rides
- Access to power, Internet
- Bike and riding accessories
- Riding - season, days, types, duration
- Training and practice
- Maintenance behavior
- Protective clothing
- Willingness to participate with respect to different levels and types of instrumentation
- Compensation requirements

A complete list of the questions is provided in Appendix C. During development of the instrumentation specification, engineers referred to the accumulating responses to this questionnaire for guidance. For example, in considering whether a participant's own luggage carrier might be used to carry equipment, it was possible to refer to the questionnaire for an estimate of how many riders have a luggage carrier and how often the storage has some extra room in it.

A comprehensive analysis of these questionnaire data will be completed later as part of the NSTSCE-funded portion of this project. Preliminary results related to willingness to participate are reported here, and indicate that it will be possible to obtain participants.

At time of writing, the survey had 229 respondents, with 90 percent male and 10 percent female. Respondents' primary location for riding came from 40 States and three countries besides the United States. Although the survey was primarily intended for riders in the United States, responses were received from riders outside the United States because an Internet link to the survey was posted on online user groups and forums. The top five States were Virginia (43), Illinois (23), New York (14), California (10), and Michigan (10). Respondent ages are shown in Table 2.

Table 2. DAS design questionnaire - respondent ages.

Age	Response Frequency
Less than 20	2
21-29	24
30-39	26
40-49	66
50-59	69
60 or older	37
Unknown	5

Willingness to Participate and Compensation

When asked their level of interest in participating in an on-road study exploring motorcycle riding behaviors and performance, 75 percent indicated the highest willingness on a scale from 0 to 5. One percent indicated 0, "Not Willing." The remaining 24 percent was distributed approximately evenly from 1 to 4. A number of differences may be present related to willingness to participate. When divided according to location of manufacture of the motorcycle that they primarily ride, there may be some differences indicating less willingness by riders of less common motorcycles. Some differences in willingness were also present between riders of different ages. Ninety-two percent of respondents in the 20- to 29-year-old age group indicated the highest willingness. Sixty-six percent of respondents in the 50- to 59-year-old age group were as willing. For other age groups, 74 to 80 percent indicated this highest level of willingness. The top four reasons for not participating include privacy (11), safety (6), too much trouble (4), and infrequent riding (4). Many respondents did not require compensation, or did not have high requirements. Accessories or clothing (25) was the most common non-monetary form of compensation mentioned, followed by payment for or replacement of damaged items (16). It should be noted that, as implied above, this was not a representative sample of riders in the United States. That said, the results generally indicate that it will be feasible to get participants, and the survey provides insight into participants' initial concerns as well as a number of instrument design requirements that likely apply to all riders, whether or not they were included in this survey. Further analysis of the survey responses will investigate willingness to participate by bike type (e.g., touring, cruiser, sport).

Various Instrumentation Related Responses

Though the questionnaire did not identify when a participant owned an extra helmet for a passenger's use, it is common for participants to have multiple helmets. Nineteen percent of participants had one helmet, 30 percent had two, 26 percent owned three helmets, and 12 percent owned four helmets. The remaining 12 percent owned five or more helmets. Approximately 86 percent of respondents store their bikes in the house or garage when at home, with the remaining storing it in the driveway, parking lots, and other locations. Approximately 90 percent of respondents have an electrical outlet near the motorcycle. Approximately half of the respondents indicated that they charge their motorcycle batteries during long breaks from riding and 26 percent indicated that they charge their motorcycle occasionally. Approximately 20 percent indicated that they never charged their motorcycle batteries. Approximately 60 percent always use luggage carriers or saddlebags. Approximately half of the respondents use a Global Positioning System (GPS) on the motorcycle. Approximately 13 percent indicated that they use a cell phone while on the motorcycle. Other communication devices included intercoms (20%) and Citizens Band radios (CBs) (20%). Related to parking the motorcycle while at work, approximately half of respondents who ride their motorcycles to work indicated that they park the bikes in ground-level parking lots, with the remaining being roughly evenly distributed between garages, parking structures/decks, street parking, and other.

IRB Preparation

For this project it was not necessary to have a large number of participants, and interaction of researchers with participants during the study would not significantly affect the outcome of this hardware assessment effort. However, where possible, procedures were followed that would support a large and robust experimental study.   The screening and consent processes were developed and executed in a manner that could be done at a larger scale. In this way, challenges could be identified and addressed during this study in a way that would apply to a larger study. For example, very little demographic or other rider information was necessary for this study; however, an extensive pre-participation questionnaire was developed and incorporated (Appendix C). In this way, feedback could be obtained from the Institutional Review Board (IRB) during the review process and from participants as they completed questionnaires.

Recruiting

The DAS design questionnaire described previously had been distributed early in this project by placing a flyer on motorcycles primarily in the Blacksburg area. At the end of that questionnaire, respondents were also asked to provide contact information if they might be interested in participating in an on-road study in which their bike was instrumented. People who indicated interest were contacted by phone and screened for participation.

Screening Script and Questions

Initial contact with potential study participants was done by telephone using a script with questions determining eligibility (Appendix D). In that telephone call, a researcher gave a general description of the study, including the instrumentation that would be installed on motorcycles and payments that would be made to participants. The researcher offered to answer questions at any time throughout the call.

If the person expressed an interest, the researcher asked questions to determine eligibility. These questions sought information regarding demographics, licensure, rider insurance, mechanical condition of the participant's motorcycle, employment eligibility, type of motorcycle, and riding experience. If the participant was eligible and remained interested, a copy of the informed consent was sent for his or her review. If the participant was interested in participation after reviewing the informed consent, a time was arranged to have the participant meet with researchers at the Virginia Tech Transportation Institute (VTTI) for an information session and to leave his or her bike for instrumentation.

Participant Questionnaire

The questionnaire used in this study collected a range of information that would be both helpful in designing data collection hardware for motorcycles and helpful in testing questions for use in a larger study. The questionnaire covered the same general topics as the DAS design questionnaire.

Participant and Bike Intake and Consent

Following the screening telephone call and reviewing the informed consent (Appendix E), participants met with researchers at VTTI for an information session. During this meeting, researchers reviewed the informed consent with the participant and answered questions from the participant. The informed consent describes the purpose of the study, procedures, risks, benefits, compensation, and participant rights and responsibilities. Attention was given to details in the informed consent regarding the instrumentation and what to do in case of a malfunction or crash. In the informed consent and during the information session, the participants were asked to ride as they normally would. The participant was also shown pictures of the instrumentation installed on another motorcycle. After the participant signed the informed consent, he or she filled out tax paperwork, a contact information form, and a pre-drive questionnaire. A photocopy of the participant's driver's license was also made.

The participant parked his or her bike in VTTI's garage. A VTTI researcher then gave the participant a ride home or to work. After the motorcycle was instrumented, the participant was given a ride back to VTTI to pick up the motorcycle.

After a participant's bike arrived in the garage, it was thoroughly photographed to document its initial condition. The odometer reading and the date and time of arrival were also recorded. Following instrumentation, the bike was again photographed and the date and time that the participant retrieved the bike were recorded. Participants were compensated at $20 per hour for the initial information session and completing the participant questionnaire, and $20 per week that they rode their motorcycles with instrumentation.

Instrumenting Motorcycles

Garage Procedures

Garage procedures were developed specifically for working on motorcycles. A separate work space was designated for motorcycle work. Equipment such as tools, riding jackets, helmets, and gloves were kept in this area. An H-frame shelving unit was covered with open cell foam material for storing components while the bike was being instrumented. Different from cars, it is common to remove finished plastic and metal parts from motorcycles while working on them. The foam on the shelving reduced the potential for scratching these parts when they were set aside during work.

Per the agreement established in the informed consent with participants, the motorcycles were started during instrumentation, but were not ridden. Movement of the motorcycles was kept to a minimum. At times they were placed on center or rear stands (for example, when testing wheel speed instrumentation). The lead instrumentation engineers involved with handling and working on the motorcycles were motorcycle riders. Most of the project's hardware and software staff own motorcycles and had considerable experience working on motorcycles.

While working on the motorcycles, the staff noted any maintenance issues, such as leaking brake fluid or missing bolts. When the participants returned to pick up their motorcycles after instrumentation, these items were discussed with the participants to ensure both parties understood how the bike was received and returned to the participant.

When participants returned their bikes to have the instrumentation removed, researchers would talk informally with the participants regarding their experience riding with the instrumentation. All three participants were enthusiastic about their participation and happy to discuss their experiences. No one indicated any changes in the way his or her bike rode or had any concerns with the instrumentation's placement.

Component Locations

The following sections discuss each of the hardware components that were installed on the motorcycles to facilitate naturalistic data collection.

Main DAS Unit and Enclosures

The main DAS unit consists of the processing unit that choreographs data from various sensors, performs pre-processing, creates data storage files, and records those files to persistent memory for subsequent retrieval. Factors influencing the design of the main unit and enclosure included: weight, conspicuity, mounting location/orientation flexibility, maintainability, ventilation, and resistance to spray and dust. Two main DAS units were used during the study. The first unit was predominantly carryover components from previous VTTI naturalistic driving studies, such as the 100-Car study (Dingus et al., 2006). The components were repackaged into a Givi Hard Luggage Box as shown in Figure 1.

Figure 1. Main DAS unit – carry-over components.

This setup provided a flexible development platform for use while the specifics of naturalistic motorcycle instrumentation were being identified. The configuration included a display and keyboard for diagnostics, extra space for inclusion of redundant sensors during testing, and easy access to the equipment. Additionally, because bracketry are available from Givi for many different motorcycles, the use of this box was intended to simplify transferring the DAS to other bikes.

During instrumentation of the second participant’s motorcycle, which was a dual-sport bike with an original equipment manufacturer (OEM) Givi rack, it became apparent that the weight of the carry-over DAS hardware (14,061 g, 31 lbs) was going to limit the range of bikes that could be instrumented. To address this, the development of an enclosure for VTTI’s compact embedded NextGen DAS was accelerated. The size (7.5 cm × 28 cm × 19 cm) and weight (1,314 g, 2.9 lbs) of this DAS hardware would permit instrumentation of a larger range of bikes.

To accommodate various participant bike configurations—such as luggage racks and passengers—an enclosure was designed that could be mounted toward the rear of the motorcycle, either centrally, possibly near the license plate or brake light, or on the side of the bike (Figure 2). Several iterations were tested during development and on the participants’ bikes.

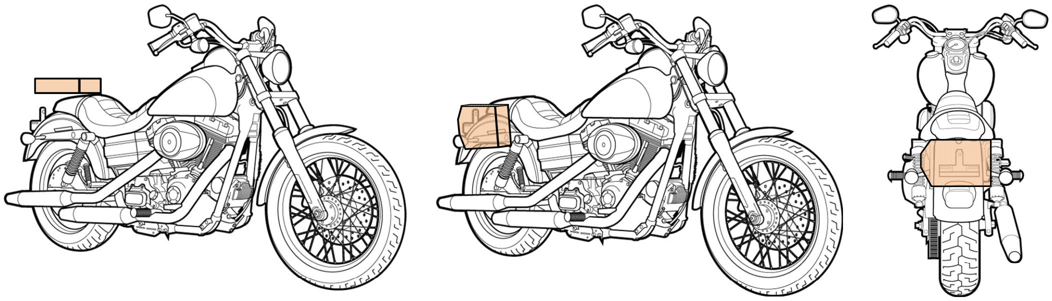


Figure 2. NextGen main DAS unit general mounting alternatives.

In the design of the enclosure, considerable work was required to balance the competing requirements for cooling and resistance from dust and spray. The first enclosures, which were fully sealed, retained too much heat from the processor. Subsequent designs tested active and passive cooling, alternative internal ducting approaches, and various minor adjustments for maintainability. An open enclosure is shown in Figure 3 with labels indicating various elements of the design.

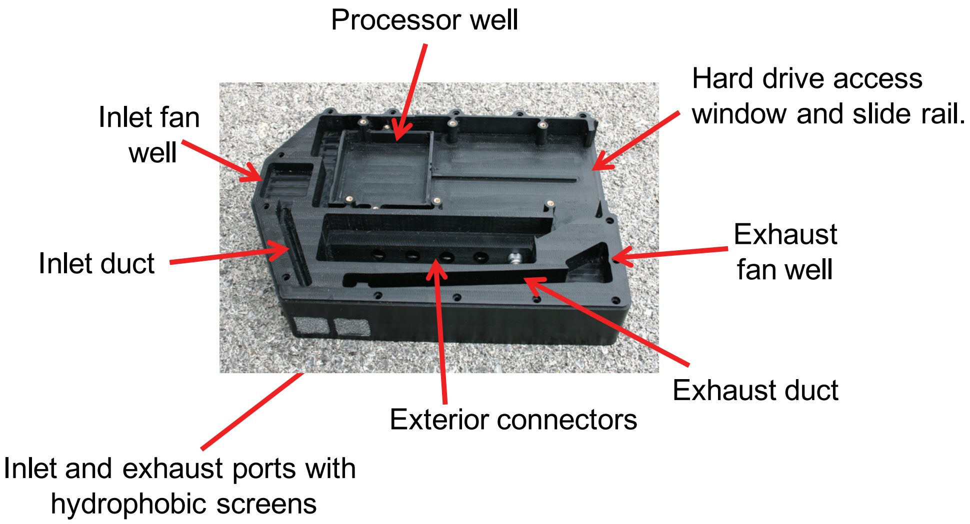


Figure 3. NextGen main DAS unit enclosure with design elements.

The enclosure shown in Figure 3 is designed to be mounted either vertically, with the inlet and exhaust ports facing the pavement, or horizontally, with the inlet and exhaust ports facing rearward. Should any moisture enter the unit, the design of the ducting ensures that it will drain without contacting any of the electronics. This NextGen main DAS unit configuration is shown mounted on participant-owned bikes in Figure 4.

(a) (b)

Figure 4. NextGen main DAS unit on two bikes.

Camera Locations and Selection

The objective with the on-bike cameras was to collect video of the roadway environment within which the rider was operating as well as to collect video of the rider’s head and torso. Views of the head and torso would provide information about how the rider leans and visually scans. Various numbers of cameras, field-of-view, and camera locations were tested on the road and reviewed to evaluate how well the behaviors of the rider, as well as the surrounding environment, were captured. The on-bike camera locations that were tested are shown in Figure 5.

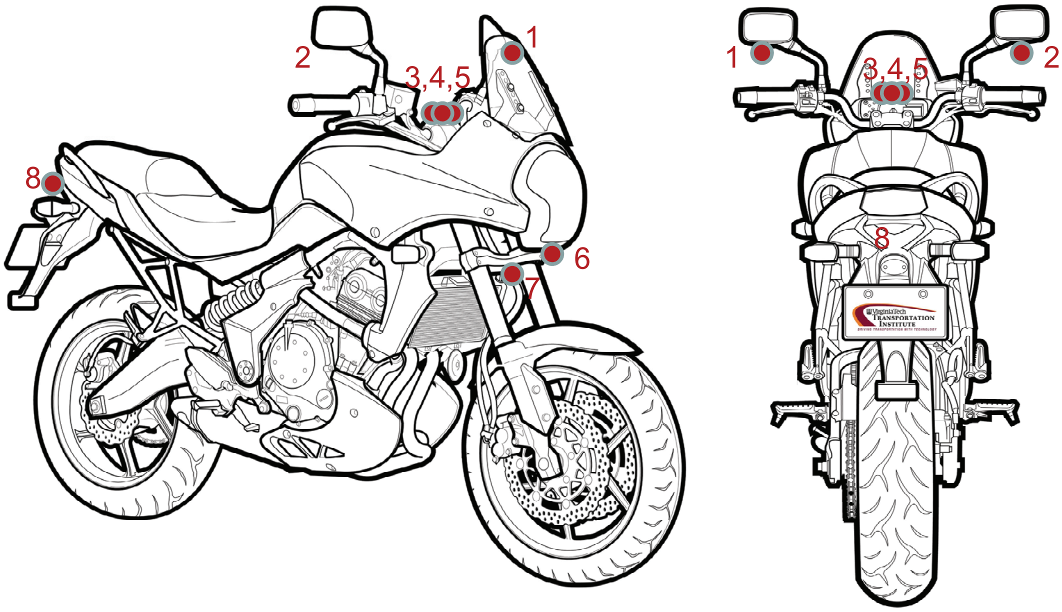


Figure 5. On-bike camera locations that were tested.

Camera locations 1 and 2 were explored for use in monitoring the area beside the motorcycle to the left and right as well as the rider's posture and use of hand controls. Three alternatives were tested for these cameras. One configuration pointed the cameras across the bike, so the left mirror camera (1) recorded the rider, the right side rearward, and the rider's use of throttle and brake. In this setup, the right camera (2) was pointed across the bike to the left, capturing the scene to the left of the bike and the rider's use of the clutch. Views from this configuration are shown in Figure 6a, and the installed camera on the left side (1) is shown in Figure 6b.

(a) (b)

Figure 6. Side-view camera Configuration #1 with mirror mounted cameras facing across the bike.

A second configuration used the same mirror camera mountings, but pointed the cameras rearward. In this setup, the left camera (1) recorded to the left of the bike and rearward and the right recorded the right side of the bike and rearward. Views from this configuration are shown in Figure 7.

Figure 7. Side-view camera Configuration #2 with mirror-mounted cameras facing rearward.

The first configuration was considered better than the second configuration because it provided a view to the side of the bike as well as the rider's torso and hands. The second configuration provides a better rearward view, but no views of the hands or torso. Though the views from the first configuration are desirable, there are several disadvantages of this configuration. Mounting the side-view cameras on the mirrors adds installation complexity to ensure durable fastening of cameras and wires. Cameras mounted on the mirrors were also considered to be excessively conspicuous and a functional annoyance to participants, particularly when adjusting mirrors.

To address these challenges, a third configuration combined the two cameras for viewing to the sides of the bike with a camera viewing the riders head. This central mounting of three cameras is depicted in Figure 5, camera locations 3, 4, and 5. The side views captured by cameras 3 and 5 are shown in Figure 8. These side views used a 140-degree camera lens, providing views of the hand and body position as well as side and rearward views of the motorcycle.

Figure 8. Configuration #3 -- Centrally mounted side-view cameras.

Though side views include the rider's head, a longer focal length camera (4) was included to provide a dedicated view of the rider's head. This view provides information about where the rider is looking and is shown in Figure 9.

Figure 9. Head view camera (4).

The central camera location provides a number of advantages. By placing the three cameras together, only one waterproof enclosure is needed. Similarly, one mounting bracket is necessary (rather than three). The central area is also somewhat more protected from inadvertent contact by the rider and, on many bikes, is protected by a windscreen.

In addition to camera mounting considerations, initial on-road testing revealed that the cameras frequently received direct sunlight that would completely wash out the image due to glare. Though charge-coupled device (CCD) cameras are generally good choices for instrumentation of cars and trucks, the small size requirements, high mounting angles, and absence of shading from an enclosed cab made these cameras less desirable on motorcycles. Complementary metal–oxide–semiconductor (CMOS) cameras were tested as an alternative. These cameras are capable of containing a glare source within a small number of pixels (Figure 10a) while leaving the remainder of the image clear. The trade-off, however, is that CMOS cameras are less capable in low-light conditions. In Figure 10b, a multiplexed view is provided illustrating the trade-offs between the two types of cameras. The forward and rear views (top right) are CCD cameras. These views generally capture the night scene, but have difficulty handling the areas of the image with high light intensities. The face view (lower left) uses a CMOS camera, and is getting just enough ambient light to capture the rider’s face. The left and right side views (lower right), which are using CMOS cameras, are too dark to discern what is occurring. In night-time riding with overhead lighting, the CMOS cameras often provide an adequate image.

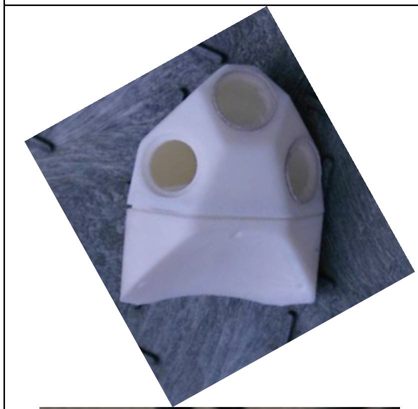
Reflective glare from sun canceled by CMOS camera

(a) (b)

Figure 10. CMOS versus CCD demonstration images.

In addition to handling glare, another advantage of CMOS cameras is that they are generally available in smaller sizes than the CCD cameras. A trade-off, however, is that in the small sizes there are fewer options available for field-of-view. Photos of several iterations of the central camera setup are shown in Table 3.

Table 3. Side- and head-view camera iterations.

	Three collocated CCD cameras. Provided the initial setup for exploring capture of scene, camera angles and field-of-view.
	Tested benefits of infrared shielding on CCD cameras as well as initial weatherproofing testing.
 	First housing designed for CMOS cameras. Provided one weatherproof enclosure. Original camera enclosures were replaced by one custom enclosure to save space. The design did not permit adjustment of cameras for different bike geometries and rider heights and posture.
	Final iteration. Houses three CCD cameras in one “puck.” Enclosure permits adjustment of camera angles for different bikes and riders, and simplifies installation.

Two locations were tested to capture views of the forward roadway. These are depicted in Figure 5, locations (6) and (7). In location (6), the forward camera is affixed (indirectly) to the bike frame, and does not rotate with the handlebars. Location (7) rotates with front forks. Location (6) is generally feasible on motorcycles with fairings, but is often infeasible on bikes without fairings because, on these bikes, all locations with unobstructed view forward rotate as the forks rotate. During development, a video was collected simultaneously from cameras located on a bike in both of these locations. A photo of this setup and captured views is shown in Figure 11.

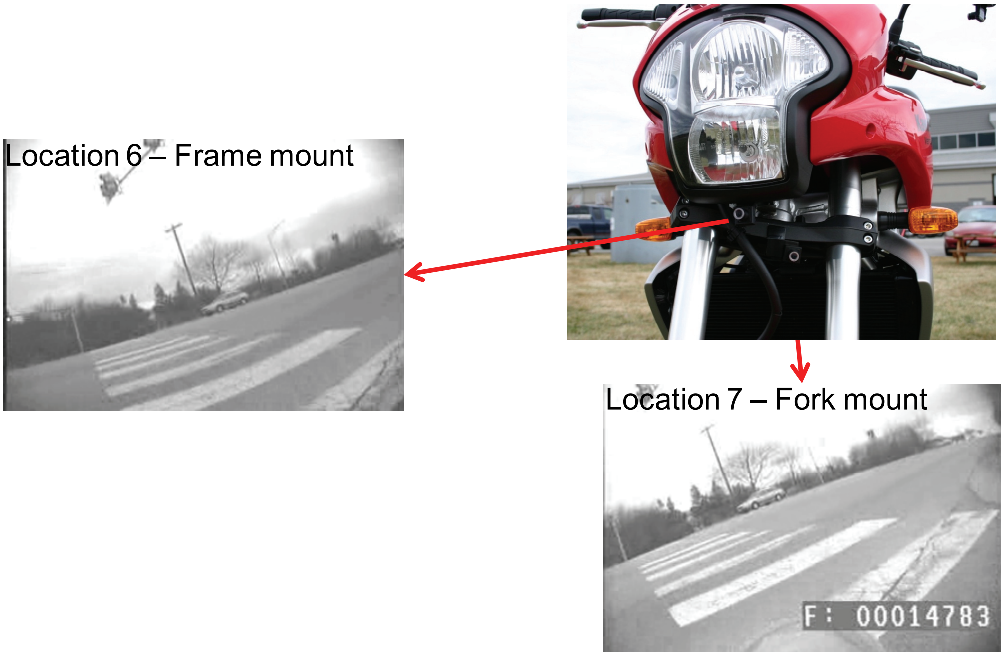


Figure 11. Forward-view camera alternatives.

Video from the two alternatives was compared to look for advantages and disadvantages of the two locations. At all but the lowest speeds, the two camera mount locations effectively provided the same forward views. In the video views captured in Figure 11, the bike is stationary and about to turn right at an intersection. A slightly more rightward view is achieved in Location 7 (fork mount), giving greater preview in the direction of travel, but only at low speeds. Overall results suggested that the forward camera could be located either on a rotating or non-rotating surface. Once testing was completed using the cameras shown, a waterproof lipstick form factor camera was selected for the forward view.

The view behind the bike was also considered of interest in order to gather understanding of the behavior of riders in the presence or absence of following traffic, as well as to provide a view of vehicles approaching from behind the rider in lanes to the left and right of the rider's lane. The location for this camera is shown in Figure 5, Location 8. A waterproof lipstick camera was also selected for this application. A photo illustrating this mounting is provided in Figure 12.

Figure 12. Location 8 - Rear-view camera.

The views from each of the cameras were multiplexed into one video frame. For Participant 1, four views were used. For participants 3 and 4, transition to the most recent DAS permitted the inclusion of the rear view. This DAS also permits software adjustment of how much area the different views are allocated in the multiplexed image. Schematics illustrating the camera views, and screen captures showing the views multiplexed, are shown for the four-camera setup in Figure 13 and for the five-camera setup in Figure 14.

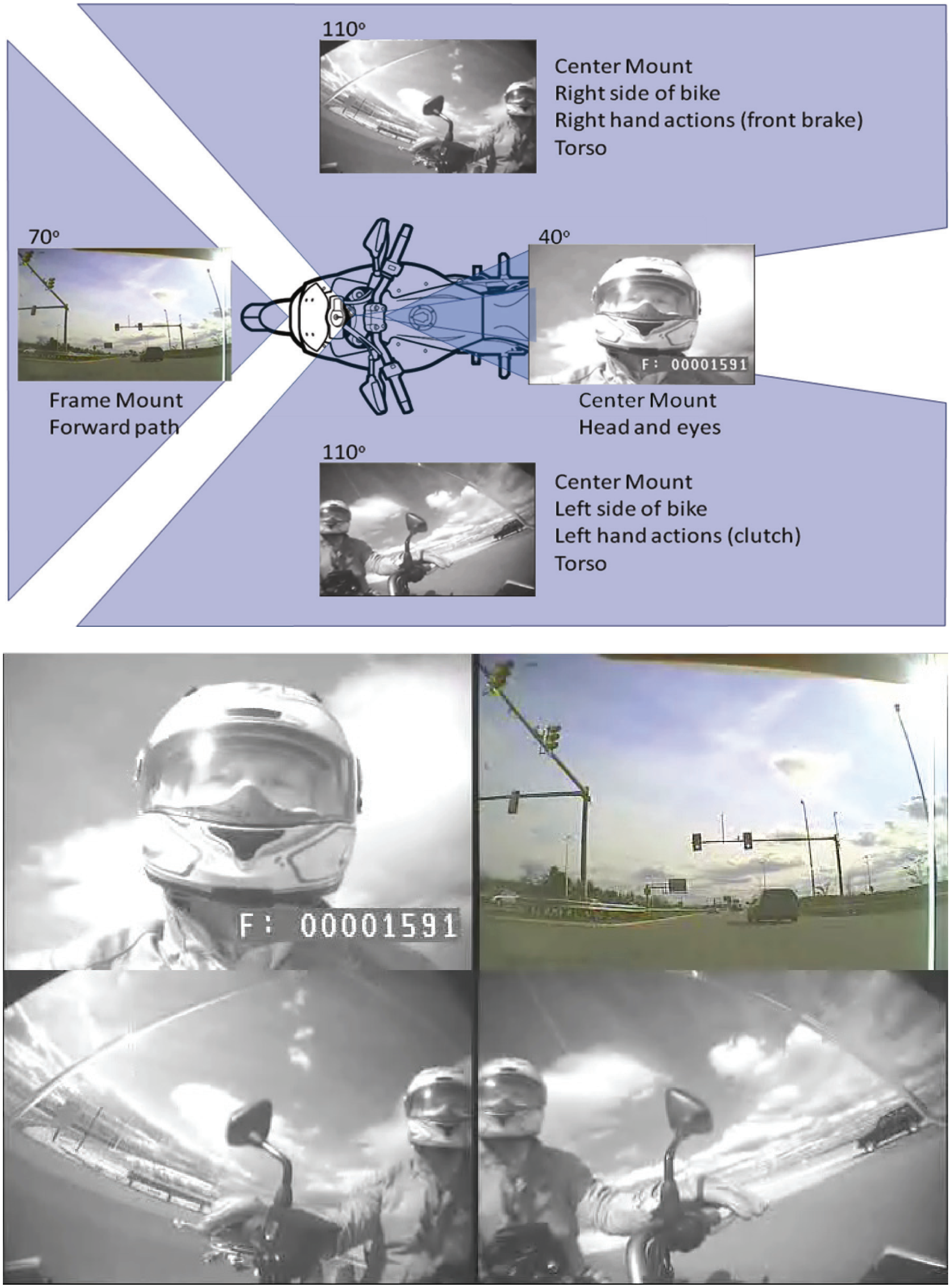


Figure 13. Four-view schematic (top) and multiplexed image (bottom).

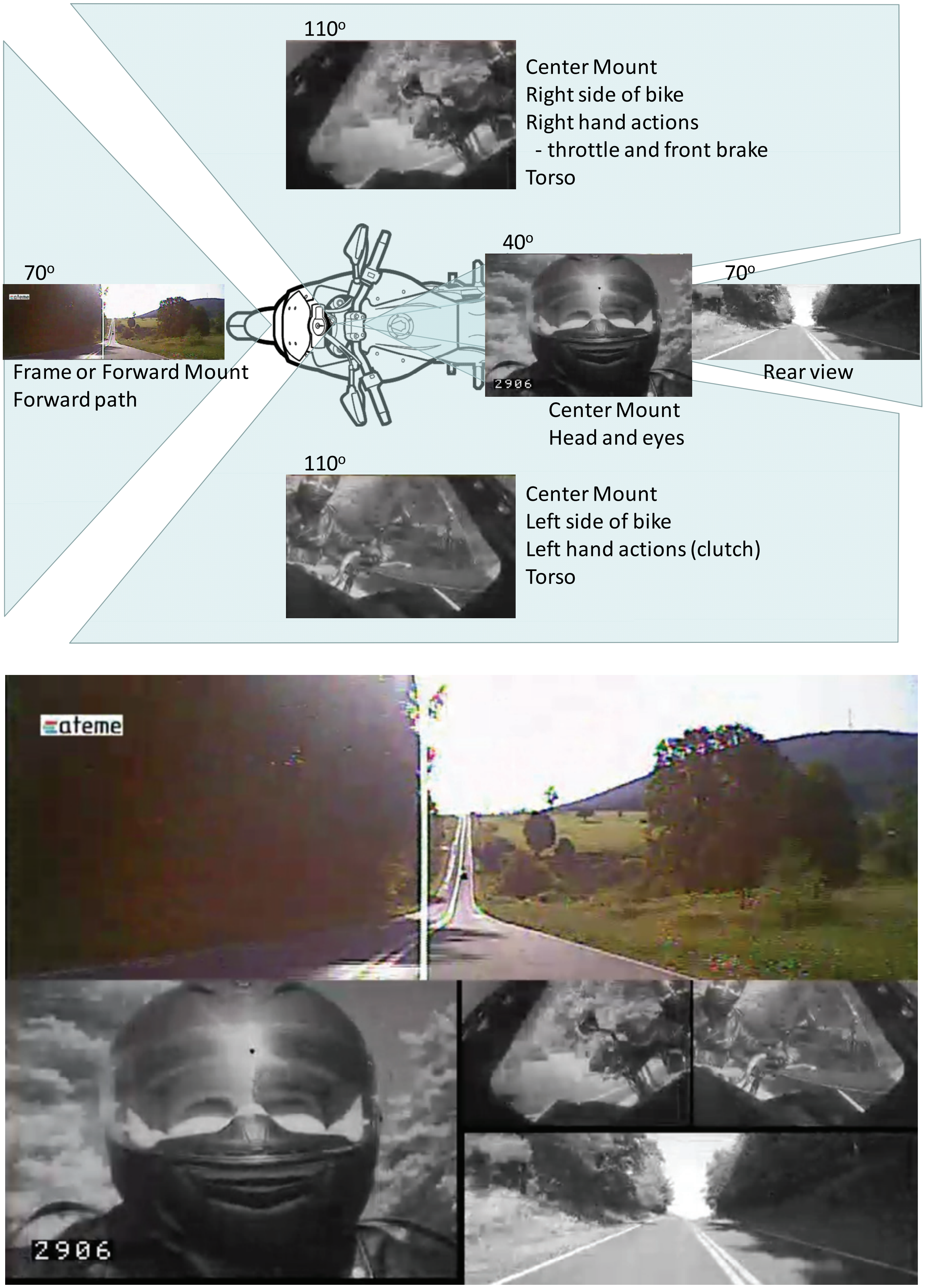
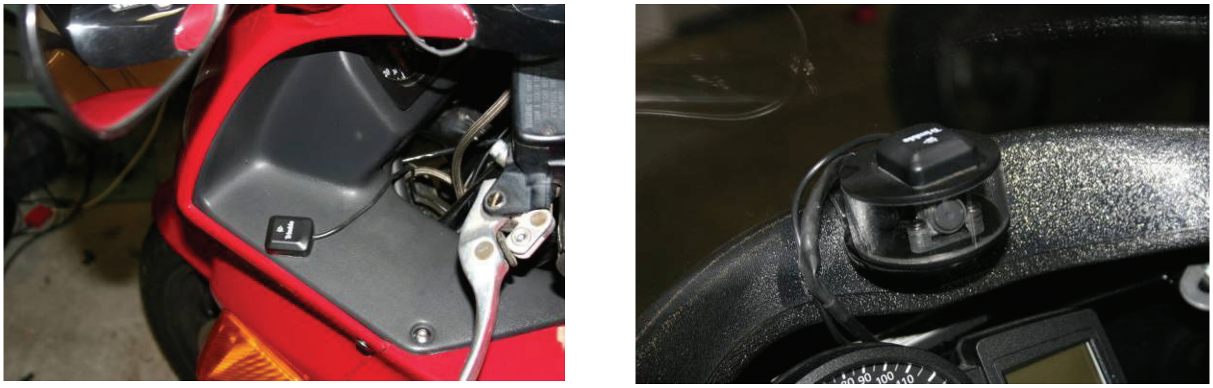


Figure 14. Five-view schematic (top) and multiplexed image (bottom).

GPS Antenna and Module

GPS was used to identify the latitude and longitude coordinates of the motorcycle while it was being ridden and to provide a GPS based speed measure. Several locations were tested for the GPS antenna and receiver module. An initial receiver module was susceptible to electromagnetic interference. Performance improved once this module was replaced with one from a different vendor. A number of locations appear to be acceptable for antenna placement, with the primary constraint being that the antenna has an unobstructed view of the sky. Figure 15 illustrates the mounting on two of the motorcycles. The position shown in Figure 15a provided fair performance, but appeared to have more frequent dropouts, probably because some angles were blocked above the antenna. The position shown in Figure 15b illustrates the antenna mounted on top of a camera housing. This location provided the best reception and eliminated the need for attaching the antenna to one of the bike's finished surfaces.



(a) (b)

Figure 15. GPS antenna placement.

IMU

The inertial measurement unit (IMU) provides sensing of acceleration in three axes and roll, pitch and yaw rates. A plastic housing (10 cm × 16.5 cm × 4 cm) was developed to protect the IMU module circuitry (Figure 16).

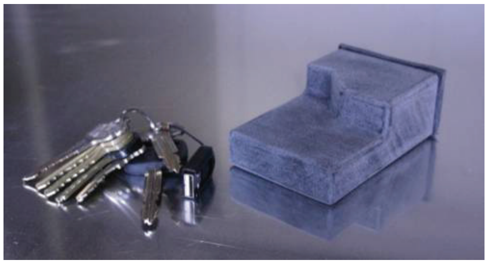


Figure 16. IMU enclosure (keys for scale).

The IMU axes and sign convention used in the data are shown in Figure 17.

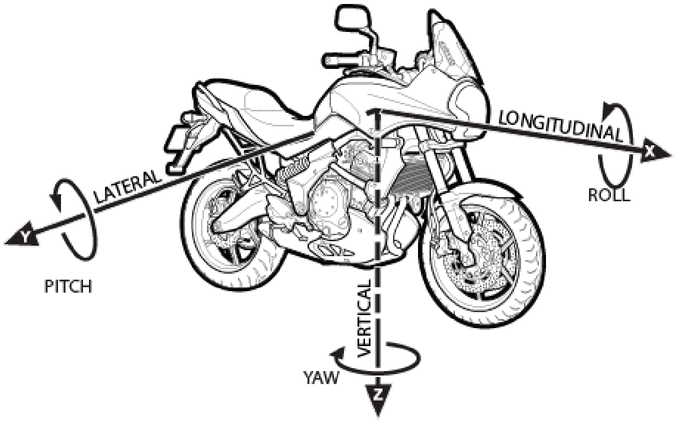


Figure 17. Axes and sign convention used for kinematic measures.

The IMU was housed separate from the main DAS unit, 1) to permit mounting it as close as possible to the center of the motorcycle to minimize measurement error, and 2) to minimize the vibrations that would be present in the typically cantilevered mounting that was used for the main DAS unit.

Collecting On-Road Data

The following section describes the pilot test that was executed to validate the naturalistic DAS and obtain a preview of impressions from the participants of a naturalistic motorcycle study.

Motorcycles and Instrumentation Used

Four participants were recruited and completed pre-participation paperwork. The first participant rode a motorcycle that is owned by VTTI and had been used for instrumentation development work. During the first participant's use, the carry-over VTTI main DAS system was mounted in a Givi hard luggage box. As described in the discussion of the main unit DAS, during instrumentation of the second participant's dual-sport bike, weight of the carry-over DAS was recognized as a constraint that would limit the variety of bikes that could be instrumented. The second participant's bike was put back together without instrumentation and returned to her while work was done to migrate to the smaller and lighter NextGen DAS. During this transition, the participant sold her motorcycle and did not participate in the driving portion. The third and fourth participant bikes were instrumented with the NextGen DAS unit. The three motorcycles that collected on-road data are shown in Figure 18.

(a) (b) (c)

Figure 18. Three motorcycles, with instrumentation.

The first motorcycle provided a convenient platform for testing a range of instrumentation alternatives and comparing data across sensor alternatives. The second and third bikes were a sport bike and a touring bike, respectively, that allowed the hardware engineers to investigate implementation on additional platforms. Specifics of the instrumentation for each bike are as follows:

2009 Kawasaki Versys 650 cc (Figure 18a)

- Four camera views (forward, face, left side/rearward, right side/rearward)
- Geospatial position from GPS
- Speed from GPS
- Speed from transmission pulses collected from motorcycle network
- Acceleration in three axes using VTTI-designed IMU
- Acceleration in three axes using Crossbow IMU
- Roll, pitch and yaw rates using VTTI-designed IMU
- Roll, pitch and yaw rates using Crossbow IMU
- Roll, pitch, and yaw angles using Crossbow IMU
- Brake status through VTTI instrumentation connected to brake light wiring
- Turn signal status through VTTI instrumentation connected to brake light wiring
- Lane tracking from VTTI-designed machine vision
- Forward radar from Smart Microsystems (SMS)

1999 Honda VFR 800 cc (Figure 18b)

- Five camera views (forward, face, left side/rearward, right side/rearward, rearward)
- Geospatial position from GPS
- Speed from GPS
- Acceleration in three axes using VTTI-designed IMU
- Roll, pitch and yaw rates using VTTI-designed IMU
- Brake status through VTTI instrumentation connected to brake light wiring
- Turn signal status through VTTI instrumentation connected to brake light wiring
- Lane tracking from VTTI-designed machine vision

- Forward radar from SMS

2007 BMWR1200 1200 cc (Figure 18c)

- Five camera views (forward, face, left side/rearward, right side/rearward, rearward)
- Geospatial position from GPS
- Speed from GPS
- Acceleration in three axes using VTTI-designed IMU
- Roll, pitch and yaw rates using VTTI-designed IMU
- Brake status through VTTI instrumentation connected to brake light wiring
- Turn signal status through VTTI instrumentation connected to brake light wiring
- Lane tracking from VTTI-designed machine vision
- Forward radar from SMS

Collection Process

Data collection began when the participant picked up his or her motorcycle after instrumentation was complete. Data were collected on the hard drive within the DAS from key-on to key-off. The hard drive capacity is sufficient to collect data for eight to twelve months for most riders without downloading. Because this study involved developmental equipment, the motorcycles were visited fairly frequently, particularly early in the data collection period. Retrieving data from the motorcycles did not require the participant to be with the motorcycle. When data were retrieved, a research assistant visited the motorcycle at the participant's home or work, and swapped a new hard drive with the one that was on the motorcycle. During the project, various occasions arose where further interaction with the participants was required. These included situations where, upon reviewing collected data, some problem or opportunity for improvement was identified (see Primary Lessons Learned section). If it was expected that these adjustments would take longer than a few minutes, the participant was contacted and a time was arranged during which the participant would not be using the motorcycle. A team from VTTI would then visit the motorcycle to make adjustments. The participants did not need to be present during these visits.

The collection process was similar to the way data are retrieved from the DAS in naturalistic studies using other types of vehicles, such as passenger cars. The main difference here was the frequency of visiting the motorcycles. Visits to the bike would be less frequent in a larger scale study, as the primary reason for visiting the bike would be exchanging the hard drives. In a larger study, a likely approach would be to visit all bikes and exchange hard drives after approximately six months. Where and when the bikes are likely to be parked are recorded during the information session. This allows research assistants to locate the motorcycles for data collection without interrupting the participants' normal schedules.

The data collection proceeded as planned, with improvements being identified and incorporated over the course of the data collection period. Summary of the data collected is provided in the Demonstrative Analysis section later in this report.

Primary Lessons Learned

The following list identifies lessons learned from each of the participant motorcycles:

Participant 1

- Power constraints and system “sleep” strategies to maintain a charged battery
- GPS module selection
- Radar feasibility
- Lane tracker feasibility
- Bracketry material selection and potential for fatigue failure
- IMU feasibility
- Initial ruggedization of components
- Useful camera views
- Glare management / CMOS camera versus CCD camera trade-offs

Participant 2

- Acceptability of screening and bike intake procedures
- Main DAS unit weight constraints

Participant 3

- Additional bike intake and garage procedures
- Motorcycle parking behaviors
- Main DAS unit enclosure design (ventilation, waterproofing, hard drive access)
- Feasibility of three-camera “puck” design
- GPS antenna placement
- Vibration issues (camera lenses)
- Solid-state hard drive requirements

Participant 4

- Main DAS unit enclosure design refinement (ventilation, waterproofing)
- Vibration issues (camera mounting)
- Camera “puck” condensation

Eye-Tracking Instrumentation Development

More time was required for exploring the feasibility of eye-tracking than for adapting the other instrumentation for use on motorcycles. To accommodate this development timeline, eye-tracking engineering work was pursued in parallel with other instrumentation work. The informed consent material was written to permit inclusion of eye-tracking instrumentation if and when it became available. Despite significant effort, a feasible eye-tracking strategy for measuring precise eye-gaze in naturalistic motorcycle riding was unsuccessful. This section is intended to stand alone and describes the efforts within development and evaluation of precise eye-gaze tracking.

Level of Precision Required for Gaze Tracking

A computational approach was included to identify the boundaries at which eye-tracking would reach its accuracy limit in supporting the research questions. For this simplified analysis, it was assumed that the roadway was flat and level. The accuracy of eye-tracking measures was then varied between 0.25 degrees and 10 degrees; the speed was varied between 30 mph and 60 mph; and, the true gaze location was varied between 2 seconds and 12 seconds ahead of the rider. The outcome was an indication that to resolve gazes to typical roadway locations, system accuracy must be less than one degree. Two examples help explain this accuracy boundary. First, consider review of the gaze location of a rider approaching a curve at 60 mph and looking at the curve apex 4 seconds ahead. If only the lateral error in eye-tracking is considered, a 2-degree error would result in incorrectly identifying the rider's gaze location as being on the center of the travel lane. Next, consider the vertical gaze position, which translates to the distance down the roadway that the rider is looking (ignoring horizontal road curvature). In this case, consider a rider who is traveling at 60 mph and looking 6 seconds ahead of the motorcycle. With these givens, a 0.5-degree variation in the eye-tracking system's indication of gaze location would encompass a region from approximately 4 seconds to 12 seconds in front of the rider. Based on the how these small errors map to expected viewing distances, it is clear that eye-tracking must be very precise, and will likely only be usable at short time-based distances.

Precise Eye Gaze Tracking System Selection

It was not fiscally or temporally feasible to develop a custom eye-tracking solution as part of this effort. Furthermore, there are a variety of commercially available eye-tracking systems from manufacturers who have been actively refining their products for a number of years. The goal of this task was to identify and subsequently evaluate available eye-tracking systems that could be adapted for use in the naturalistic motorcycle data collection.

The first step in identifying a suitable eye-tracking system was to perform a market review of commercially available solutions (Appendix F). All of the systems identified could be categorized by whether they were mounted to the head or a fixed surface forward of the facial plane (i.e., the instrument panel of a motorcycle). Prior to selecting a style of eye-tracking system, a brief experiment was conducted to gather additional information on the two alternatives.

Mockup Eye-Tracking Evaluation

With the research questions in mind, VTTI researchers created a static-scenario representative of a roadway scene (Figure 19). Traffic cones were laid out at 26 locations in three columns starting at 22 ft from the rider's eye position and extending out 176 ft. The positions represent sight distances out to 4 sec at 0.5-second intervals, assuming a speed of 30 mph. If a speed of 60 mph is assumed, the positions represent sight distances to 2 sec, with intermediate positions marked at 0.25-second intervals. The first row was 6 ft to the right of the rider and represented the right lane line in a straight section of roadway. A second column was located 12 ft to the left of the rider and represented the center of a lane to the left of the rider. A third column extended from the centerline of the rider and represented the center of the occupied lane. To look at far-range eye locations a cone was also placed on centerline at 200 ft (4.5 sec at 30 mph, 2.3 sec at 60 mph) from the rider and one at 400 ft (9.1 sec at 30 mph, 4.5 sec at 60 mph) from the rider.

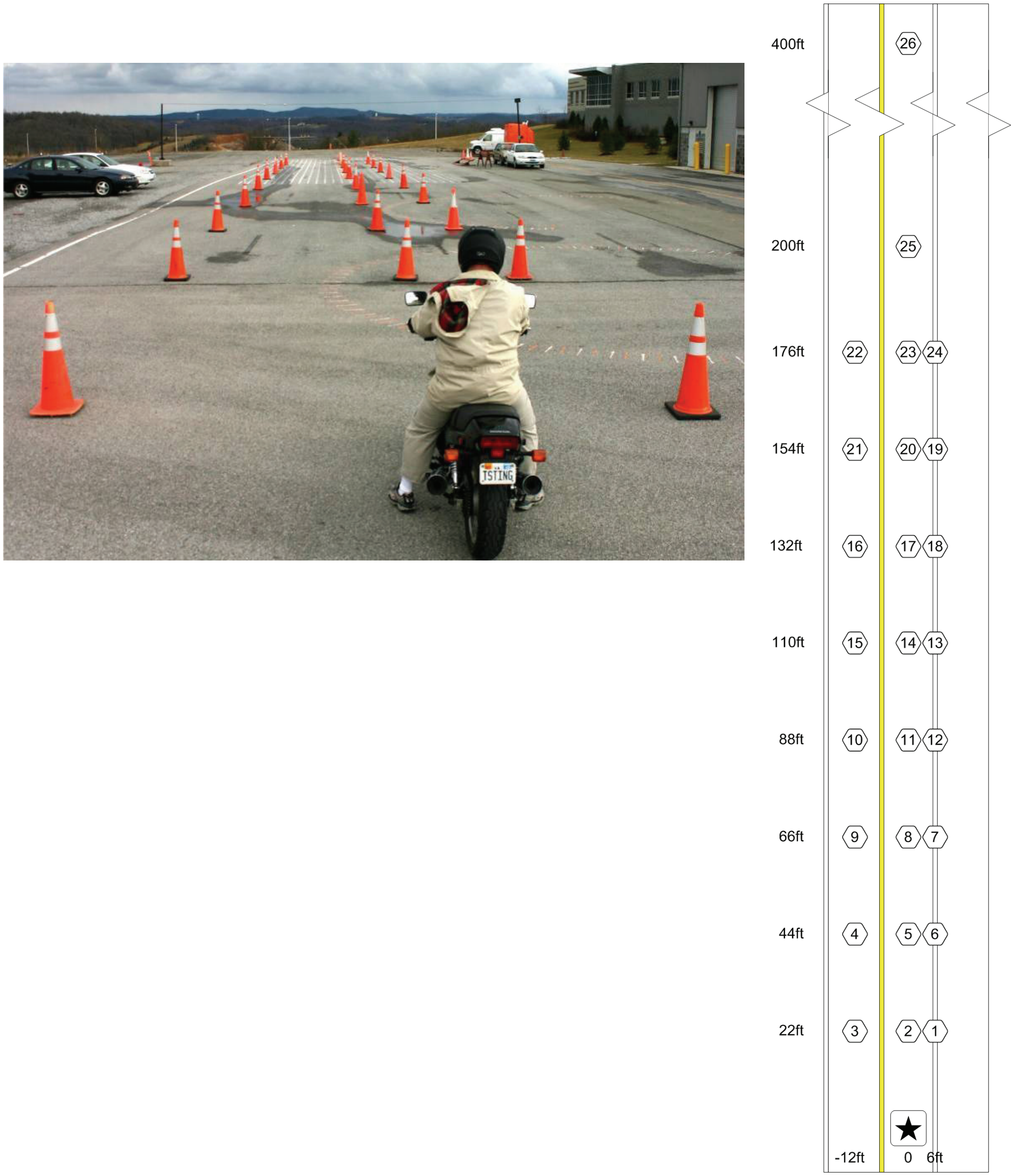
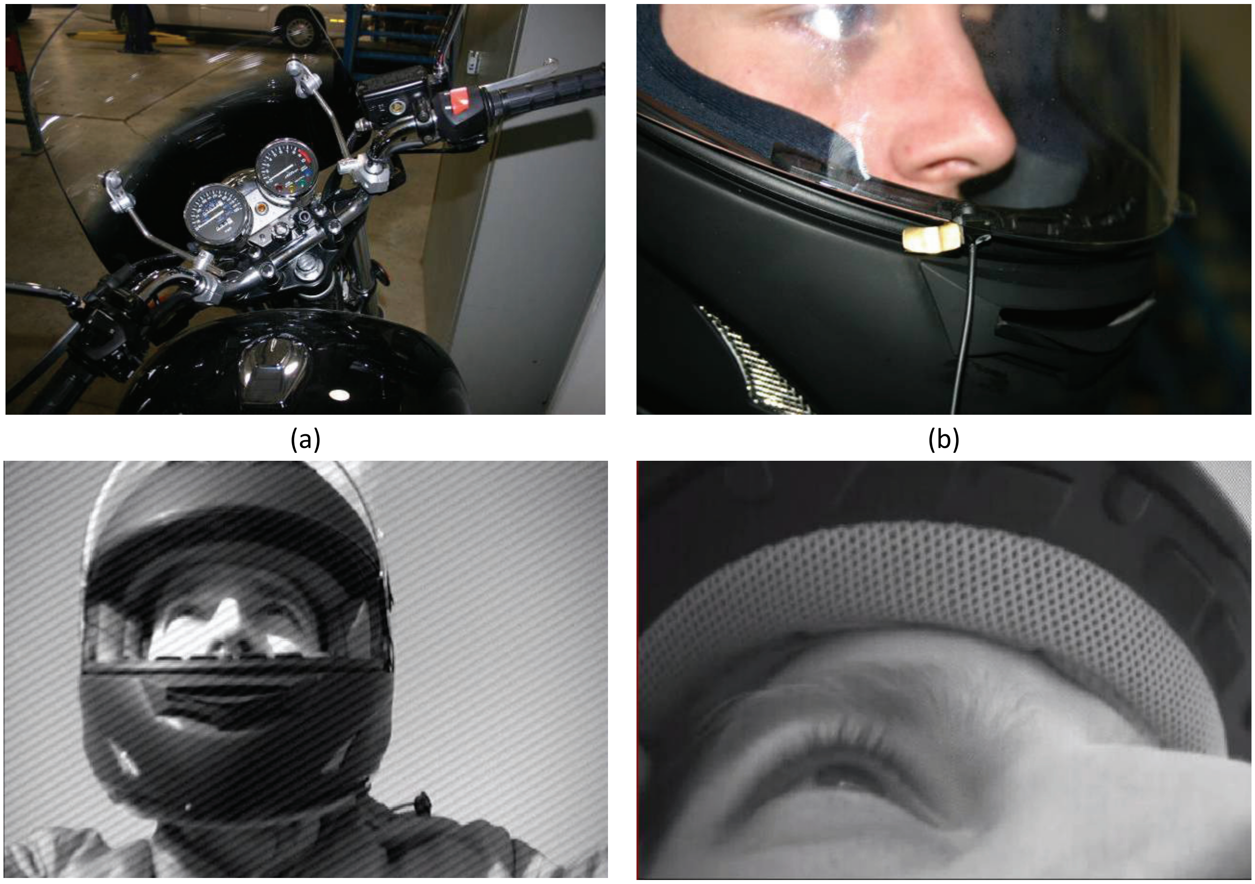


Figure 19. Test setup for evaluating different eye-tracking alternatives.

Cameras were mounted to the handlebars (Figure 20a) and to the helmet (Figure 20b), which were the anticipated locations of the two eye-tracking alternatives. Both cameras were attached to video recording equipment to capture the movements that would be interpreted by the machine vision applications underpinning the eye-tracking alternatives. Figure 20c and Figure 20d provide the view captured from the handlebar and helmet mounted locations.



(a) (b)

(c) (d)

Figure 20. Eye tracking camera locations and recorded views.

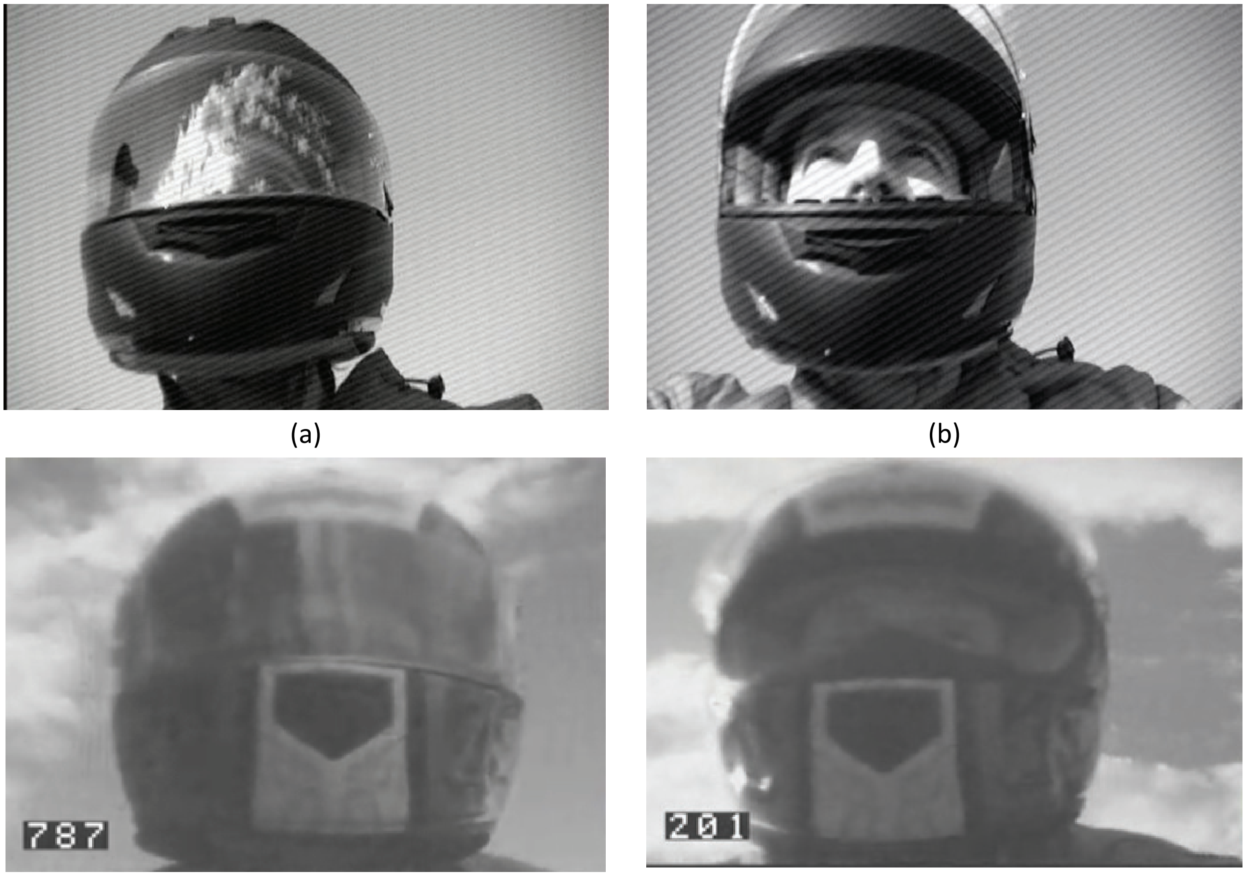
During testing, a research assistant moved from cone to cone to provide a clear point among the cones on which the rider would focus. The rider looked at the speedometer, and when the assistant was ready at the next cone position, the rider looked at the assistant for 1 to 2 sec, and then returned his gaze to the speedometer while the assistant moved to the next position. The assistant crouched by the cone at each position to be more similar to the height of a sedan.

The images collected at each of the points were organized into a slideshow and played in rapid sequence to analyze the location of the head and eye position across the range of roadway markers. From this analysis several key observations were made to guide the eye-tracking development, including:

- Differences between pupil orientations are very small and sometimes negligible, particularly as gaze distance increases.
- Small differences in the pupil orientations are not discernable with the instrument-panel-mounted camera. Differences are always easier to detect in the helmet-mounted camera view.

- Pupil location relative to the helmet does not independently indicate gaze location. The orientation of the head must also be considered.
- Helmet orientation does tend to be different for each marker; however, differences are not absolute and helmet location alone will not be sufficient for precise measurement of gaze location.

Optimally, eye-tracking equipment would be mounted to the motorcycle such that it could unobtrusively collect the precise glance location of the rider. For any precise eye-tracking system to function, it must have a clear unobstructed view of the rider's eyes. The camera mounted to the instrument panel of VTTI's development motorcycle was used to determine whether eye tracking from this location was feasible. A series of videos collected from the camera during a trip were reviewed by VTTI's resident machine-vision developers to determine if the image quality was sufficient for eye tracking. As depicted in the left images of Figure 21a and Figure 21c, glare across the face shield typically distorts the view of the eyes such that a machine-vision application will not be able to identify and track the gaze location from outside the face shield. Furthermore, due to the relatively low camera location, the eyes are occluded by the chin protection portion of the helmet even when the visor is lifted (Figure 21b). This effect is exacerbated on cruiser-style motorcycles that tend to have a lower instrument panel height relative to the helmet. Based on these discoveries, the machine-vision experts recommended against the use of motorcycle-mounted eye-tracking equipment due to a low likelihood of returning valid eye-tracking data.



(a) (b)

(c) (d)

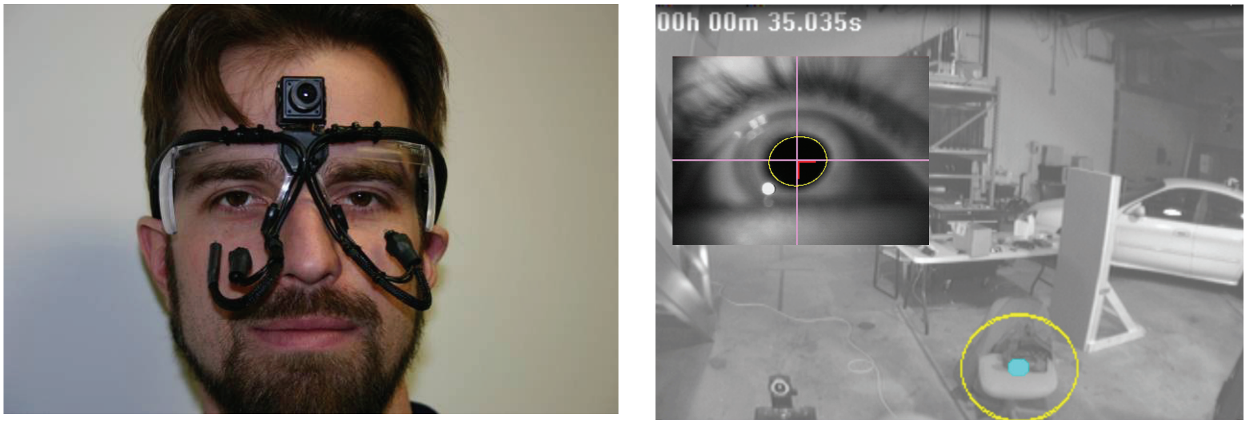
Figure 21. Example images that would be processed by a motorcycle-mounted eye-tracking system.

Final Selection of Precise Eye Gaze Monitoring System for Further Evaluation

Given the findings summarized previously, selection of eye-tracking equipment was limited to head-mounted systems. These systems have some advantages such as a head-mounted scene camera that "sees what the rider sees." The eye-tracking information can be overlaid on this head-mounted camera image to provide a visual log of gaze location on the riding scene. Relative to a motorcycle-mounted tracking camera, head-mounted systems will work across a broader range of head and rider body positions.

The primary drawback of these systems is the increased level of obtrusiveness. Since these systems have to be fixed to the head in some way they will require the rider to don the equipment prior to each ride. Furthermore, these systems need power and high-bandwidth communications connections for the head-mounted cameras that require a rider "plug in" before each ride. Finally, there is potential for increased liability due to the equipment that must be mounted onto the rider and located within the helmet safety structure.

After reviewing the available alternatives, Arlington Research's ViewPoint Eye Tracker (VPET) with the optional head-mounted scene camera was selected for further study (Figure 22a). The VPET uses two independent cameras to monitor binocular eye-gaze location. Infrared light-emitting diodes are used to provide consistent lighting across the eyes, improving performance across a range of lighting conditions. In addition to numerically providing the relative eye-gaze location, the system also uses a scene camera to capture the forward view. When the system is active, the gaze location will be painted on this forward scene indicating what the rider is looking at (Figure 22b).



(a) (b)

Figure 22. VPET eye-tracking system and illustration of gaze mapping.

The VPET was selected over the alternatives because of the clear potential for translating the stock eyeglasses-mounted system into a helmet-integrated solution. For a successful naturalistic data collection system, VTTI researchers and hardware designers felt that the eye-tracking system must be integrated into the helmet. A helmet-mounted system would be more stable over time because the cameras could be affixed with a secure mount providing consistent focal points; thus, reducing calibration requirements. Furthermore, a helmet-mounted system is significantly less obtrusive than the stock mounting eyeglasses, which are difficult to wear inside many helmets and maybe have an unacceptable appearance for many riders. The following specifications were provided by the manufacturer:

Table 4. Specifications for the VPET with the optional head-mounted scene camera.

Tracking Method	Infrared video. Dark pupil. Monocular or binocular options.
Software	PC
Measurement principle	The user can select between three methods: Pupil only, corneal reflection only, or both together.
Accuracy	Approximately 0.25° - 1.0° visual arc
Parallax Error Correction	Parallax error correction provided in the binocular system for viewing distances different from the original calibration distance.
Spatial resolution	Approximately 0.15° visual arc
Temporal resolution	Selectable by the user between 60 Hz and 30 Hz.
Head Movement	Unlimited
Scene Camera	Default camera is: Color, diagonal=70°, horizontal=56°, vertical=42°
Pupil size resolution	Measures pupil height and width to better than 0.03 mm instantaneous (no averaging).

Converting the Eye-Tracking Monitor to a Helmet-Mounted System

The VPET system is well suited for mounting on a full-face helmet. The full-face helmet provides a solid mounting location for the eye cameras and corresponding infrared (IR) emitters. The HJC model FS-15 helmet was selected for developing the prototype helmet-mounted eye-tracking system. From this helmet a prototype eye-tracking mounting system was designed.

Figure 23. Prototype helmet-mounted eye-tracking system.

The prototype system was developed with the goal of providing flexibility to allow optimization of the location and type of cameras installed. It was not intended as a final solution, but rather an engineering proof-of-concept, design aid, and performance evaluation platform. The stock fog-shield was removed from the helmet and replaced with a custom fog-shield that contained a camera mounting system. The camera mounting system used a ball-mount configuration that mated with custom manufactured camera bodies. Although somewhat large, the cameras were selected because they provide the ability to swap lenses, mount filters, adjust focus, and boast a higher resolution than their smaller counterparts. The IR emitters were mounted to flexible rods that allowed them to be moved and aimed to cast IR light on the eyes from various locations. The goal was to determine the optimal camera and emitter parameters with this arrangement and then migrate to less-obtrusive miniature cameras for which a custom fog shield was also designed and constructed. Figure 24a illustrates the prototype that permitted flexibility in lens configuration during design. Figure 24b represents the production intent design that utilizes miniature cameras with fixed mounts.

(a) (b)

Figure 24. Fabricated fog-shield mounts for ocular cameras.

Complete Eye-Tracking System

The following functional eye-tracking system was assembled with the goal of evaluating performance in a set of controlled experiments. The VPET required a computer to digitize the camera images and process the data to determine eye-gaze location. The VPET is designed to work in a Windows environment and has high processor requirements such that it was not feasible to integrate the eye tracker into VTTI's embedded DAS as part of this effort. Since this is a proof of concept, it was decided instead to mount a compact computer within a Givi luggage rack to run the VPET software in parallel with the DAS (Figure 25).

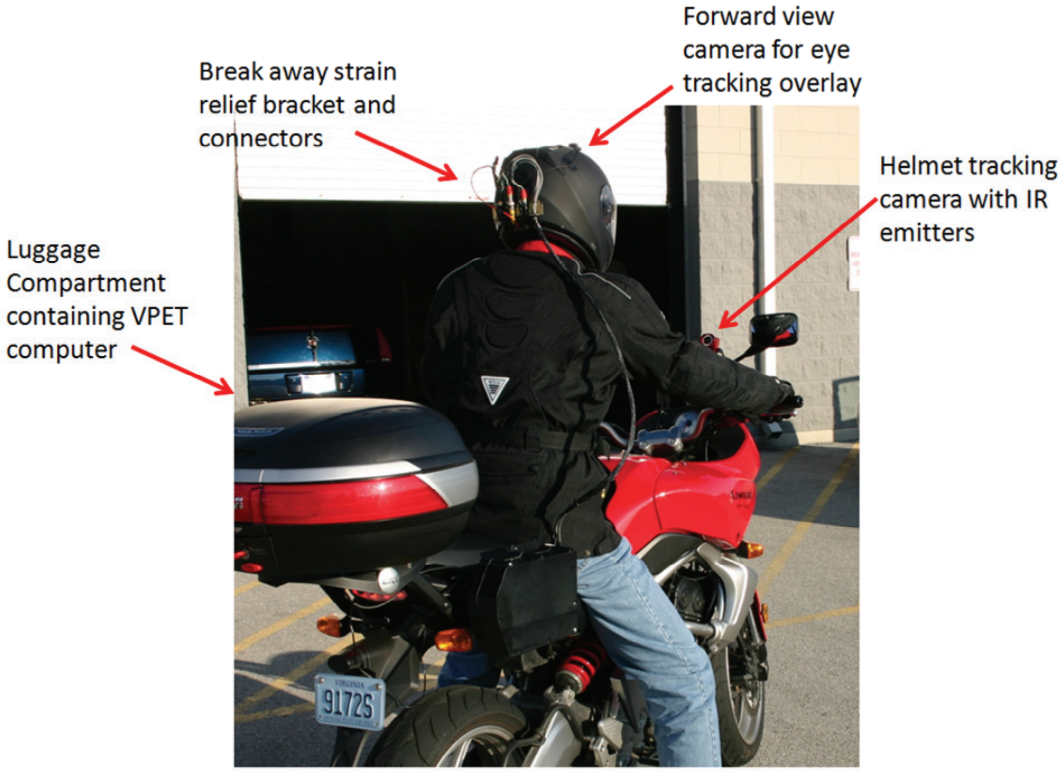


Figure 25. Test motorcycle equipped with helmet-mounted eye-tracking system.

In addition to the helmet-mounted eye-tracking equipment, a second optical tracking system was installed. This second system is called the OptiTrack optical motion capture system produced by Natural Point. The second tracking system used a small camera mounted above the instrument cluster (Figure 25). This system tracks the position and angle of an object represented by reflective markers on the helmet face shield (Figure 26). This system provides position and angle data for the helmet in all six degrees of freedom. Details behind the purpose of installing this system are provided below in the section titled "Alternative Gaze Measurement."

Figure 26. Helmet-mounted eye-tracking system and reflective markers.

Eye-Tracking Evaluation Test Plan

Two experiments were designed to exercise the eye-tracking system. These experiments included both static and dynamic evaluations measuring the extent to which the eye-tracking system captured the true location of the rider's gaze.

The first experiment was performed inside the lab with the bike stationary. A rider sat on the motorcycle at approximately 60 ft from a large white wall surface. A grid was drawn on the surface creating boxes that represented a 2-degree change of visual angle from one corner of a box to another (Figure 27). The experimenter directed the rider to look at a set of specific points on the grid. Each glance to a point on the grid was followed by a glance down to the speedometer so that the rider would have to move both his head and eyes to fixate on the indicated grid location.

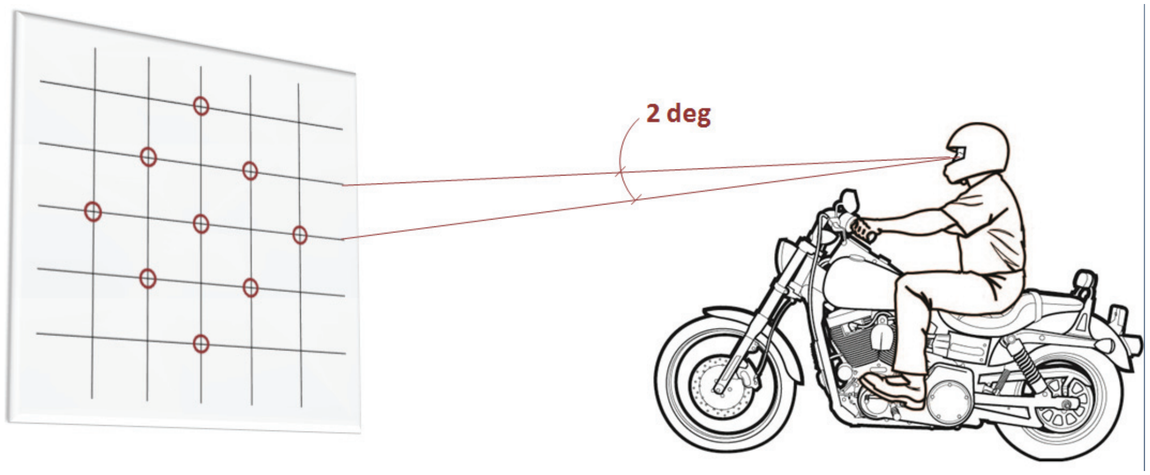


Figure 27. Static experimental grid designed to evaluate eye-tracker accuracy in the lab.

The eye-tracking system was first calibrated. To calibrate the eye tracker the rider must keep his or her head very still while looking at a wall. On the wall, the experimenter projects a point using a handheld laser pointer and the rider is instructed to fixate on the projected point. The experimenter looks at the projected laser point through the digital image captured by the scene camera. On this camera image, the calibration software prints a series of dots with one dot that is highlighted. The projected laser is aligned with the highlighted dot and a button is pressed to record the calibration offsets at that location. This process was repeated for 30 locations throughout the field.

Calibration takes approximately 5 minutes to complete and, once finished, the eye tracker is ready to record data. It should be noted that the calibration distance was equal to the distance at which the evaluation took place. The accuracy of the system is reduced when the calibration distance is different than the viewing distance, which is an unavoidable problem on live roadways in which the viewing distance is continually changing.

After calibration was completed the riders were asked to look at the specified points while data were being logged. The rider would then be asked to perform an action after which accuracy would again be evaluated followed by recalibration. This process repeated three times to evaluate:

1. Static Test A: Accuracy after large head movements
    a. Calibration
    b. Accuracy Evaluation
    c. Rider turns head right, then left, then down, then up
    d. Accuracy Evaluation
2. Static Test B: Accuracy after helmet removal
    a. Calibration
    b. Accuracy Evaluation
    c. Helmet removed and then re-installed
    d. Accuracy evaluation
3. Static Test B: Accuracy across body position

a. Calibration
b. Accuracy evaluation
c. Rider leans forward onto tank (sport bike position)
d. Accuracy evaluation

The static testing provided data regarding the accuracy of the system across a few foreseeable situations. The goal was to evaluate the robustness of measures across these situations since the ability to calibrate in a naturalistic study will be limited. It is imperative that calibration be maintained throughout a ride and likely between rides. Optimally, calibration should only be necessary when the rider's bike is initially instrumented.

The second evaluation planned was a dynamic test to take place immediately after the static testing. Once calibration was performed, the rider would ride the bike outdoors and onto public roadways. A confederate vehicle would be followed on a prescribed 10-minute ride in the area near VTTI. The goal of this test was to obtain a general sense of performance in the real world where challenges such as wind and vibration could influence the measures.

These evaluations were intended to be followed by a more thorough evaluation of performance using a larger set of riders, extended trips, and precise measuring techniques. However, as noted in the subsequent section, the eye-tracking system was not found to be sufficiently robust to conduct this on-road investigation with more than one rider.

Results of the Eye-Tracking Evaluation

The eye-tracking system evaluation indicated unsatisfactory performance of the recorded measures. Although the system is accurate immediately after calibration, measurement accuracy quickly diminishes as the rider moves his or her head. Measurement accuracy at any given point in time is dependent on the rider's head orientation relative to the rider's shoulders. The following results will demonstrate and explain the cause of this phenomenon.

When the evaluation was made immediately after calibration (no movement of the rider's head), the system provided average accuracy results of 0.11 degrees (stdev=0.22) lateral and 0.17 degrees (stdev=0.35) vertical. This level of accuracy is better than the advertised accuracy of 0.25 degrees for the eye-tracking system. It is also sufficient to perform analysis of precise eye-gaze location analyses as indicated in the analytical analysis presented earlier in this section. From this evaluation alone the eye-tracking system appeared to be very effective in measuring precise eye-gaze location.

The next evaluation was Static Test A that asked the rider to move his head to the far left, far right, down, and then up. This movement was followed by a reassessment of the accuracy. Accuracy decreased significantly with an average error of 2.6 degrees (stdev=1.9) lateral and 5.4 degrees (stdev=4.5) vertical. This level of accuracy is no longer sufficient to answer the research questions as indicated by the analytical analysis that dictates accuracy within 1 degree. Upon closer inspection of the results within a rider, there appear to be relatively consistent offsets at each evaluation point. This offset indicates that the helmet is shifting relative to the rider's eyes when the head is moved, despite returning to a similar location prior to the evaluation procedure).

The accuracy measured during Static Test B (helmet removal) and Static Test C (body movement) could not be determined. When the rider removed and re-installed his helmet, the error was larger than the measurement grid (greater than 6 degrees) and often was not represented within the helmet camera view (approximately 25 degrees). This test indicated that the ocular cameras did not return to the same location relative to the eyes after the helmet was removed and put back on. The results were starting to demonstrate that small changes in the ocular camera location cause large errors in the predicted eye-gaze location.

In Static Test C the rider was asked to lean forward onto the tank while looking at the central point of the grid. The projected gaze location was initially on the central point; however, as the rider leaned onto the tank, the point would drift vertically until it was no longer within the image captured by the scene camera. After careful examination of the ocular camera images and the helmet position, the cause was identified as a slight shift of the helmet, and therefore the ocular cameras, relative to the eyes.

To investigate the sensitivity of the movement, one rider was asked to fixate on the center point on the grid and to keep his head as motionless as possible. The experimenter then gently pressed up on the chin of the helmet. Moving the chin of the helmet about 1 mm introduced approximately 8 degrees of error. As the rider leaned forward onto the tank, the skin on his neck compressed, causing the helmet to shift slightly forward; thus causing the large measurement error.

The final portion of the evaluation was the dynamic test ride with the eye-tracking system enabled. As expected, based on the static evaluation results, the data from this on-road evaluation were essentially without a recognizable association to the rider's gaze locations. The indicated gaze location was often over 20 degrees from the roadway or other objects known to be fixation locations. Factors such as wind and rough road segments had a clear impact on accuracy (e.g., a bump in the road resulted in a sudden and sustained shift of indicated gaze location).

Discussion of the Eye-Tracking Evaluation

Based on the collective results, VTTI does not recommend moving forward with eye-tracking on a naturalistic motorcycle project at this time. The ocular cameras must have a clear view of the eyes and be as unobtrusive as possible; this requires a helmet-mounted location. The helmet-mounted location works well in a lab without significant head or body movement. However, accuracy diminishes to an unacceptable level once the head and body are free to move. Based on discussions with Arlington Research, the company who builds the eye-tracking system, this is a problem with the stock eyeglass mount as well; albeit to a lesser degree. The helmet-mounted system is likely worse since the skin on the nose (where the eyeglass frame rests) does not move as much as the skin surrounding the skull when the head is moved relative to the body.

Another important note should be made with regard to the helmet-mounted eye-tracking scheme in general. The numeric data provided by a helmet-mounted eye-tracking system will be relative to the scene camera (the camera mounted on the helmet looking forward). The numeric data in isolation is of little use because the coordinate axis is relative to the helmet not the motorcycle or roadway. This means that the data cannot be directly used to asses where in a corner, for example, a rider is looking. Furthermore, it cannot be used to automatically determine if the rider's eyes are on the roadway or if the rider is looking elsewhere.

To automatically provide gaze location relative to the roadway, a system to measure the helmet orientation relative to the bike and a system to measure the roadway geometry would also be needed. A high level of accuracy would be required from all three subsystems to make an automated assessment of gaze location relative to the roadway. Therefore, without developing these complex systems, the useful information provided by the head-mounted eye-tracking system is the digital gaze overlay printed onto the head-mounted scene camera image. Thus, manual reduction is required to look at the scene camera and corresponding gaze location overlay in order to determine where on the roadway the rider is looking.

A summary of the key outcomes of the eye-tracking development and evaluation are provided below.

- Helmet movement will provide general gaze information
    - The rider's helmet movement indicates the general gaze regions such as forward, left mirror, right mirror, blind spots, and instrument panel.
- Ocular cameras must be located on the helmet and near the rider's eyes
    - A clear view of the rider's eyes is required to obtain an accurate measure of eye-gaze location.
    - Cameras must be installed behind the shield on a full-face helmet to obtain a clear view of the eyes.
    - Although not directly investigated, it will be challenging to mount equipment to half helmets and three-quarter helmets without becoming obtrusive to the rider. Furthermore, the goggles worn by riders using these helmets will likely degrade performance (similar to the visor on full-face helmets).
    - A specialized helmet equipped with the eye-tracking equipment will have to be provided to the riders. Asking riders to wear unfamiliar helmets reduces the naturalistic nature of the data collection effort.
- Additional work is necessary to integrate a commercial eye tracker into the naturalistic DAS
    - Commercial systems are designed for computers with significant available processing power and mainstream operating systems. They are not simple to implement on embedded systems.
- Measurement accuracy is not sufficient to differentiate gaze position.
    - Small helmet movements, such as those that occur while the rider turns his or her head, have substantial impact on measurement accuracy.
    - Larger body movements, such as leaning forward onto the tank, decrease accuracy to an unusable degree.
    - Wind and roadway surfaces will move helmet and inject further error.

- Calibration is paramount to system accuracy and is frequently required
    - Taking the helmet off and putting it on un-calibrates the system.
    - System quickly falls out of calibration during a ride
- Riders may not be willing to wear the necessary equipment
    - The umbilical cord required to attach the helmet to the DAS may be too cumbersome for riders.
    - Riders may not be willing to wear the helmet due to fashion and/or safety concerns.
    - Requires riders to plug in, a step that participants may inadvertently neglect to perform.
- Additional hardware will have a significant increase in system cost.
- Any helmet-mounted eye-tracking system will provide numeric data relative to the helmet coordinate access. As such there is no automated method to determine whether the driver is looking forward or elsewhere without additional systems that relate the helmet orientation to the bike and bike orientation onto the roadway.

Alternative Indirect Eye-gaze Measurement Methods

The infeasibility of the precise eye-gaze tracking method described above led VTTI researchers to consider alternatives for acquiring a useful surrogate of eye-gaze location. An analytical technique relying on manual data reduction can be applied to the existing data. This method is presented in the results section later in this report (under the “Rider Gaze” heading). The present section, on the other hand, addresses some alternative automated methods for identifying the rider’s gaze region.

Although precise eye tracking appears infeasible on a naturalistic motorcycle study, there are alternatives that will provide a measurement of eye gaze at a more coarse level. Based on the data reviewed during the mock-up eye-tracking evaluation (discussed previously) and the on-road evaluation (discussed in a subsequent section), VTTI is confident that automated methods can be used to determine the region in which the rider is looking.

OptiTrack Gaze Measurement Method

The regions that can be reliably discerned include: (1) forward roadway, (2) instrument panel, (3) right mirror, (4) left mirror, (5) left blind spot, and (6) right blind spot. There are a few methods for acquiring this information. The first method is through manual data reduction. As discussed in a subsequent section, data reductionists were able to determine the gaze region using video collected during naturalistic riding. The downside to this method is the manual process that precludes any large scale classification of glance patters. An automated machine vision approach might be used to pre-classify gaze to be followed by more detailed reduction, or could be used to look for combinations of actions that indicate unsafe behaviors (e.g., neglecting to check a blind spot prior to changing lanes).

As discussed previously, an OptiTrack motion sensor was installed on the test motorcycle during the helmet-mounted eye-tracker evaluation. This commercially available sensor could be installed on a naturalistic fleet of motorcycles with relative ease. The OptiTrack system uses a camera mounted near the windscreen that sends out infrared pulses and reads the reflections of three markers mounted on the helmet. The three markers are assembled into a digital object for which position and orientation information is provided. This information, in turn, could be used to determine the gaze region of the rider. The initial plan was to compare the results of the helmet-mounted eye tracker and the OptiTrack to obtain a measure of agreement between the two systems. Unfortunately, the poor performance of the helmet-mounted eye tracker precluded this analysis; however, some observations regarding the OpitiTrack can still be made.

The OpitiTrack reliably provided accurate position data at 100 Hz when inside the lab. Some rough estimates of accuracy indicated that position prediction was within approximately 1/16 inch and angular data were within approximately 0.5 degrees. Once outside, the performance was significantly impacted due to reflections from various sources other than the reflectors. Object tracking accuracy appeared to decrease as the data dithered and frequently dropped out. Based on these results, VTTI does not recommend moving forward with the OptiTrack for naturalistic rider head tracking unless performance can be improved. According to the manufacturer, one way to improve performance is through the use of multiple cameras.

Other commercial technologies, such as radio frequency, may work better in the motorcycle environment. However, as with the OptiTrack system, these will require that a transmitter be mounted to the helmet and will add cost to the overall system.

Extending the Capabilities of VTTI's Machine-Vision Application

Machine-vision techniques currently in development can be modified to monitor helmet movement if automated processing of head movements is desired. The Mask software is currently designed to track the orientation of a driver's face (Figure 28). This six-degrees of freedom tracking data is used to identify the gaze regions of drivers without any manual calibration. Furthermore, it provides information regarding the driver's body orientation, a particularly useful measure on motorcycles. The functionality of the Mask could be extended to the motorcycle context.

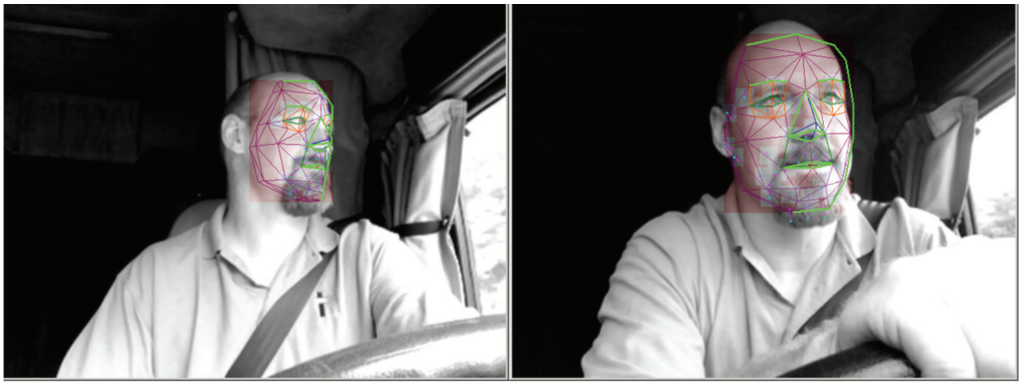


Figure 28. Screen captures of the VTTI machine-vision-based face-tracking software.

To assess the likelihood of success in tracking motorcycle helmets, VTTI's resident machine-vision expert reviewed the video captured by the motorcycle DAS and passed it through a series of pre-processing filters. These filters are the first step in tracking objects through machine vision. An example of a line segmenting filter on a helmet is provided in the screen capture below (Figure 29).

Figure 29. Example one of the pre-processing filters used by the Mask applied to a motorcycle rider.

Based on these images, VTTI’s machine-vision expert indicated that the Mask program could be augmented to track the helmet with ease relative to the effort required for faces (helmet edges are more distinct than facial features). This process would include building spatial models of the different helmet styles (full face, three-quarter, etc.) into the machine-vision program. Once the models are built the program would be configured to match the model to the helmet in the image. Once a match occurred (within 20 seconds), the application would provide continuous measures of helmet orientation that could be used to determine when the rider is turning his or her head—for example in mirror checks—glances to the instruments, over the shoulder glances, and looking into curves.

On-Road Data Collection Results

To demonstrate the analyses that might be expected with an actual experimental dataset, data mining was used to identify events followed by video reduction where appropriate to collect additional information measures. This section describes the methods used for reviewing the events, and discusses results obtained. Note that these data were accumulated to assess the feasibility of instrumenting motorcycles. Data were collected with this goal in mind such that instrumentation was refined throughout the study period. Therefore, the analyses are discussed according to what they illustrate, rather than attempting to convey generalizable findings or conclusions about riding behavior, which will require a larger scientifically rigorous naturalistic study. As mentioned in the section describing the main DAS unit, Participant 2’s motorcycle was prepped for instrumentation, but it was returned to the participant when it was determined that the weight of the first iteration DAS was beyond the luggage carrying capacity of the motorcycle. For this reason, in this results section, only participants 1, 3, and 4 will be discussed.

Data Reduction Method

The following sections illustrate the data reduction process that was exercised during the data collection. The goal of performing data reduction was to develop protocols for motorcycle reduction and to identify instrumentation issues.

Locating Events

For the purpose of this document, *event* is a general term used to identify a finite period of time during a trip that has been identified as being of interest for further analysis. In previous naturalistic studies, a *crash* was defined as “[a]ny contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated.” A *near-crash* was defined as “[a]ny circumstance that requires a rapid, evasive maneuver by the subject vehicle, or by any other vehicle, pedestrian, cyclist, or animal, to avoid a crash. A rapid, evasive maneuver is defined as steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities. As a guide, a subject vehicle braking greater than 0.5*g* or steering input that results in a lateral acceleration greater than 0.4*g* to avoid a crash, constitutes a rapid maneuver” (Dingus et al., 2006, p. 139).

Depending on the research question, crashes and near-crashes are can be identified as events. In naturalistic driving research, these crashes and near-crashes are often detected by data mining using simple Boolean combinations of vehicle measure values, combinations of measures, or algorithms designed to locate patterns in the data using single or multiple measures. Prior to searching for these events it is valuable to first summarize the available data with the aim of minimizing assumptions about what an event will look like. For example, rather than setting thresholds a priori, and only reviewing cases that exceed the threshold, data mining code can be written to identify the beginning and end points in every deceleration in the data, no matter how small or large. One deceleration may range from 0.0*g* to −0.8*g* and back to 0.0*g* while another ranges from 0.0*g* to only −0.1*g* and back to 0.0*g*. These values are written to an intermediate database table. Once this table is generated, the events within it can be reviewed using descriptive statistics and data visualization techniques. Next, these epochs can be selected for video review (e.g., review of the video footage from these events) in a stratified approach across the observed levels of acceleration, picking 100 epochs from 0 to −0.25*g*, 100 epochs from −0.25*g* to −0.5*g*, 100 epochs from −0.5*g* to −0.75*g*, etc. The video review performed across these levels, prior to setting criteria for inclusion in a full review of the data, improves the outcome in several ways.

First, the video review may expose previously unknown safety-related rider behaviors. For example, a stratified review that includes low level accelerations might reveal that near-crashes often occur when novice riders try to accelerate from a stop in third gear instead of first. Second, it allows the researchers to explore the sensitivity of a threshold value. Understanding the numbers of events of interest found within different stratification cells permits design of a reduction effort that is feasible while minimizing the risk of missing events of interest. Finally, because data mining methods may vary in effectiveness across a measure of interest it provides a map for identifying hit/miss/false alarm rates at different levels of a measure.

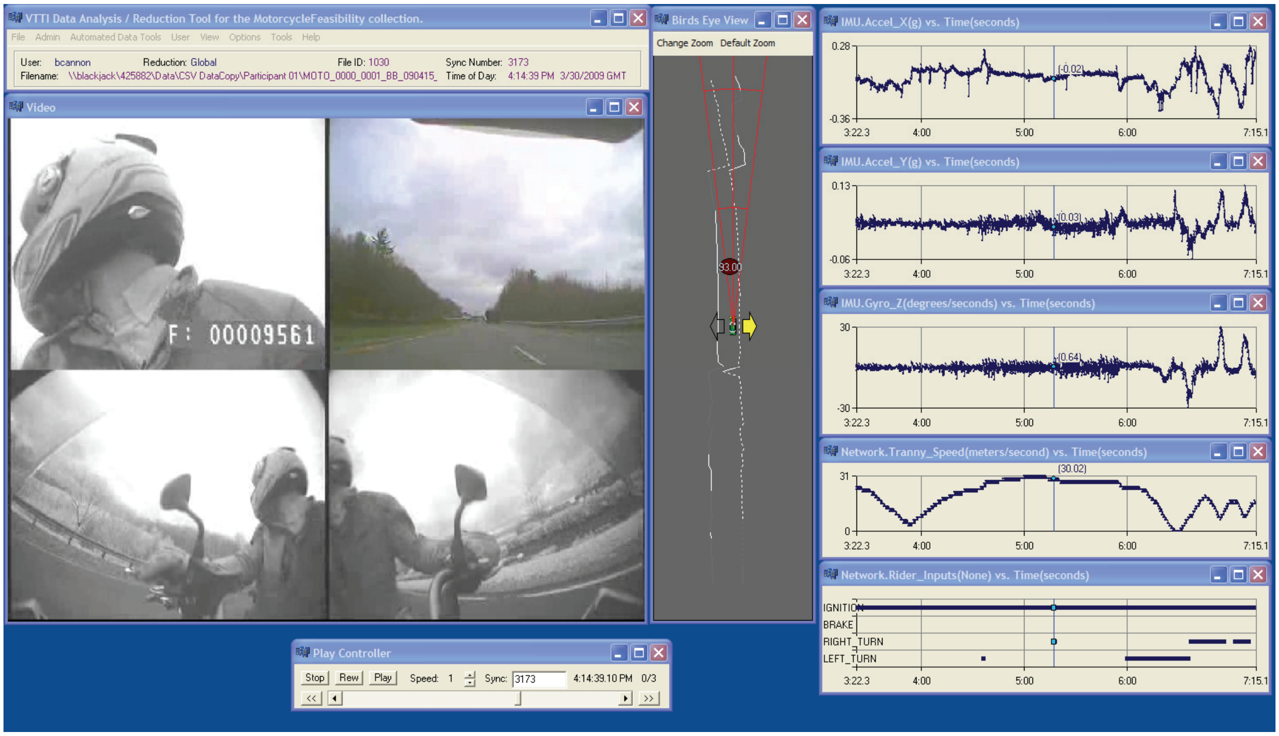
In addition to simple thresholds or use of combinations of measures, algorithms can be written to identify more complex signatures in the data. An algorithm might locate roll rate indicative of the bike leaning interspersed with the bike being brought upright and deceleration being applied. An intermediate table could then be created capturing epochs with this signature in the kinematic data. Then, similar to the previous example, the cases believed to be most severe could be reviewed as well as cases believed to be milder. It is likely that some part of this set would reveal cases of riders entering a curve at too high a speed and struggling to decelerate while turning. Other algorithms might combine decelerations identified in parametric data with distance to an intersection from geographic information system (GIS) data, to understand the range of deceleration behavior and what severe events at intersections look like.

The epochs of interest are identified in intermediate tables using start and end points, which allow researchers to address the epoch in follow-up analyses. In addition to the start and endpoint of an epoch, it is also helpful to retain other data that describe the epoch of interest and permit stratified sampling of epochs during review. Speed, longitudinal acceleration, latitude and longitude, and yaw rates are often useful for this type of stratified sampling.

In this project, for demonstration purposes, the data were mined for events using various kinematic measures. Small samples of these events were then reviewed on video using data reduction techniques that are similar to those that might be used in a full-scale study.

Reviewing Events

Events are reviewed using reduction software that presents strip charts of parametric measures over time, aligned with video of an event. The reductionists are able play events in real time, at partial speed, or probe the data in detail at specific points to understand what is occurring. A screen capture from this software is shown in Figure 30.



VTTI Data Analysis / Reduction Tool for the MotorcycleFeasibility collection.

User: bcannon
Reduction: Global
File ID: 1030
Sync Number: 3173
Filename: \\blackjack\425882\Data\CSV DataCopy\Participant 01\MOTO_0000_0001_BB_090415_
Time of Day: 4:14:39 PM 3/30/2009 GMT

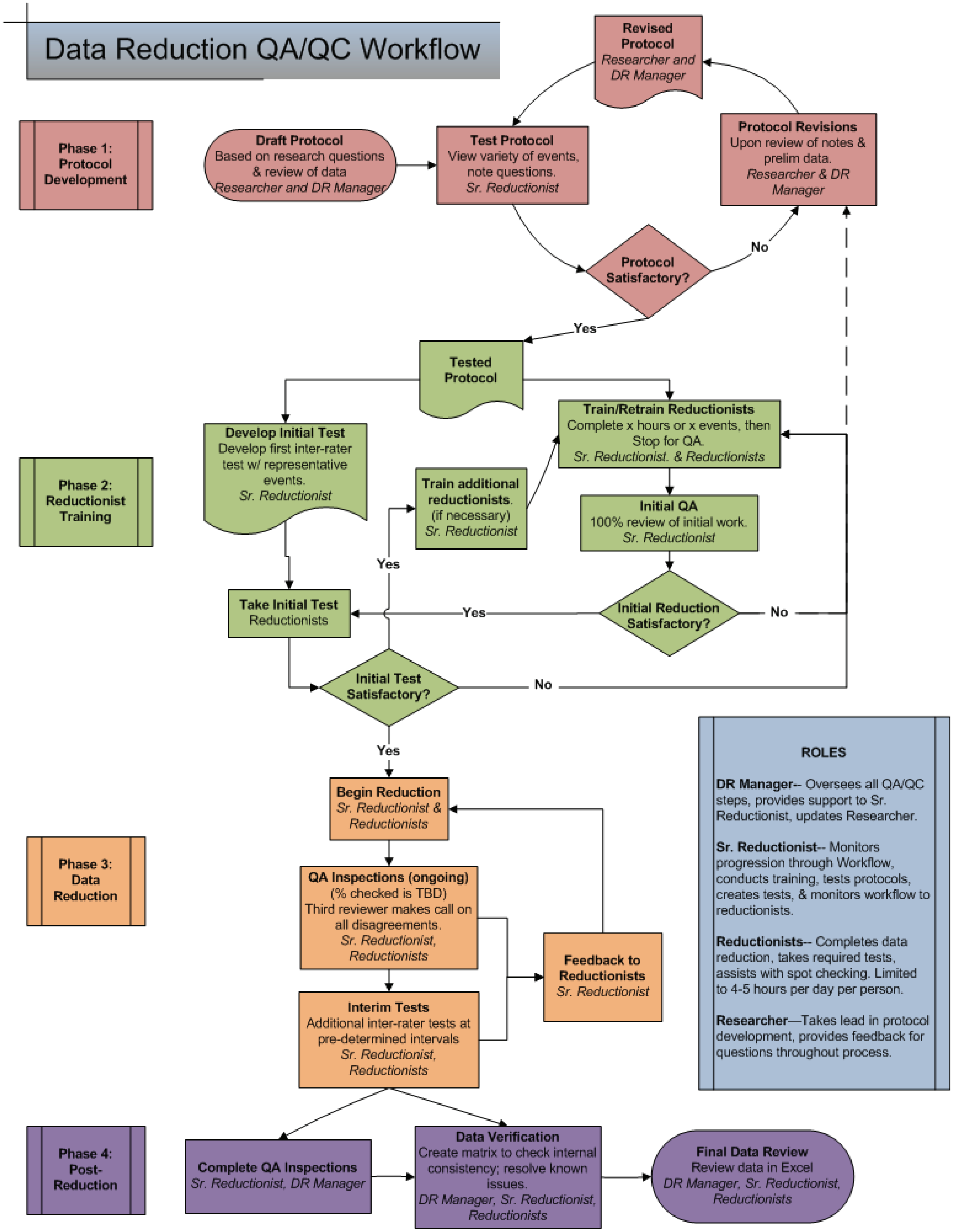
Speed: 1
Sync: 3173
4:14:39.10 PM 0/3

Figure 30. Screen capture illustrating data reduction software.

The left portion of the display provides video views. The central vertical panel is an aggregation of information from the radar, machine-vision lane tracking, and turn signals into a bird's-eye-view of the motorcycle as well as the roadway ahead and behind. The strip charts to the right describe longitudinal acceleration, lateral acceleration, yaw, speed, and brake and turn signal status. Any time-series variable collected from the motorcycle can be reviewed in this manner. Others include radar range, closing speeds, headway, time-to-collision, and roll-rate. Reductionists can also open maps displaying the rider's location on the roadway network.

Examples of Event Reduction

The process used for review of crashes and near-crashes on video is described in Figure 31. A number of measures of interest in the research questions can be identified during reduction of events or baseline epochs. Events are often reduced in multiple stages. One reduction might collect overview information such as weather, presence of personal protective equipment, traffic levels, rider position in lane, and presence of a passenger. These types of measures are often applicable to a range of transportation-related questions. Another review might be more research-question-specific.



ROLES

DR Manager-- Oversees all QA/QC steps, provides support to Sr. Reductionist, updates Researcher.

Sr. Reductionist-- Monitors progression through Workflow, conducts training, tests protocols, creates tests, & monitors workflow to reductionists.

Reductionists-- Completes data reduction, takes required tests, assists with spot checking. Limited to 4-5 hours per day per person.

Researcher—Takes lead in protocol development, provides feedback for questions throughout process.

Figure 31. Data reduction workflow.

None of the riders crashed during the study, but four events were analyzed as potential near-crashes using the data dictionary. The questions used by the reductionist to analyze these events, and the possible responses, are presented in Appendix G. When these events were identified, the video segment pertinent to that occurrence was viewed and evaluated in order to select the appropriate category for each of the 52 variables included in the dictionary, and a narrative was created to describe each event. There were some similarities between many of the events: in three cases, the pre-incident maneuver was negotiating a curve, one case involved animal incursion, and two cases involved another vehicle attempting to pull into the participant rider's lane. In all four cases, the road and surrounding conditions were similar.

As an example of the type of narrative that could be created, in one event the rider was negotiating a curve as a car began to pull from the right onto the road in front of the motorcycle. As the motorcycle rider came around the corner enough to see the car, he was riding at a speed of 64 mph. He began braking 0.2 s later. He reached his peak deceleration of 0.45*g* after braking for 1.1 s. He completely released the brake after 1.4 s of braking. When he released the brake, he was traveling at a speed of 46 mph. He continued to decelerate and reached a minimum speed of 42 mph. At this point, it became clear that driver of the car had seen the motorcycle and stopped to wait for him to pass. The motorcycle rider then accelerated to 60 mph. Throughout the event, the rider's gaze was in the forward direction.

The data dictionary served as a useful guide in the analysis of variables applicable to motorcycle transportation. With a full database of naturalistic driving videos, many analyses would be possible using the information gleaned from the video reduction. Relationships between the variables within categorizations (such as the type of incident or the precipitating event) could be determined in order to characterize similarities and provide information useful in the reduction of motorcycle accidents.

Rider Gaze

The following subsections describe how the fielded instrumentation can be used to collect measures of gaze location, sight distance, and adequacy of the rider's sight distance.

Gaze Direction

Gaze measurements were derived from video reduction in which the participant's gaze direction is determined frame-by-frame. This video reduction process makes use of riding context, gross head movement and, to the extent possible, participant eye glances. It is typical for reviewers to first become familiar with a driver to understand that movements align with glances to different locations. In this demonstration analysis, gaze positions (described below) were recorded based on video review of the helmet or eyes. The reductionist recorded which of these (helmet or eyes) was used in each event. These gaze measures can be used to establish scanning behaviors and to address research questions relevant to where riders are looking in different riding scenarios and when they are involved in safety-critical events. Gaze reduction was completed using the following categories of gaze location: forward, left mirror, right mirror, instrument cluster, left, right, left rear, right rear, unable to determine, and eyes closed (Figure 32).

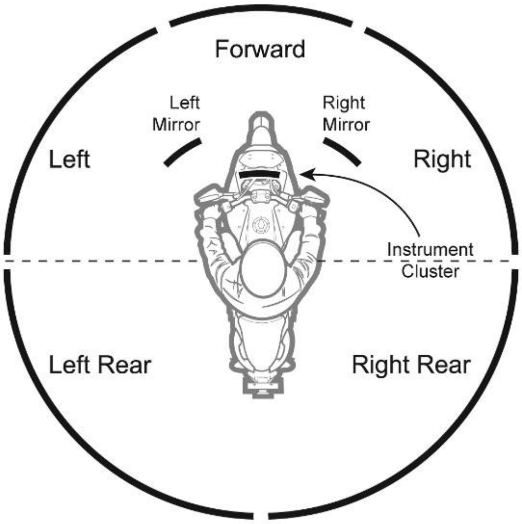


Figure 32. Gaze Locations.

The following definitions were used by the reductionist to define the gaze locations:

Forward: Most common orientation. Helmet or eyes oriented primarily in the direction of the path of travel.

Instrument Cluster Area: Helmet or eyes oriented looking down from the forward direction, and centered on the bike. Generally a shorter duration glance when bike is in motion and not tracking with objects around the bike.

Left: Helmet or eyes oriented to the left of the path of travel, higher than mirrors. Angles include range from Forward location and the line formed by the rider to the left, orthogonal to the path of travel.

Left Mirror: Helmet or eyes oriented down and left from the Forward location. Not as low as an Instrument Cluster view. Generally a shorter duration glance when bike is in motion and not tracking with objects around the bike.

Right: Helmet or eyes oriented to the right of the path of travel, higher than mirrors. Angles include range from Forward location and the line formed by the rider to the right, orthogonal to the path of travel.

Right Mirror: Helmet or eyes oriented down and right from the Forward location. Not as low as an Instrument Cluster view. Generally a shorter duration glance when bike is in motion and not tracking with objects around the bike.

Right Rear: Helmet or eyes facing to the rider's right, from the shoulder and behind.

Left Rear: Helmet or eyes facing to the rider's left, from the shoulder and behind.

These definitions would likely be adjusted for specific research questions and/or with additional understanding of glance behaviors across a wider group of riders.

Estimation of Sight or Stopping Distance

Rider sight distance was estimated by identifying roadside objects that provided points of reference for time and distance measurement. Video was queued to a point at which the reference point is just visible or at maximal sight distance. The video was then advanced to the point that the rider reaches the object to measure the time, distance, and speed profiles leading up to the event. Figure 33 illustrates how this measurement is made. By reviewing video, position B is identified as the farthest point the rider can see in the path-of-travel due to the bushes adjacent to the roadway. The time it takes the rider to travel from point A to point B provides the rider's sight distance, measured in time. Integrating the rider's speed over time provides the distance traveled. This method was used to calculate the distance that a rider should be able to see if the rider is looking forward, not necessarily the distance that the rider was looking.

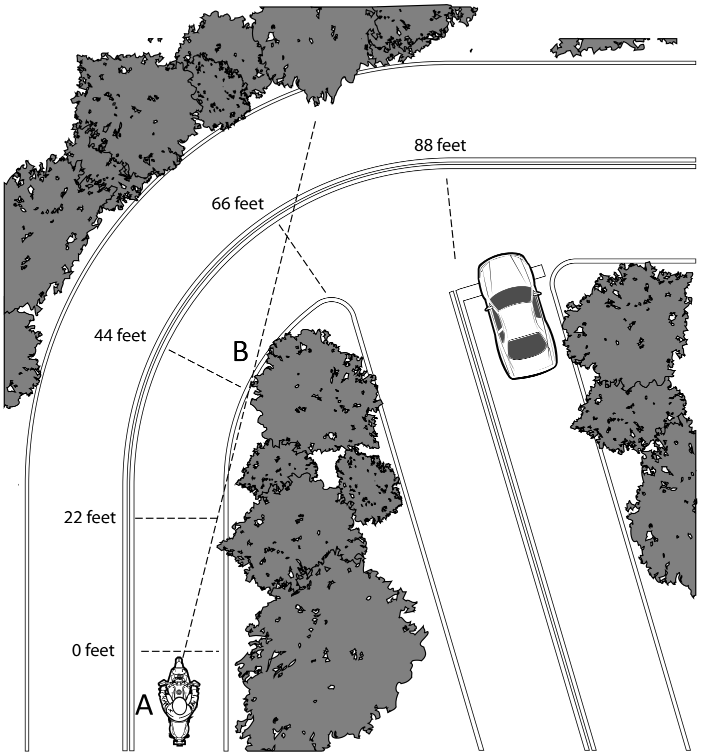


Figure 33. Sight and stopping distance illustration (distance not to scale).

This method of identifying sight distance was used to analyze two events per participant. The average of the two values is identified for each participant in Figure 34.

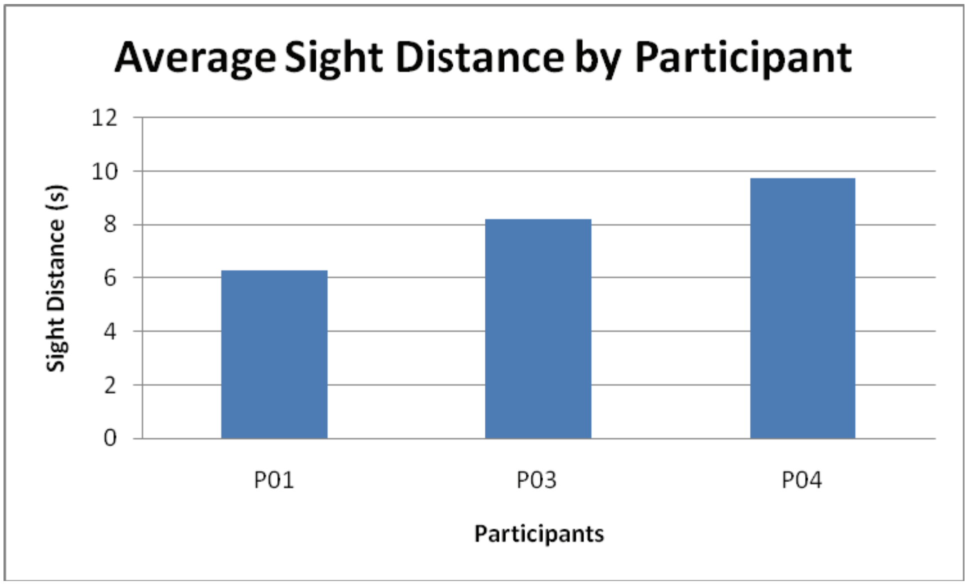


Figure 34. Average sight distance by participant.

Though measures such as this require approximation in reviewing the video and identifying the furthest position (e.g., position B), the approach will likely provide sufficient approximation to identify differences between riders. For a rider traveling around a curve at 35 mph, locating point B at 300 ft instead of 330 ft would create a 10-percent difference from actual time-based sight distance. A rider traveling around the same curve at 10 mph faster than the first rider would have a 22-percent different time-based sight distance. Looking at the error in terms of distance, at true sight distances in this range, the video reduction estimate would need to incorrectly locate the maximum sight distance by 85 ft to create the same change in time-based sight distance that a 10 mph faster speed would create. This error would constitute missing the correct spot by 1.6 s of real time, which is 16 video frames. These values suggest that reduction-based site distance estimation is sufficiently robust to provide meaningful results that identify differences in riding behavior.

Operational definitions of roadside object type and placement as well as frame determination for maximal distance will need further refinement to ensure consistent results. These types of video-based measures of sight distance, when coupled with judicious selection of normative baseline epochs, will address questions regarding the role of sufficient sight distance in motorcycle safety-critical events. It is also feasible that these video-based measures could be augmented with eye-tracking data collected during closed circuit sessions (with frequent calibration and eyeglass-mounted equipment) with study participants. This would be similar to current longitudinal motorcycle studies currently underway.

Collection Summary

The following is a summary of some of the naturalistic data collected and examples of how they can be analyzed and used. As mentioned previously, instrumentation of one bike was stopped and the bike returned to the participant, leaving three participants who provided on-road data. There was one young male, one middle-aged female and one middle-aged male. The motorcycles used, and demographic categories, are described in Table 5.

Table 5. Demographic and motorcycle data for the three participants.

Participant Number	1	3	4
Age Category	Middle (35–55)	Younger (18–34)	Middle (35–55)
Gender	M	M	F
Motorcycle Type	2008 Kawasaki Versys	1999 Honda VFR	2007 BMW R1200
Engine Displacement (cc)	650	800	1200

There are 282 trip files in the dataset. Each trip file begins with engine start-up and ends with engine shutdown. Participant 04 rode the least number of trips at 48, and Participant 03 had the most with 124, slightly more than Participant 01 with 110 files.

Day of Week

Differences are evident in the days of the week that the participants rode. Participant 01 rode some on every day of the week, but his most common days to ride were Mondays and Fridays. Participant 03 primarily rode his bike during the work week. Participant 04 rode her bike throughout the week, but Saturdays and Sundays had more trips than any other days. A comparison of the number of trips taken by day of the week is shown in Figure 35.

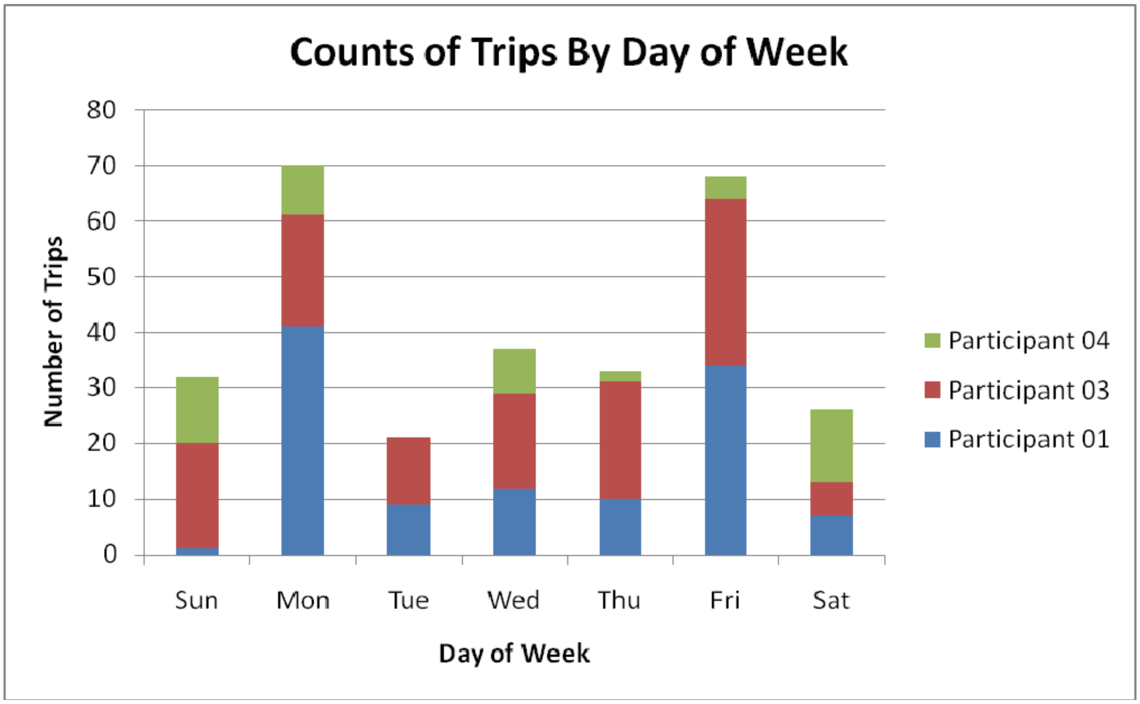


Figure 35. Counts of trips by day of week.

Time-of-Day

Most of the riding in the dataset was done during daylight hours. More trips began during the hour between noon and 1 p.m. than any other hour. Two riding patterns, in terms of time-of-day, appear to be present in the data. Participants 01 and 04 spread their trips out more throughout the day than did Participant 03. Participant 03's daily travel pattern was more typical of using the bike while commuting to and from work. Participant 03's trips occurred Monday through Friday, and most commonly began between 7 a.m. and 8 a.m., around noon, and between 5 p.m. and 6 p.m.. A comparison of the number of trips began during each hour of the day is shown in Figure 36.

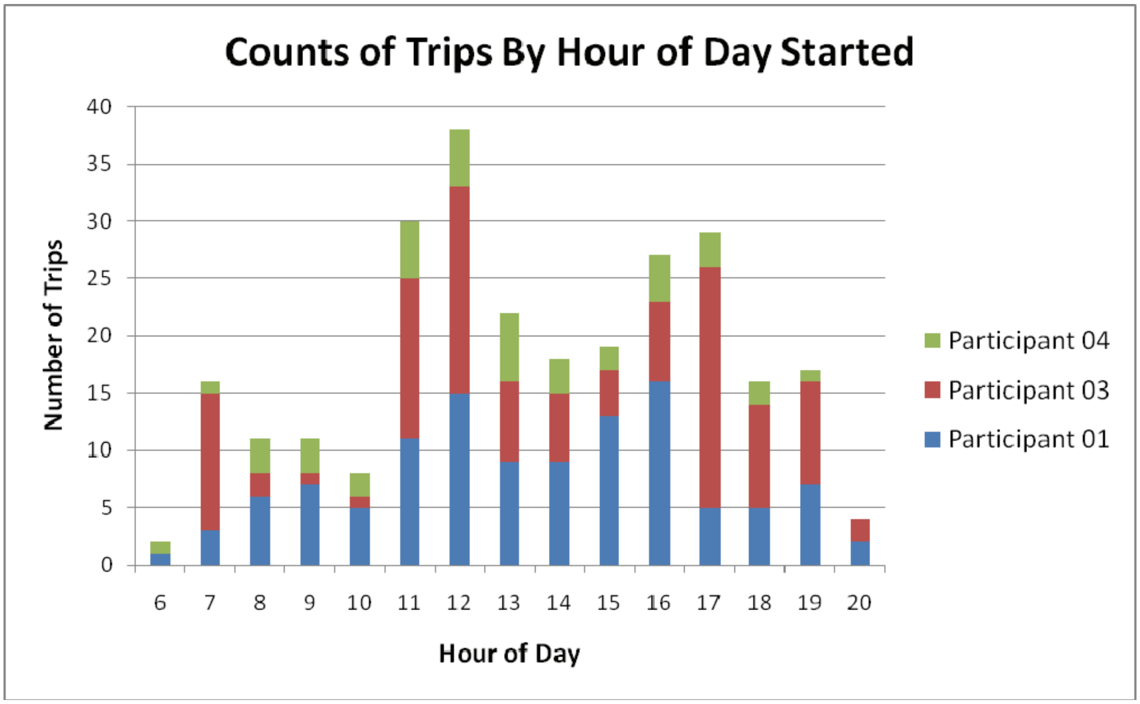


Figure 36. Counts of trips by hour of day started.

Demographics / Experience

Pre-drive questionnaires were completed by the participants, and the resulting information was analyzed for the three riders. Age categories are used here for demonstration purposes. There were two age categories: Younger (18 to 34 years old) and Middle (35 to 55 years old). The resulting categories were Middle Male, Middle Female, and Younger Male. Details about each participant's motorcycle were also collected, including make/model, engine displacement, year of purchase and condition at purchase, modifications, and details about other accessories used while riding.

Elements of the pre-drive questionnaire were combined to create categories describing current involvement in riding, lifetime riding experience, and crash history. These categories and included questionnaire elements are as follows.

a. Lifetime Riding Experience
    i. Age when obtained motorcycle license
    ii. Age when began riding street/on-road motorcycles
    iii. Age when began riding off-road motorcycles
    iv. Number of different street motorcycles ridden regularly in past year
b. Involvement in Riding
    i. Number of motorcycles currently own/lease
    ii. How many days and miles per year the motorcycle is ridden , taking into account characteristics such as length of individual rides and the timing of breaks within a trip

    iii. Riding exposure (miles driving a car versus a motorcycle during the previous year)
    iv. Riding season
    v. Riding characteristics (weekday versus weekend, commute versus pleasure, day versus night, urban/rural/suburban, purpose of trips)

c. Crash History
    i. Number of crashes
    ii. Fault
    iii. Crash description

Four other elements from the questionnaire were also included for demonstration purposes.

d. Formal Training (types of training)
e. Practice Situations (types of situational training)
f. Maintenance (level of self-maintenance)
g. Helmet Usage (type of helmet, frequency and reason for usage)

Pre-drive questionnaire responses in each of these areas were rated as Low, Medium, or High and are presented by Age and Gender in Figure 37. Categorization of responses into the three levels was performed relative to the values of the actual data collected during this exercise. For example, responses to the questions comprising the variable "Lifetime Experience" were used to determine the number of years each rider has had with their motorcycle license, the number of years each rider has been riding street and off-road motorcycles, and the number of different motorcycles the respondent has ridden. These values were simply totaled for each respondent and ranked relative to the other riders' responses in order to provide a reasonable indication of comparative experience. In this demonstration, one rider had much higher totals than the other two for these variables (in the range of 30 years of experience, compared to 5 years or less), so that rider was categorized as a high level of lifetime experience, whereas the other two were categorized as low. There was a reasonable gap between these values to allow another category, medium, for example, if any rider had exhibited around 20 years of experience. Similarly, for the variable "Crashes," riders were categorized based on the number of reported crashes they have had. One rider reported two crashes, the other two reported none. Thus, within this small data set, one rider was categorized as medium, while the other two were placed in the low category. It is expected that these limits would be wider with a larger data set because the range of the number of crashes would be much higher. All of the categorizations were based on the actual data—for a larger study, categorization values would most likely be redefined for many variables.

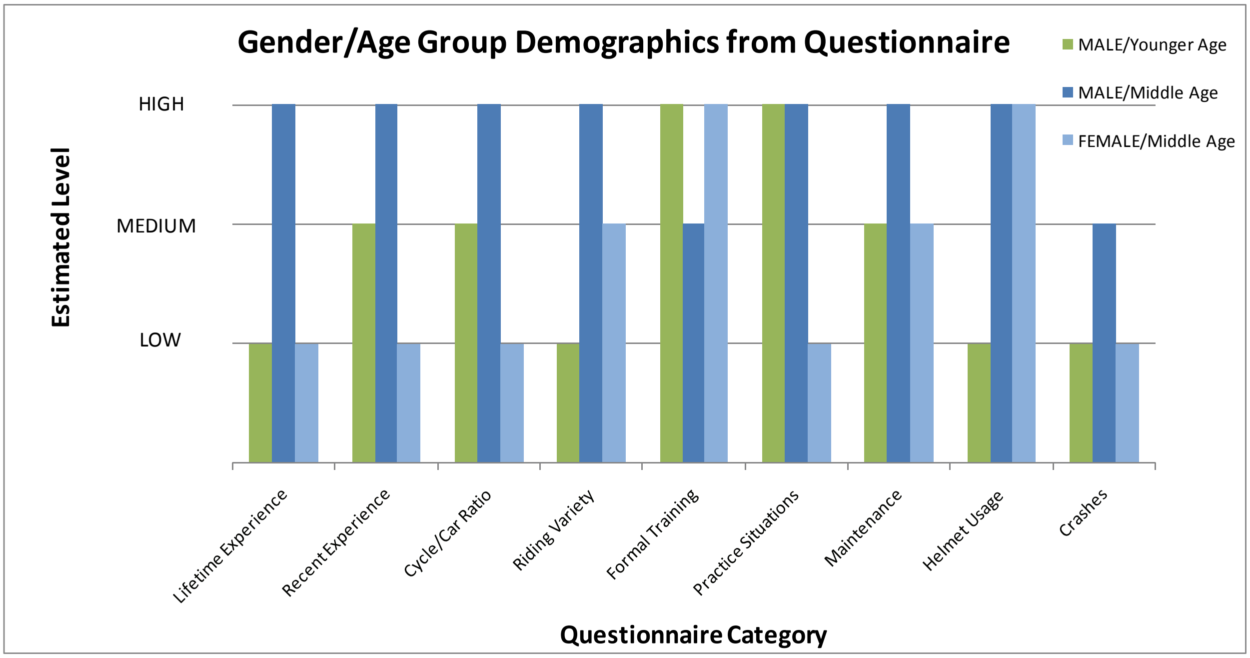


Figure 37. Gender and age group demographics from questionnaire.

With a larger database of naturalistic driving videos, all of the variables listed above could be tested for interaction with measures such as event (crash, near-crash) rates, exposure, riding behavior, etc.

Exposure

Separation of riding miles and time by road type or by rural area versus urban area classifications provides quantification of riding exposure. The participant data illustrate distinct differences in exposure to different road types between riders. Geographic information system (GIS) software was used to map and analyze the GPS data collected by the DAS. The road types used by the Virginia Department of Transportation were used to classify road type for trips in Virginia. The four road types in Virginia are *interstate*, *primary* (two to six lanes between local jurisdictions), *secondary* (local connector or county roads), and *other* (typically urban surface streets). Participants rode their bikes in seven States in addition to Virginia. These States included Delaware, Georgia, Kentucky, Maryland, North Carolina, South Carolina, and Tennessee.

As the study was based in Virginia, data from VDOT were readily available to identify road type. Likely due to proximity, about 31 percent of the riding distance in the dataset was done in North Carolina. Since this made up a substantial portion of the riding data, additional road data were acquired from the North Carolina Department of Transportation (NCDOT) to allow road type identification in North Carolina. In a larger study, road data from additional States would be required and would be feasible to obtain. In North Carolina, roads are classified as interstate, primary, and secondary (which includes the kind of roads that are in the "other" category in Virginia).

Participant 01 had the most equal spread of distance traveled on each of the four road types. Participant 03's and Participant 04's data include a much larger proportion of driving data on primary roads with a substantial proportion also on interstates. A comparison of the distances traveled on each of the road types is shown in Figure 38.

In Virginia and North Carolina, where road types were identified, 60 percent of the riding distance across the participants was on primary roads, 29 percent was on interstates, and 11 percent was on secondary or other roads. Looking at time spent on each road type instead of distance traveled, the participants rode about 60 percent of the time on primary roads, 23 percent on interstates, and 17 percent on secondary or other roads. Of the total 3,100 mi in the dataset (in all States), 81 percent of the distance ridden was in rural areas and 19 percent was in urban areas.

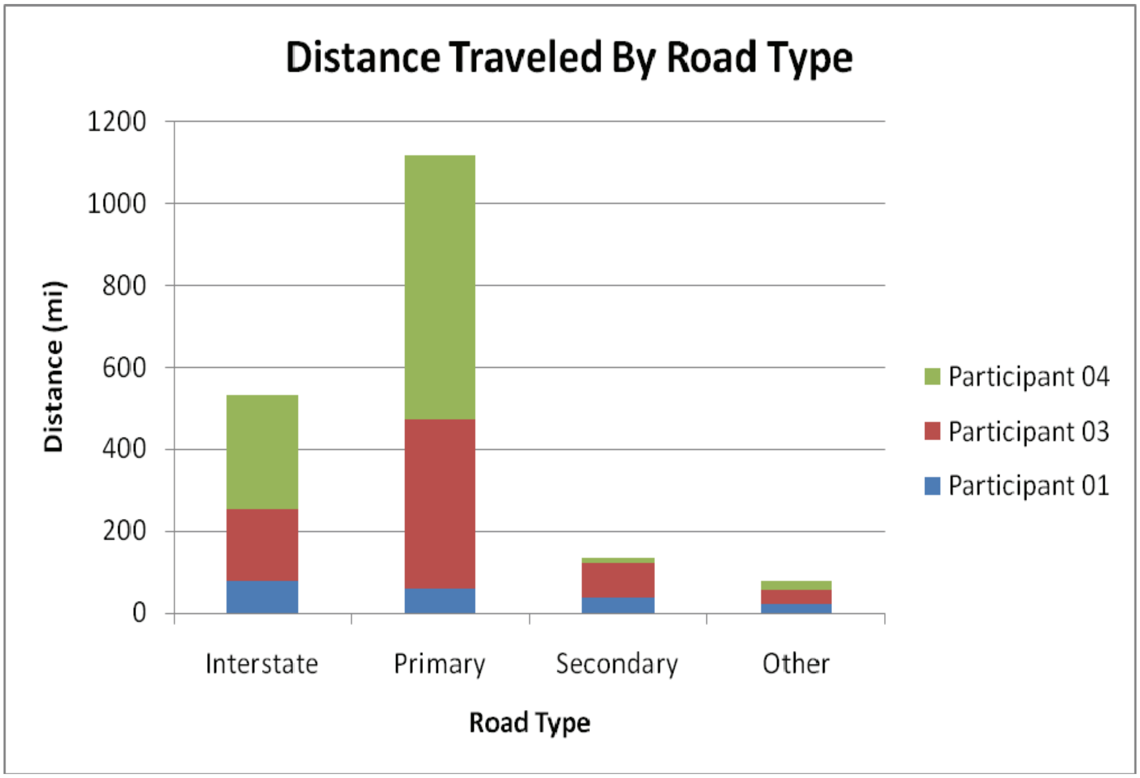


Figure 38. Distance traveled by road type.

Intersections

Geospatial data mining was used to locate riders negotiating intersections in the naturalistic data. Road network data were queried to identify where three or more transport edges (road segments) met as a transport junction (intersection). A buffer with a radius of 200 ft was placed around each of these intersections. Then, GPS breadcrumb trails were overlaid on these areas to find participants passing through the intersections. This process was done for all of the riding data in Virginia.

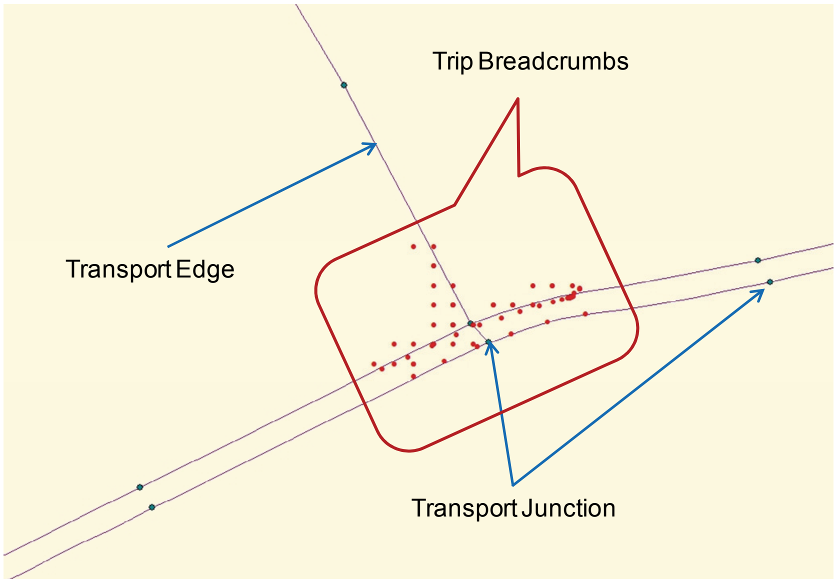


Figure 39. Geospatial identification of riders passing through intersections.

The data collected in this development effort capture the three riders passing through intersections (in Virginia) 2,489 times. These records include intersections controlled by traffic signals or stop signs as well as junctions on limited-access highways. Once the validity of this type of data mining is checked through a stratified review of cases in video, the output can be used directly—for example, in computing exposure or summary statistics—or the output can feed into more detailed investigation of rider behavior in specific scenarios. An illustration of a direct use of the mined data is shown in Figure 40.

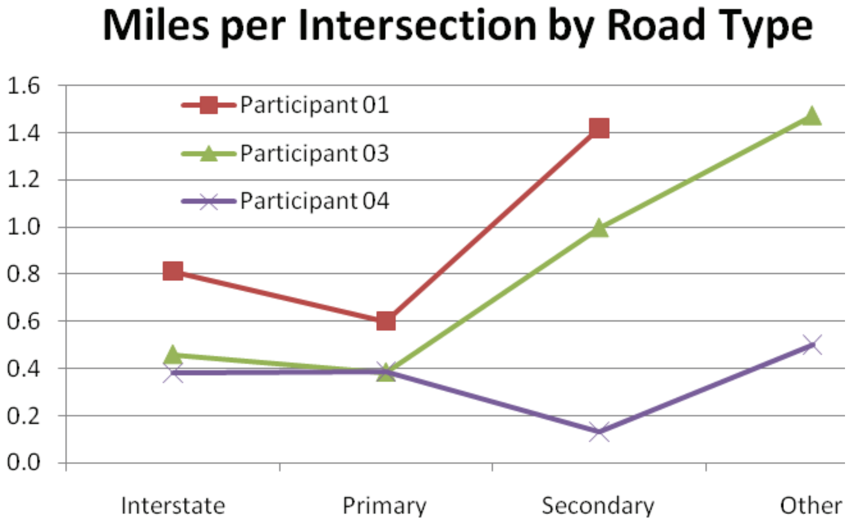


Figure 40. Participant exposure to intersections.

In this analysis, the number of miles ridden in Virginia on the four specified road types was identified for each participant as well as the count of intersections traversed for each participant on those road types. Division of the miles ridden by the number of intersections on each road type provides an indication of how many miles are ridden between intersections for each participant. The figure indicates that the interstates and primary roads ridden on by Participant 01 and Participant 04 have intersections spaced with similar frequency. However, the secondary roads on which these two participants ride appear to differ. Participant 1 only encounters intersections every 1.4 mi on the secondary roads on which he rides, while Participant 4 encounters intersections every 0.1 mi.

More detailed investigation of behaviors can be conducted to explore potential contributing factors in intersection-related crashes. Figure 41 illustrates a time-series reduction of the rider’s gaze, speed, yaw, turn signal use, and brakes as he traverses an intersection.

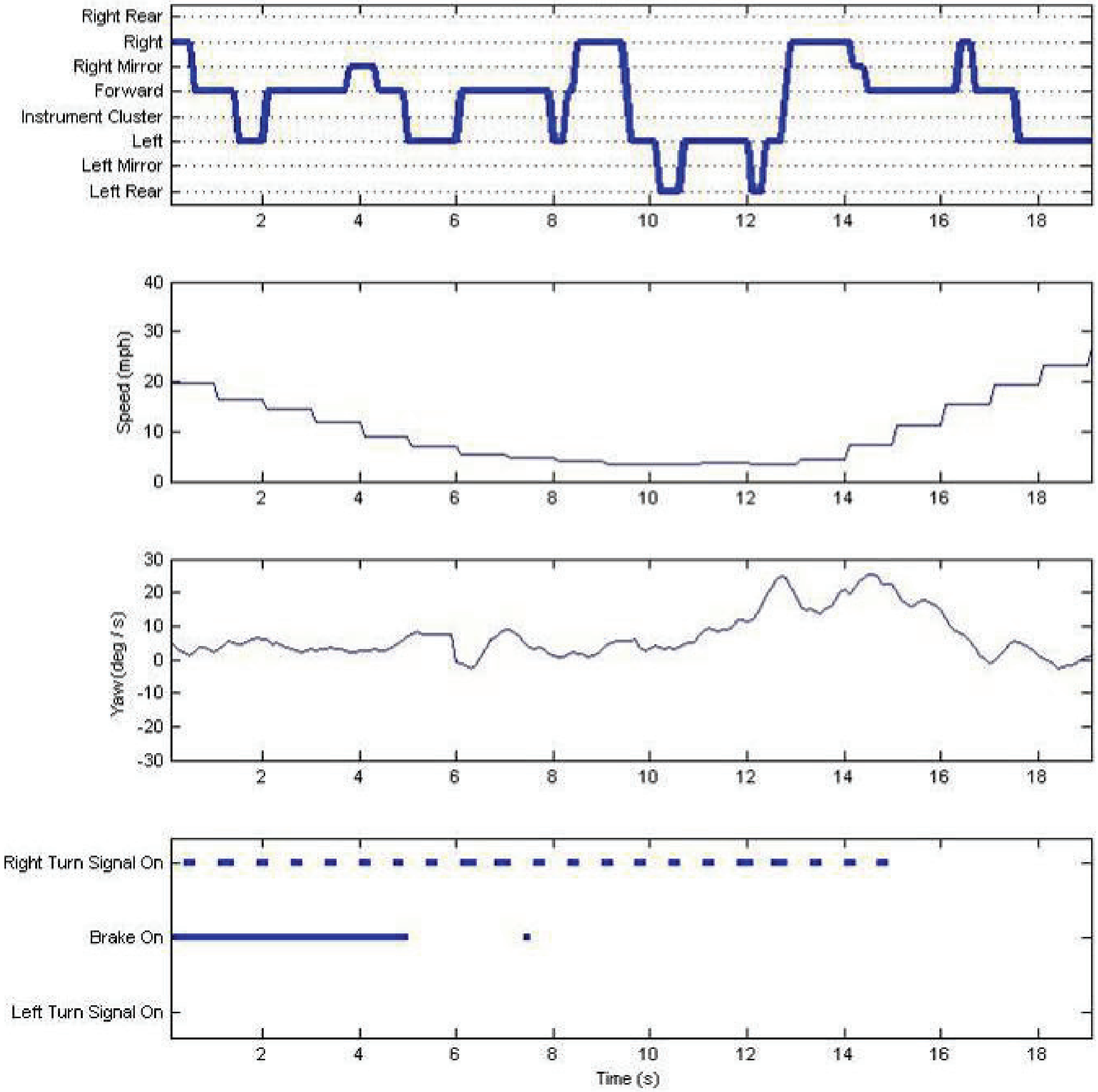


Figure 41. Time-series representation of various measures while riding through an intersection.

In the example shown in Figure 41, the rider slows and makes a turn to the right at the intersection. The turn signal is used. The rider is observed looking left, checking traffic for a gap during the deceleration from approximately 20 mph to 5 mph. The rider looks right at the intended path, looks left finally before accelerating and is looking to the right and forward as the intersection turn is completed. The participant taps the brakes while looking into the turn and before the last leftward traffic check occurs.

This type of reduction can be used to study behaviors in specific events, or aggregated across similar events, for different riders, etc. In the interest of demonstrating an aggregation of naturalistic data related to defensive riding practices, the rider's speed (collected by GPS) was retrieved from the time-series data for each intersection crossing beginning 2 s before entering the 200-ft buffer until 2 s after leaving the buffer. The rider's minimum, maximum, and mean speeds were located for each crossing. The speed varied by less than 2 mph 63 percent of the time. Speeds varied by less than 6 mph 80 percent of the time. A difference of greater than 20 mph was recorded in 9 percent of the intersection crossings. In 10 percent of the intersections, the bike was brought to a stop.

Because the speed data were not reliable for Participant 01, between-subject comparisons can only be made with Participants 03 and 04. Participant 03's speed through intersections varied by less than 2 mph 41 percent of the time, less than 6 mph 58 percent of the time, and more than 20 mph 21 percent of the time. Participant 04's speeds varied by less than 2 mph 77 percent of the time, less than 6 mph 90 percent of the time, and more than 20 mph 4 percent of the time. Participant 03 had lower minimum speeds through intersections with an average of 27 mph, compared to 44 mph for Participant 04. Interestingly, the average difference of speed through an intersection was 9 mph for Participant 03 and 3 mph for Participant 04.

Although intersections were chosen for this demonstration, curves of different radii could also be analyzed in a similar way and could provide very useful information for researchers. Analysis could be done on the data of riders going around curves to identify if and when riders brake, if the riders look into the curve or straight ahead, and whether riders downshift before leaning the bike or after. The speeds that are common in the varying radii of curves could also be calculated. By comparing these and other riding data with data regarding the training of the riders, their ages, and other demographic data, guidance for various countermeasures could be developed.

Event Analysis

Frame-by-frame video analysis can be used to deconstruct events, either safety-event-related or normative riding, into elements of interest. To understand the differences between inexperienced and experienced riders, analysis might also identify the timing of control inputs while executing normal maneuvers, such as stopping at an intersection and continuing on or entering different radii curves on two-lane rural roads. An example of the data available for this type of analysis is shown in Figure 42. These same input values could be identified during crashes and near-crashes.

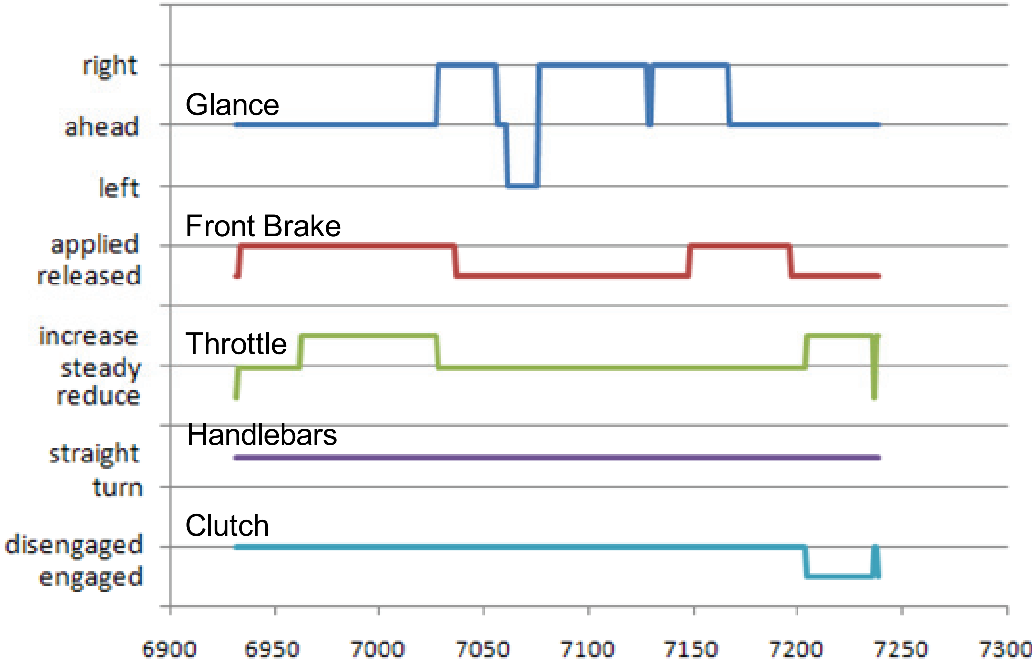


Figure 42. Time-series representation gaze and rider control inputs.

In Figure 43, the percentage of time spent looking to different positions around the bike are presented for the three participants as they pass through intersections. While the gaze data like that presented in Figure 43 do not identify specific objects that the rider is looking at, gaze data do identify the general area that the rider can see. This can identify times when the rider may be looking in the wrong direction to identify impending threats. For example, the rider may not be looking at danger in the forward direction because of real or perceived dangers to the side or may be distracted by secondary concerns. By researching data like these, it may be discovered that riders have a tendency to be looking in the wrong direction while performing a specific type of maneuver or in certain circumstances. This information could provide guidance as to how this combination of factors, or sequence of events could be altered to improve safety.

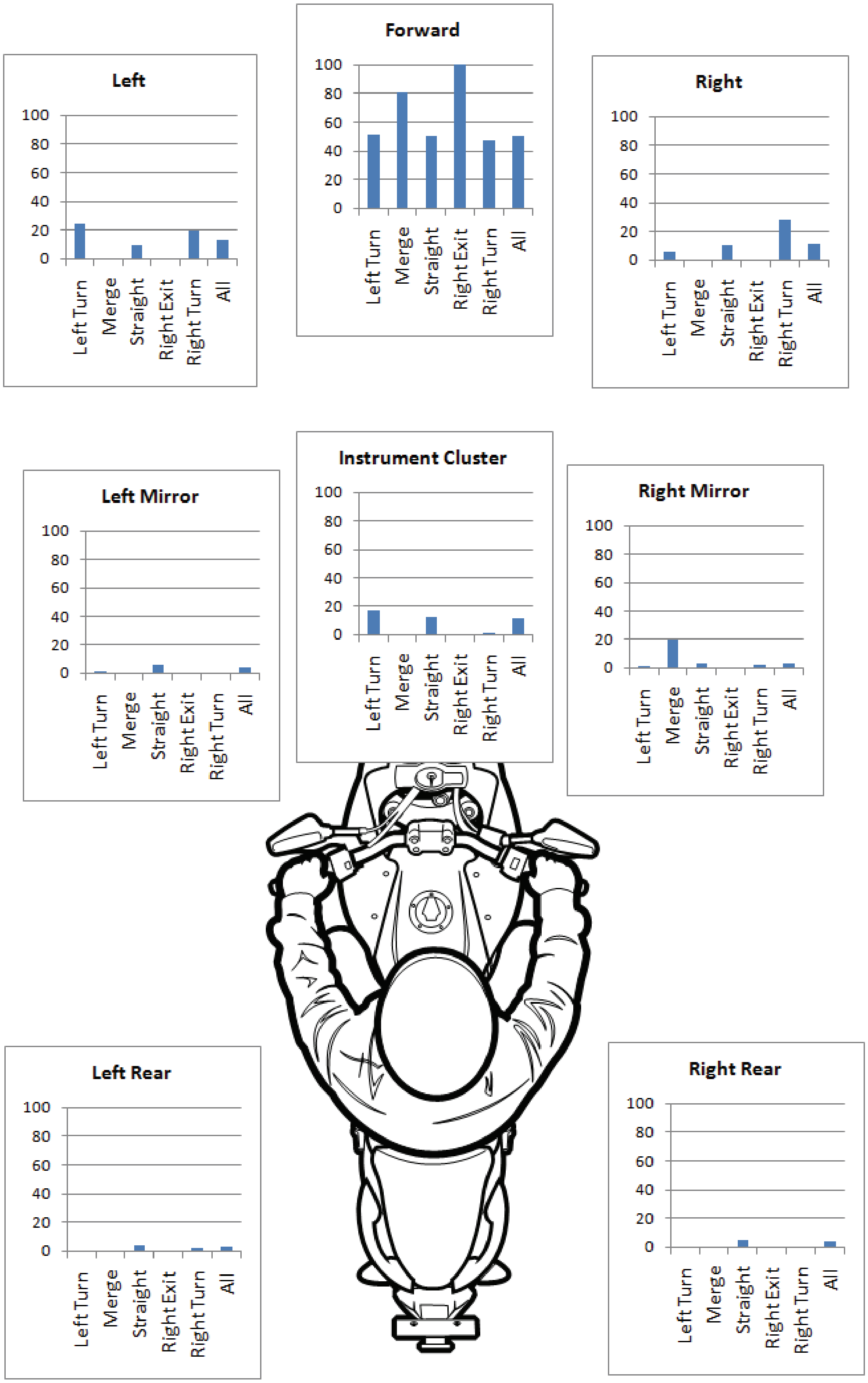


Figure 43. Aggregated gaze data for riders traveling through intersections.

Forward Measures

The radar sensor provided measures of adjacent vehicle interactions. Figure 44 and Figure 45 illustrate the radar-based measures depicting an aggressive passing maneuver. Figure 44 depicts the time-to-collision (TTC) and Figure 45 depicts the range to the lead vehicle. In Figure 44 the TTC can be seen to vary during the initial period as the rider gradually closes on the lead vehicle. To the right side of the figure, TTC then decreases rapidly towards zero.

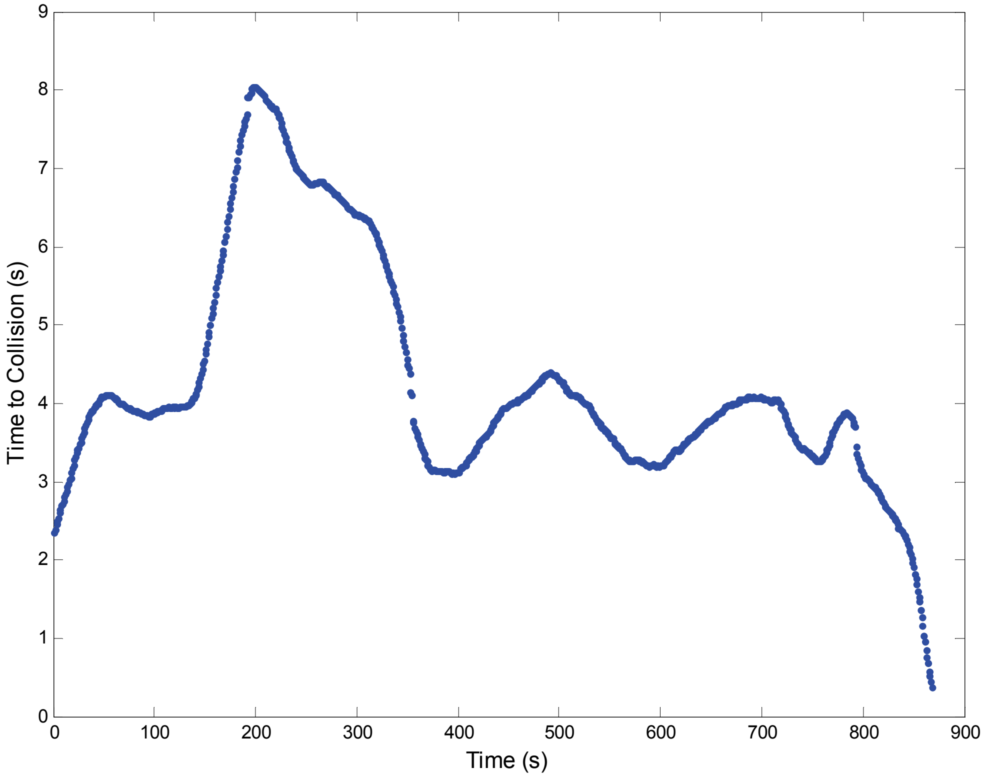


Figure 44. Time-to-collision during approach.

Inspection of Figure 45, which plots the lateral and longitudinal range of the lead vehicle, indicates that the subject drove around the lead vehicle. This is indicated by the trace of position measures extending towards -0.1 m as longitudinal position decreases to zero.

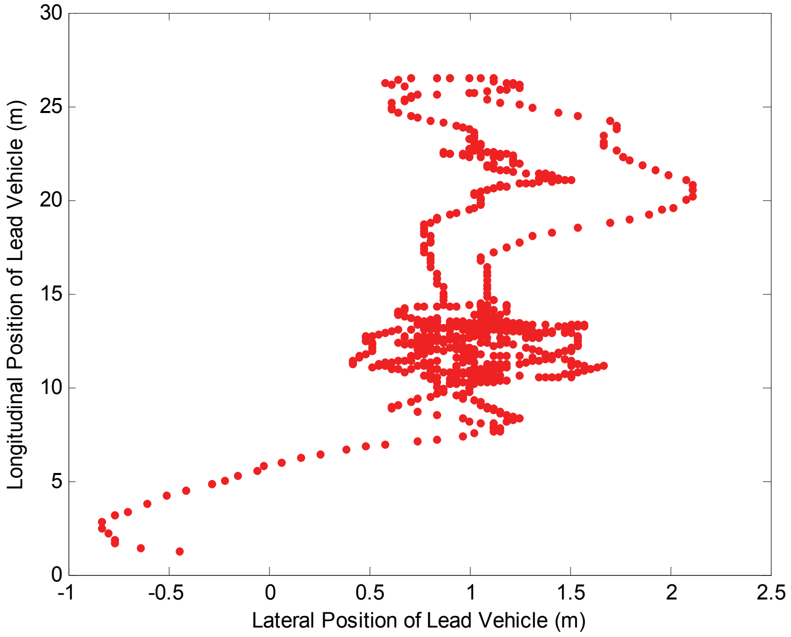


Figure 45. Range and lateral position of a lead vehicle during approach.

Trajectories

Kinematic measures collected by the DAS can be analyzed for a variety of purposes during specific maneuvers. The following figure demonstrates a motorcycle's trajectory as the rider navigates a small alleyway with a variety of obstacles (Figure 46). To mitigate sensor noise, a non-parametric piece-wise smoothing algorithm was first applied to the raw data. These data were then plotted over time to depict the motorcycle velocity, acceleration, and rotational rates during the maneuver. These data can be used for quantifying rider behaviors, for quantifying rider performance, and during events, these measures can be translated into a roadway based coordinate system for investigation of the position and trajectory of the motorcycle over time.

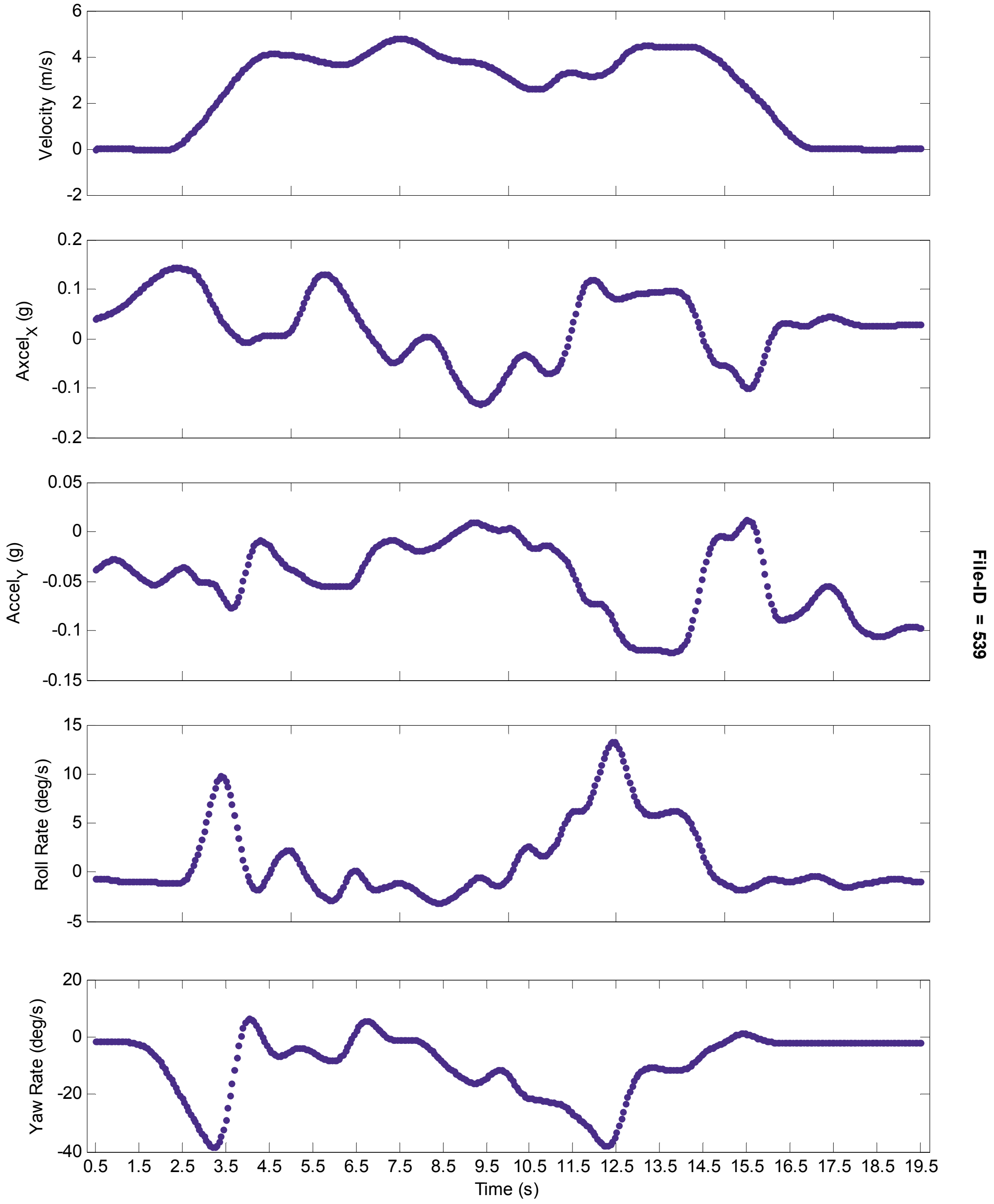


Figure 46. Illustration of kinematic measures.

Braking profile

Understanding the braking behavior and performance of riders over the course of a deceleration event can be used to classify event severity, to compute stopping distance, to understand braking effectiveness, to classify riding styles, and (in combination with other measures) to identify driving scenarios. The figure below was created by data mining the longitudinal acceleration of riders and isolating cases where decelerations occurred. These were then queried to plot the 20 epochs that represented the strongest decelerations for the two latter participants (Figure 47).

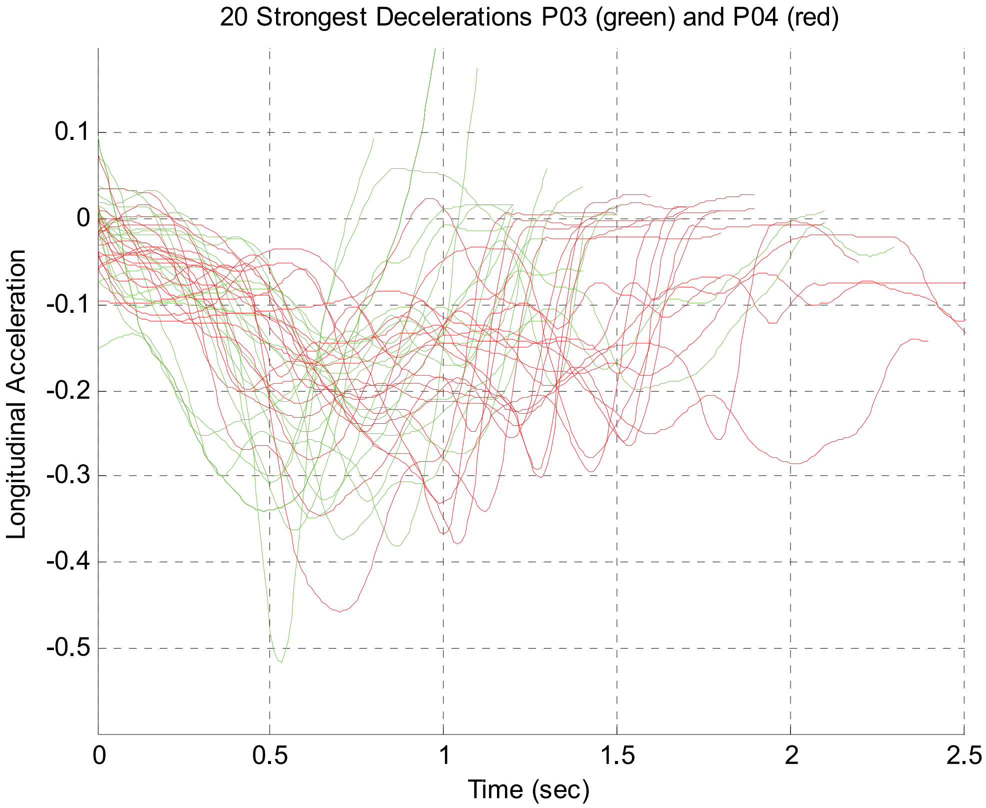


Figure 47. Deceleration profiles for Participant 03 and 04.

From the figure, it appears that in the more severe braking events, Participant 04 (red traces) tends to have a gradual onset with the higher deceleration towards the end. Participant 03 (green traces) applied the brakes earlier in these cases and then has a longer deceleration offset.

Descriptive measures

Descriptive measures can be computed for all of the parametric measures and are of value in understanding the range of values, identifying extreme cases, and quantifying rider differences. Comparison of the yaw rates recorded between riders provides an example of how descriptive measures might be used to understand normative riding as well as extreme maneuvers. The figures below illustrate measures comparing yaw between participants and within a participant (Figure 48 and Figure 49). The boxplot in Figure 48 illustrates the dispersion in recorded right hand yaw rates for the three riders. Descriptive measures such as these might be used to explore differences in riding behavior between riders and the frequency of exercising more rapid turns. The distributions could also be used to identify extreme, or outlier events, for more detailed investigation. Comparison of this type for left and right yaw for an one individual (Figure 49) might reveal different performance envelopes for a rider in one direction versus another.

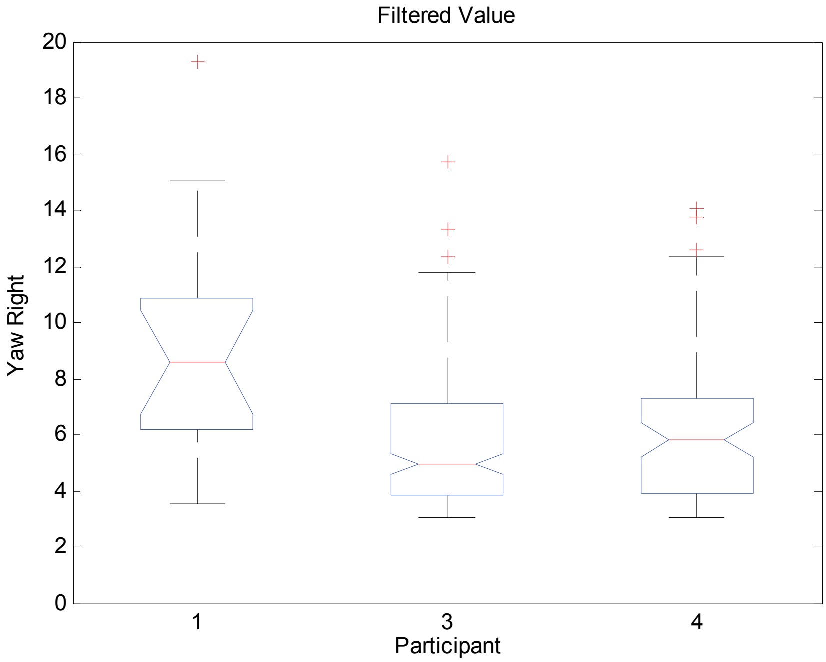


Figure 48. Comparison of performance-related measures between participants.

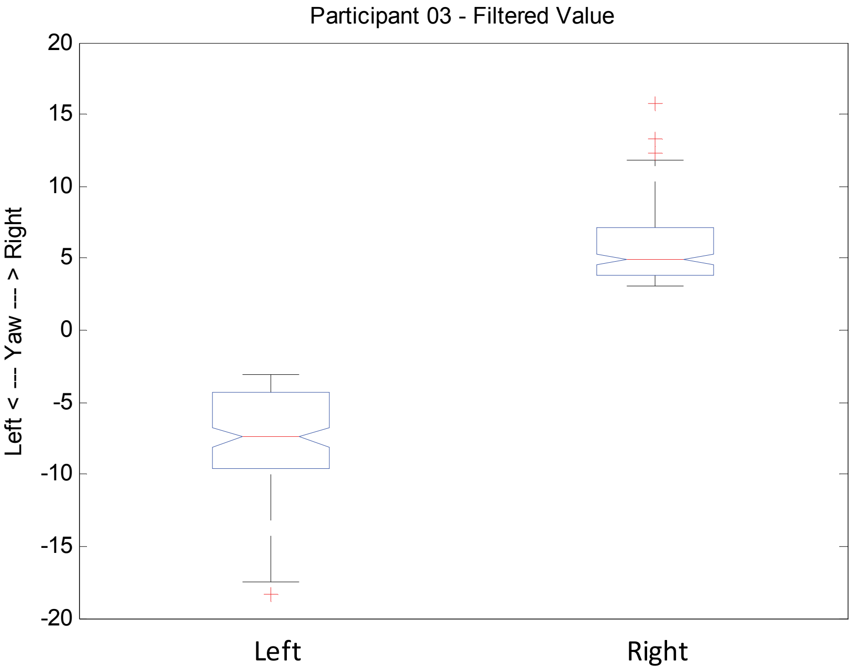


Figure 49. Comparison of performance-related measures within a participant.

Lane Tracking

The performance of machine vision lane tracking was tested with data from one participant. This type of system uses image processing techniques to process the forward camera view and translate the images into numeric values describing lane position. The machine vision algorithm was originally developed for cars and trucks. In this test, it was adjusted for height of the camera on the motorcycle, but otherwise was the same implementation as used on four-wheeled vehicles. The investigation reviewed lane tracking output in good lighting conditions on divided highways, two-lane roads, a gravel road, and in intersections. The lane tracker position data were found to be available on two-lane and four-lane divided roads approximately 60 percent and 90 percent of the time. Solid lines were more easily detected than dashed lines. It appeared that for the two- and four-lane roads, with increasing speed, availability decreased, apparently due to vibration.

Feasibility of Collecting Data to Identify On-road Rider Behaviors

Feasible methods of instrumenting individuals' own motorcycles for naturalistic collection of riding behaviors were developed. The data collected by these systems will support researchers in understanding the rider's crash risk created by different combinations of factors (e.g., roadway environment, rider behaviors, interaction with their bike and other vehicles) as well as exposure and typical driving behavior. In addition to more precise crash risk quantification, the data will provide detailed event records sufficient for guiding countermeasure identification, development, and partial testing through simulation and modeling.

Installation

Physical installation of DASs for long-term data collection on motorcycles is feasible with costs that are similar to the cost of studies conducted for automotive and truck drivers. Similar to those studies, approaches would be necessary to control complexity and cost, such as selecting a representative sample of motorcycles for participation. This would eliminate the need for customized bracketry and installation procedures for every type of motorcycle.

Sight Distance

Forward and head view cameras, combined with distance or time measurements, will provide data which support determination of (1) whether sight distance is a potential factor in crashes and near-crashes, and (2) the sight distances within which motorcyclists ride. The data will be sufficient to understand differences in these measures between many factors of interest—crash/near-crash involvement, event scenario (e.g., curve taking, intersection negotiation), rider experience, training, etc. Quantification of gaze location within the available sight distance, and the effect it has on crash risk, could be accomplished by collecting eye-tracking behaviors of riders during prescribed rides conducted with additional instrumentation. These rides could be conducted at the beginning of a participant's involvement and/or at intervals during participation. Measures collected during these controlled observation points would be used as a covariate with behavioral measures collected during the naturalistic riding to investigate the impact of precise gaze location on performance and safety.

Primary Sensing

Other instrumentation specifics, such as measurement of accelerations, roll rates, latitude, longitude, and speed, have been demonstrated as feasible through this study. It is also feasible to quantify and parse rider exposure into many different conditions of interest (where riders are riding, road class, intersection type, annual average daily traffic, weather, day/night, etc.).

Rider Inputs

Turn signal and brake state were also collected. Brake state is measured through the brake light wiring; therefore, it is either on or off.

Events

Identification of events, including crashes and near-crashes, is feasible. Definitions of these can be developed prior to data collection. It is likely that further tuning will also be useful as more is learned about scenarios and behaviors arising in naturalistic riding.

Lane Placement

It is feasible to evaluate lane position as a factor in avoiding crashes and near-crashes. Two approaches are available. Current technology is available to provide machine-vision processing to measure lane placement when the bike is upright. To evaluate lane position as a factor when the bike is not upright, the most immediate solution is to manually reduce samples, either randomly or paired with events. Some algorithm modification may be necessary for bikes with high amplitude vibration at common riding speeds.

Forward Range Measurement

Understanding various forward distance and closure rate measures may be relevant in understanding rider behaviors related to crashes and crash involvement. Radar units were included on the motorcycles in this feasibility piloting (through separate funding). The radar systems provided reliable data even when the motorcycle was not upright. Analysis is underway to explore the extent to which forward measures are necessary, and what sensor alternatives are available (e.g., manual video reduction, radar, lidar, machine-vision based on forward view)

Additional Variables of Interest

Braking behaviors, including deceleration through down shifting, appear to be factors of interest related to motorcycle crashes. While not implemented in the current study, additional instrumentation of the brakes to collect independent front and rear braking level-of-effort is feasible in a near-term naturalistic study. Down- and up-shifting are visible in the data with current instrumentation for longitudinal acceleration. It is believed that instrumentation of revolutions per minute (rpm) and/or engine vacuum are also feasible in the near term and would provide researchers with a more salient indication of rider control of acceleration and deceleration than longitudinal acceleration alone.

As recommended by the independent evaluator, the pre-drive questionnaires should be expanded to include surveys of personality and attitudes. Measures of this kind may be of value in understanding the willingness of riders to engage in risky riding behaviors. This type of information may be of value in developing effective countermeasures.

Independent Evaluation

Once the participant data had been collected and demonstration analyses were conducted, VTTI worked with NHTSA to narrow down a list of individuals who could provide an external review of the instrumentation and its ability to support NHTSA's research questions. Dr. John Campbell of Battelle Memorial Institute provided this evaluation by reviewing the research objectives and questions, visiting VTTI to see the instrumentation and look at data, and reviewing supporting material related to the instrumentation, analyses, and research plan. The complete independent evaluator (IE) report is provided in Appendix H. Selections of the report are provided here to explain direction for Phase 2.

The IE provided both general and specific evaluation. Overall, VTTI's planned approach was found to be a technically sound approach to learn about real-world riding behavior. The instrumentation is capable of capturing the necessary data, and surrounding methodology was found to be appropriate and aligned with NHTSA's study objectives. With respect to tracking precise gaze locations while riding, the IE indicates that fine-resolution gaze tracking on a naturalistic motorcycle study is not feasible. Though the precision and accuracy of the method described in the Estimation of Sight or Stopping Distance section of this report are lower than requested in NHTSA's research questions, low cost and non-intrusiveness of the method are significant advantages. The IE found that the instrumentation and analyses methods are able to address questions regarding exposure, including relating it to event rates, fatality data, riding seasons, rider experience, lane placement, speed selection, and event involvement.

The IE provided the following recommendations related to the instrumentation and analyses methods. The proposed method for quantifying sight distance could be evaluated through a controlled study. Availability of exposure data from various sources could be surveyed and understood in greater detail to determine its specific applicability and scope. Power analyses would be beneficial to assist in determining the appropriate Phase 2 study approach and sample size. Pre-participation questionnaires should include instruments to measure rider personality, attitudes, and risk taking.

Recommended DAS for Phase 2

Instrumentation components for the motorcycles can be considered as groups based on function and implementation complexity (or cost). The first group includes the main DAS box, GPS, IMU, and cameras. This group addresses a large number of functions of interest in motorcycle research and has been demonstrated as feasible with the NextGen DAS. Additional discussion of the NextGen implementation as well as use of VTTI's miniDAS will be provided after the instrumentation groups are discussed in more detail. While the measures included in this group describe fully what the bike is doing, a second functional group would describe rider braking and throttle adjustments, providing a direct measure of the rider's inputs. This additional information differentiates things such as what the rider tried to do and what the bike actually did, or why the braking achieved was less than what the bike is capable of doing. A third group of instrumentation type is a sensor to measure forward range and closing speeds. This is typically a radar system, but could be lidar or machine-vision range measurement. This function supports quantification of how near a near-crash is and, through the range values, provides a coordinate system on which the interaction of the motorcycle with surrounding objects can be described. The cost of sensors of this type is roughly twice the cost of the instrumentation included in the two previous groups, and so it is appropriate to consider the additional value it provides independently. The fourth group involves instrumentation to quantify where the eyes are looking on the roadway.

To evaluate what instrumentation should be used in Phase 2, each of the research questions were reviewed and these four groupings of instrumentation were identified as providing the primary source of measurement for the research question (indicated with a 1), secondary (indicated with a 2), etc. If the instrumentation group was not required for a research question, no rating was indicated. These ratings are provided for the highest priority research questions in Table 6.

Table 6. Research questions and instrumentation sources.

Questions	Base	Enhanced brake/throttle	Radar	Gaze
Where are riders looking when they have conflicts, near-crashes, and crashes? Is this the same between trained and untrained riders?	2		3	1
Do riders who have sufficient sight distance (i.e., looking 6+ seconds ahead of them) have fewer crashes and near-misses than riders who are overriding their sight distance?	2		3	1
How does exposure among the study participants affect involvement in crashes or near-crashes?	1		2	
How does exposure affect where riders are looking?	1		3	2
Does the number of conflicts, near-crashes and crashes increase with exposure, or is there an inverse relationship?	1		2	
What is the study participants' riding exposure over a riding season?	1			
What is the interaction between experience and exposure?	1			
Defensive riding - General	2		3	1
Do crashes and near-crashes arise during curve negotiation?	1	3		2
What are the trajectories (speed, direction, time-to-collision, etc.) of the subject motorcycle and other involved vehicles?	2		1	
Evasive maneuvers - General	1	2	3	

Questions	Base	Enhanced brake/throttle	Radar	Gaze
What is the relationship between riding style (braking, leaning, etc.) and pre-incident speed?	1	2		
What is the relationship between riding style (braking, leaning, etc.) and rider experience?	1	2		
What is the relationship between riding style (braking, leaning, etc.) and weight:power ratio?	1	2		
How often do one or both wheels skid?	1	2		
Lateral control - General	2	1		
What is the sequence of events/precipitating factors in crashes and near-crashes?	1	3	4	2
What is the sequence of events/precipitating factors in crashes and near-crashes involving a second vehicle (leading, following, crossing, oblique crossing, adjacent)?	1	4	2	3
Is there a difference in riding characteristics (brake bias, braking force, counter-steering, lean angle) between trained and untrained riders during crash or near-crash events? Does this correlate to the same differences above?	1	2		
Are trained riders more effective in evasive maneuver choices? Execution?				
What loss of control mode occurs leading up to the event (e.g., capsize, slide out, high side, wide on turn, end over, wobble, weave, lost wheelie)?	1	2		
What is the timing and cause of rider separation from bike?	1			

Using this approach can help identify the value in pursuing each of the four groups of instrumentation. Focusing first on the 22 research questions identified as high priority, the base package is used for all 22 research questions and provides the primary factors being measured for 77 percent of these. Braking measures and forward-range-related measures are found in half of the high-priority research questions. Measures of gaze are involved in 7 of the 22 high-priority research questions, or 32 percent. For 3 of the 22 highest priority research questions, gaze measurement is the primary factor being measured.

Considering the additional research questions (listed in Appendix I), by including questions rated with average priority greater than 2.0, expands the set of questions to 63. Of these, the base package provides the primary measure for 89 percent of the questions. Enhanced measurement of brakes, throttle, forward range, and gaze each provide the primary measures for between 3 to 5 percent of the research questions.

Though an approximation, based on this approach it appears that deployment of a base instrumentation package would provide data to answer a large portion (80 to 90%) of the research questions of interest. This base instrumentation package would address questions related to exposure to different riding conditions, crash/near-crash involvement, intersections, curves, traffic, event scenarios, sequence of events, rider longitudinal and lateral control norms, lane placement, and relation of riding factors to questionnaire and database information on experience, fatality statistics, demographics, personality, and risk taking inclination.

Experimental questions related to gaze can be answered to some extent with the base package. As illustrated in the demonstration analyses, it will be possible to sample riding at different road geometries and estimate the sight distance that is available to a rider based on his or her self-selected speed. Measures collected in this manner can be used to test differences between riders in different categories of training, crash/near-crash involvement, exposure, roadway scenario, etc. Identification of precisely measuring where within the forward roadway a rider is looking is not feasible with naturalistic instrumentation.

Further instrumentation of brakes and throttle sufficient to provide data to support the research questions related to how riders use these controls was not part of this effort, but appears to be feasible. Brake and throttle instrumentation is currently in development and it is anticipated that it will be available for use in Phase 2 of this research.

Continuous forward range and range-rate measures are not a requirement for addressing many of the research questions, but provide a number of advantages. In defining near-crashes, forward-range measures permit quantification of how “near” the rider was to crashing, both in distance and time-based measures (i.e., range and time-to-collision). Range combined with speed provides a time-based description of the relationship of the motorcycle to other forward objects also provides a continuous coordinate system on which other measures can be viewed. For example, the timing of first brake input can be related to the time available in an event to execute a successful deceleration. Different braking alternatives can be tested within real-world events. Continuous range and range-rate measures also provide a data source that can be mined using automated methods. It is possible to approximate these measures at points in time that are of interest using video, speed, and time data.

Based on this review of the research questions, and grouping of measures, it appears that an efficient instrumentation strategy for Phase 2 is to deploy two levels of DASs and instrumentation. The Base group of measures can be addressed both by the NextGen DAS and VTTI’s miniDAS. The miniDAS is a self-contained DAS and sensor package that collects acceleration, location, speed, and two video views. It is a small unit that could be easily mounted on or near the handlebars. With the two video views, the miniDAS will also capture the forward road scene and support coarse gaze measurement. For additional detail in measurements, the NextGen DAS would be used. This DAS supports forward radar as well as enhanced braking and throttle measures. Bikes with this more comprehensive instrumentation suite would be the first to be instrumented. These bikes would collect both the base measures and provide data on rider inputs and relationships of the bike to surrounding objects during events. Bikes instrumented with the miniDAS would collect exposure measures, frequency of events, and conditions in which the events occur, but would have slightly less detail from the bike and rider during events. The two levels of instrumentation can be used to efficiently collect both detailed event data and greater numbers of events and exposure information.

Targeted Research Questions for Phase 2 and Recommended Analyses for Phase 3

As mentioned in the independent evaluation, the research design used to address the motorcycle crash problem could use one of two strategies. One strategy is to identify likely contributing factors in crashes and target those factors in data collection. By focusing only on factors believed to be important to crash risk this approach is efficient as it requires fewer participants to maintain an acceptable level of statistical power. The second approach is appropriate if it is important to establish understanding of what all riders are experiencing and the range of behaviors and capabilities present in the riding population. The following section will first present the targeted rider selection and sampling strategy and then provide a research strategy to establish broader understanding of riding.

Targeted Strategy and Research Questions

Motorcycles are the only on-road vehicle type that has not been included in safety research methodologies that collect behavior and performance data continuously during every-day (non-experimental) conditions. Whether the emphasis in Phase 2 is on explanatory factors observed in crashes, or on broader understanding of rider behaviors and exposure, motorcycle centric safety insight will be obtained from a naturalistic riding study. Early discussion of Phase 2 sample size used 50-60 riders as an estimate. Previous naturalistic data collections with similar numbers of participants have been successful in providing data that support rulemaking, vehicle system design, and have highlighted factors (e.g., fatigue and distraction) that could not be fully recognized through other analysis methods. If it is possible to increase the number of participants, the range of applicability of the data will broaden and the number of questions that can resolved by the study will increase. The following sections describe two alternative strategies; one is focused on events and one is focused on understanding rider exposure for use in risk computations. As mentioned in the previous section, an efficient design that provides insight in a range of areas would likely incorporate elements of both strategies.

The first strategy targets explanatory factors in the motorcycle crash problem. Though these factors are considered strong candidates for investigation, further review with NHTSA should be done in the early stages of Phase 2. Three factors will be used here to define the riders, with levels indicated in each factor.

- Age (old, young)
- Experience (low, medium, high)
- Bike Type (sport, touring) – Type should probably be defined according to what classification is available in crash records.

Specific definitions of the levels of these types of factors would be determined in early stages of Phase 2. For example, age grouping would likely be guided by accident statistics. Because amount of riding experience is not solidly related to years of licensure, an experience factor would probably screen for actual riding experience according to several measures; miles ridden, types of riding, etc.

Many approaches can be used to determine the relationship between the events and behaviors for these riders, and the conditions within which they ride (i.e., Exposure Categories). Some examples have been provided in the demonstration analyses section of this report. The following high level Exposure Categories are likely candidates for Phase 3.

- Road Type (interstate, primary, secondary, other) – miles and hours ridden
- Intersection Type (signalized, non-signalized, driveway entrance) –miles between intersection, time between intersection
- Curve Size (intersection turn (20m-50 m), small (70-90 m), medium (120-140 m), large (170-190 m), straight (greater than 900 m) – number per mile, number per hour
- Normative baseline

These three rider factors and four exposure categories provide an example framework for Phase 2 and Phase 3. While the analysis conducted in Phase 3 to address each of the research questions will, at a minimum, describe the observed rider behaviors and rate of critical events according to factors and categories such as these, many additional rider and exposure factors will be explored.

Based on the research questions discussed so far, and the results of this feasibility test, 10 research questions were defined to address the motorcycle crash problem within a targeted research strategy (i.e., focusing on likely explanatory factors). The next sections indicate the 10 questions and how the analysis will be conducted for each question.

Q1. What is the interaction between the rider factors and the exposure categories?
Q2. How does the number of events riders have relate to their exposure?
Q3. What is the relative risk for riders in different conditions?

The objective of these research questions and analyses is to determine whether riding exposure appears to explain the numbers of fatalities observed in databases. For example, are older riders covering more miles and, therefore, having greater numbers of crashes, or are older riders having more crashes per mile than the younger group? The exposure categories will be used to control for the types of miles ridden. For example, if greater numbers of curve-related crashes and near-crashes are found for younger riders, the quantification of exposure will permit comparisons if one group tends to be exposed to curves more than the other group. Event rates and exposure will be used to compute relative risk of the different rider factors and exposure category combinations. In Phase 3, analysis for Q1 and Q2 will provide summary measures for each rider and groupings defined by the rider factors. These analyses will be the sub-analyses that support determination of relative (Q3) risk of different conditions for different rider groups. Logistic regression will be used to compute odds ratio approximations of relative risk. The model formulation will depend on the sampling approach used to select baseline epochs.

Q4. What is the relationship between the type of riders and the sight distance within which they ride?

This research question will explore whether riders defined by the different rider factors tend to ride at different sight distances. The primary analysis will separate the participants according to the three rider factors, and measure sight distances while they ride in different exposure categories. In addition to the three primary rider factors defined previously, additional classification of rider type based on either observed riding behavior or personality questionnaire results will likely be of interest in this analysis. For example, sight distance may be considered with respect to rider classifications of either conservative or aggressive based on other riding behaviors or pre-participation attitudes questionnaires. The Phase 3 analysis will use analyses of variance (ANOVAs) to compare group differences. The change in experience of riders occurring during participation may be modeled to understand changes in riding behaviors. The objective of this analysis is to support understanding of what elements of riding influence crash rates.

Q5. What is the relationship between exposure categories and the sight distance within which motorcyclists ride?

This research question will explore whether riders employ or accept different sight distances in different conditions. It will identify the conditions in which sight distance tends to be insufficient. When combined with event counts, this analysis will provide guidance as to whether sight distance may explain rates of occurrence of events in different conditions. ANOVAs will be used to identify differences in the riding sight distances observed in different exposure categories. Modeling will be used to relate near-crash and crash event rates (i.e., relative risk) as a function of sight distance.

Q6. What is the frequency with which different behaviors are observed for different riders?

This research question will determine whether there are differences in riding behaviors based on rider age, experience, and bike type. Behaviors that will be explored will include speed relative to the speed limit, lane position selection, scan behavior at intersections, and time headway while following. It may be possible and/or informative to define these behaviors to differentiate, for example, defensive behaviors from general riding. Exposure measures will be used to normalize the counts of these behaviors according to different riding conditions. Analyses to support this research question will use ANOVAs, and Chi-square analyses will be used to compare frequencies of behaviors. General linear models may also be useful. Understanding how behaviors change over the course of involvement may use growth modeling techniques.

Q7. How does typical (non-event) bike handling, or riding style, relate to age, training, and bike type?
Q8. How does bike handling differ between exposure categories?

Analyses supporting these questions will quantify the riding performance of motorcyclists using kinematic measures. In addition to the more composite-type behaviors explored in Q6, questions Q7 and Q8 will provide understanding of the norms of riders in terms of accelerations, yaw rates, roll rates, speeds, and stopping distances in different conditions. Together with event rates, the results of these analyses will indicate whether bike handling can be associated with rider factors, and whether event rates are more accurately predicted by the rider factors or by riding styles. Analyses to answer these questions would first summarize kinematic measures with simple summary measures. Basic generalized linear models could then be used to understand differences. More advanced approaches would use functional data analysis or clustering. The outcome of the analyses supporting this question would explain crash rates, not from their a priori rider factors (e.g., older experienced rider on touring bike), but from the way they actually ride.

Q9. What are the details of crash and near-crash scenarios?

This question will use the naturalistic data to understand crash types and contributing factors in greater detail than is available in police reports and crash databases. Details that will be identified in the crashes and near-crashes will include the sequence of events, sight distance, precipitating factors, pre-event speeds of the motorcycle and other actors (e.g., vehicles, pedestrians, animals), pre-event paths of travel time series trajectories, lane position, orientation of vehicles, and lean angles and rates necessary to avoid collision or departing the roadway in a curve. The results will provide validation of the crash causes identified through police reports and database analysis, and will guide identification of appropriate countermeasures. These details would be described with basic counts and descriptive statistics. More advanced analyses might make use of structural equation models to understand the sequence of events across crash cases. As with the other questions, the outcome here will support understanding contributing factors in crashes and relative risk of different factors for motorcyclists (Q3).

Q10. What are the details of rider response in crashes and near-crashes?

This question is similar to the previous, but focuses on the rider’s response. Events will be analyzed in detail to identify time available for response, decelerations achieved, steering achieved (changes in path), lean angle achieved, success of maneuver and/or details of loss of control. Response maneuvers will be compared to kinematic measures developed in question Q7 analyses. The results of this comparison will provide an indication of severity of near-crashes and relate the required maneuvers in crashes and near-crashes to typical handling. The results will be of value in targeting training curricula as well as identification and testing of countermeasures.

Broad Rider Behavior Strategy

As mentioned previously, there are little data providing unequivocal and comprehensive indication of the causes for the high rates and increasing trend of motorcycle crashes. The previous strategy targeted factors that are hypothesized to be involved. A broad rider behavior strategy would use a sampling approach that pursues measurement of riding behaviors and exposure of the entire riding population. A broad strategy would emphasize recruitment of a larger number of participants and actively include additional levels for each of the rider factors and exposure factors described previously. For example, in addition to sport and touring bikes, traditional bikes and cruisers would be included. Other factors that would be pursued include training type and how recently it occurred, rider physical and perceptual capabilities, trip objectives, etc. The initial research questions would likely include those described in the Targeted Strategy, but many other research questions would also be supported. The advantages of this approach are that it provides effective data even if initial assumptions about crash causation are incorrect and it provides a dataset that has ongoing value in a wide range of transportation research areas—safety, efficiency, vehicle design, roadway design, etc. For example, through initial investigation of events, fork rake might appear as a possible factor in loss of control. A broader data collection approach would already have data on cruisers that, because of the consistently greater rake angle, could be used to confirm or refute the developing hypotheses.

Conclusions

The guiding objective of this project was to determine the feasibility of migrating naturalistic data-collecting methods that have been successfully employed in both light- and heavy-vehicles to a motorcycle platform. Crash database analyses indicate that motorcycle crashes create a large proportion of the roadway fatality problem. This is particularly true given that the exposure (miles or time) for motorcyclists is much less than for other roadway users. Although researchers have hypothesized about the reasons for the ongoing increase in motorcyclist fatalities, the root causes have not been verified and are not fully understood. Currently there is arguably no foreseeable countermeasure to reverse this trend. Naturalistic data collection is a valuable technique for: (1) providing the data and additional resolution for validating hypotheses, (2) providing detailed time-series event data that can increase understanding beyond identification of simple relationships between factors, (3) revealing unanticipated contributing factors, and (4) providing guidance from riding in which things are going well for the rider. This effort indicates that although motorcycles have unique challenges, a large naturalistic study is currently feasible.

References

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Appendix A - Research Question List

Q#	Questions	Average Priority
1.1	Where are riders looking when they have conflicts, near-crashes, and crashes? Is this the same between trained and untrained riders?	3.0
2.1	Do riders who have sufficient sight distance (i.e., looking 6+ seconds ahead of them) have fewer crashes and near-misses than riders who are overriding their sight distance?	3.0
3.1.1	How does exposure among the study participants affect involvement in crashes or near-crashes?	3.0
3.1.2	How does exposure affect where riders are looking?	3.0
4.1	Does the number of conflicts, near-crashes and crashes increase with exposure, or is there an inverse relationship?	3.0
5.1	What is the study participants' riding exposure over a riding season?	3.0
7.1	What is the interaction between experience and exposure?	3.0
15.1	Defensive riding - General	3.0
16.3	Do crashes and near-crashes arise during curve negotiation?	3.0
17.1	What are the trajectories (speed, direction, time-to-collision, etc) of the subject motorcycle and other involved vehicle?	3.0
18.1	Evasive maneuvers - General	3.0
19.5	What is the relationship between riding style (braking, leaning, etc) and pre-incident speed?	3.0
19.6	What is the relationship between riding style (braking, leaning, etc) and rider experience?	3.0
19.7	What is the relationship between riding style (braking, leaning, etc) and weight:power ratio?	3.0
20.7	How often do one or both wheels skid?	3.0
21.1	Lateral control - General	3.0
23.1	What is the sequence of events/precipitating factors in crashes and near-crashes?	3.0
23.2	What is the sequence of events/precipitating factors in crashes and near-crashes involving a second vehicle (leading, following, crossing, oblique crossing, adjacent)?	3.0
24.3	Is there a difference in riding characteristics (brake bias, braking force, countersteering, lean angle) between trained and untrained riders during crash or near-crash events? Does this correlate to the same differences above?	3.0

Q#	Questions	Average Priority
24.4	Are trained riders more effective in evasive maneuver choices? Execution?	3.0
31.1	What loss of control mode occurs leading up to the event (e.g., capsize, slide out, high side, wide on turn, end over, wobble, weave, lost wheelie)?	3.0
32.2	What is the timing and cause of rider separation from bike?	3.0
8.1	Are there differences between riders who have near-crashes and/or crashes and riders who experience none? What are they?	2.7
11.1	How often do adjacent drivers appears to fail to see the motorcycle rider (i.e., turning in front of the rider when there really isn't enough time to do so)?	2.7
14.1	How much riding is done in mixed traffic versus open road?	2.7
15.3	How is speed controlled at different types of intersections (T, angled, alley, signaled, unsignaled)?	2.7
15.4	How is speed controlled at different types of intersections in the presence and absence of potentially encroaching traffic?	2.7
16.1	In what scenarios do crashes and near-crashes arise (e.g., following, intersection approach, curve taking, lane change)?	2.7
18.3	What evasive maneuvers are used? Braking, swerving, both?	2.5
18.4	What is the sequence of braking, steering, leaning?	2.5
18.5	What distances are consumed for different evasive maneuvers (braking, swerving).	2.5
20.3	What following distances and TTCs do riders employ?	2.5
20.4	How effective are riders at controlling deceleration?	2.5
24.2	Is there a difference in riding characteristics (brake bias, braking force, countersteering, lean angle) between trained and untrained riders in baseline conditions?	2.5
25.1	What is the interaction between rider age and exposure?	2.5
27.4	Differences between rider types (trained, untrained, experienced, inexperienced)	2.5
28.1	What decelerations are achieved for different braking systems (ABS, Combined Brake Systems (CBS), Conventional Hydraulic)?	2.5
28.4	For similar time-to-collision scenarios, does braking profile differ across braking systems?	2.5
6.1	Where do riders ride most often and how does this compare to the fatality data?	2.3
9.1	How does lane placement affect a rider's ability to avoid crashes and detect hazards?	2.3

Q#	Questions	Average Priority
11.2	How often do adjacent drivers appears to fail to see the motorcycle rider (i.e., turning in front of the rider when there really isn't enough time to do so) when other vehicle's view is obstructed?	2.3
12.4	How does recreational riding compare to riding for transport in terms of crashes and near-crashes?	2.3
15.2	Does lane position vary with road geometry? Curves, blind intersections, passing parked cars, merging?	2.3
10.1	Are riders who avoid crashes and near-crashes less likely to travel over the posted speed limit?	2.0
11.3	How often do adjacent drivers appears to fail to see the motorcycle rider (i.e., turning in front of the rider when there really isn't enough time to do so) in limited visibility (fog, rain, glare)?	2.0
12.1	How does recreational riding compare to riding for transport in terms of event rates, acceleration event rates, lean angles?	2.0
18.2	How familiar are riders with near-evasive maneuvers?	2.0
19.2	What is the relationship between riding style (braking, leaning, etc) and engine displacement?	2.0
19.3	What is the relationship between riding style (braking, leaning, etc) and motorcycle type?	2.0
20.2	Longitudinal control performance distributions (decelerations, accelerations)?	2.0
20.5	Which brake is applied first?	2.0
21.4	How effective are riders in maintaining their lane?	2.0
21.5	How often do riders cross into an oncoming lane?	2.0
23.5	What is the sequence of events/precipitating factors in crashes and near-crashes involving animals?	2.0
23.7	What is the sequence of events/precipitating factors in crashes and near-crashes gravel or similar?	2.0
27.2	Does rider torso position vary during curve negotiation?	2.0
27.3	Does rider torso and head position vary during evasive maneuvers?	2.0
28.3	Is time between start of braking and maximum deceleration different?	2.0
29.2	Do people practice braking?	2.0
29.3	Do people practice swerving?	2.0
29.5	How frequently do people practice?	2.0
32.1	Rider separation from bike?	2.0
33.1	Prevalence of secondary tasks in crashes, near-crashes and related to other safety-related measures	2.0

Q#	Questions	Average Priority
12.2	How does recreational riding compare to riding for transport in terms of speeds, traffic, road class, duration, environment?	1.7
13.2	How does car driving frequency relate to motorcycle skills in terms of compatibility / negative transfer?	1.7
15.5	How does rider clothing conspicuity (helmet and clothing color, retroreflective markings) relate to other safety-related measures?	1.7
21.2	Lateral control performance distributions (lean, lateral accelerations)?	1.5
21.3	What range of lateral velocities do riders achieve at different speeds?	1.5
21.6	What type of steering is used (counter steering vs. standard steering) to initiate lean?	1.5
21.7	How often are wheel lockup or low coefficient-of-friction precipitating factors in lateral control events?	1.5
21.8	Does bike cornering clearance relate to other safety-related measures?	1.5
22.1	How does exposure versus incidents compare for time of day, day of week, month of year?	1.5
23.6	What is the sequence of events/precipitating factors in crashes and near-crashes from wheelies etc?	1.5
26.1	What is the relationship between off-road experience and other safety-related measures?	1.5
29.4	What levels of braking and swerving are achieved in practice?	1.5
29.6	Are there relationships between practice and riding styles?	1.5
30.1	How often are passengers on bikes?	1.5
12.5	How does recreational riding compare to riding for transport in terms of safety/protective attire?	1.3
19.4	What is the relationship between riding style (braking, leaning, etc) and motorcycle modifications?	1.0
23.3	What is the sequence of events/precipitating factors in crashes and near-crashes involving a roadway defect or design hazard?	1.0
23.4	What is the sequence of events/precipitating factors in crashes and near-crashes involving a pedestrian?	1.0

Appendix B - Instrumentation Specification

1 HARDWARE REQUIREMENTS

The DAS hardware must adhere to the following requirements:

- DAS hardware must:
    - NOT impact rider safety
    - Have no impact on the motorcycles functions or rider experience
    - Fit unobtrusively on various types of motorcycles ranging from dual-sport to cruiser.
    - Collect and store specified variables in a efficient and reliable manner
- DAS hardware should
    - Install in less than 2 days
    - Reliably collect and store specified variables for at least 200 hours before retrieving data
    - Reliably collect and store specified variables for at least 3 consecutive hours without ignition cycle
    - Require no maintenance or calibration for 1 year
    - Be unobtrusive
    - Provide a mechanism for unobtrusively downloading data

1.1 MAIN-UNIT, ENCLOSURE, AND NETWORK SPECIFICATION

Parameter	Specification	Justification
Operating System	Linux	Required to support VTTIs data collection software package
Collection Software	SOL	Standardized VTTI data collection software package to ensure reliability and maintainability
Data Retrieval	DAS must include a method for retrieving data through manual hard-drive swap, and support wired/wireless, download for future data collection efforts	During development data must be easily obtained for validation and refinement.
Inconspicuous and unobtrusive	Enclosure shall be mounted such that it will not alter the riding experience (rattling for example), nor shall it touch the rider during typical use (including getting on/off cycle), nor shall it impact any of the motorcycles typical functionality (inhibit reaching the fuel switch for example)	Safety and rider acceptance
Collection Status	The DAS shall collect data whenever the ignition is turned on and there is sufficient power to sustain operation without draining electrical system. When the cycle is not running the DAS shall enter a low-power standby state.	Automatic data collection enables un-supervised operation. The low power mode ensures that sufficient power will be available for the next ignition cycle.
Water Resistance	The system shall resist water from rain, road splash, and cleaning.	Some riders may perform trips during rain and most will wash their cycles during the collection periods.
Vibration Resistance	The system shall continue to operate in the presence of significant vibration caused by traversing the roadway and by some engines (particularly large displacement single and dual cylinder engines)	System must operate in motorcycle environment which often includes vibration.
Crash Resistance	The system shall retain data recorded prior to a crash including instances in which power is severed.	One of the primary goals of this study is to investigate pre-crash scenarios. Thus, data should be retained whenever possible.

Weight	The system shall not weight more than 7 pounds.	A heavy system could impact ride of the cycle
Power	The system shall operate at 12 volts and will not draw more than 4 amps while recording or 200 milliamps while in standby mode.	Motorcycles operate at 12 volts (6 volt cycles will not be part of the study). The maximum draw rate ensures that sufficient power is available for typical operation of the motorcycle
Isolation/shielding	The system and relevant cabling will be isolated and/or shielded such that data quality is retained (e.g. electrical fields from ignition pulses)	System must operate in motorcycle environment
Cabling	Cabling shall be routed and secured such that it is non-obtrusive and does not interfere with riding or maintaining the motorcycle.	Lose or messy wiring could entangle the rider leading to a safety hazard. Also user acceptance must be maintained to ensure participation in study
Temperature Resistance	System shall function in ambient temperatures ranging from 0° C to 40° C ambient temperatures	System must operate in motorcycle environment during riding season.
Wind Resistance	System and cabling mounting must withstand winds up to 300 kph.	System must operate in motorcycle environment which can include high speeds coupled with significant wind.

1.2 Sensor Specifications

The following sensors are required for the motorcycle DAS. These sensors are directly related to the variables listed in the software specifications.

Sensor	Specifications
Forward Camera	CCD color camera Rain and road water resistant or within water resistant enclosure Protected from road rocks and other debris 70 deg field of view
Face Camera	CCD grayscale camera Rain and road water resistant or within water resistant enclosure Protected from road rocks and other debris 40 deg field of view
Side Cameras	CCD color camera Rain and road water resistant or within water resistant enclosure Protected from road rocks and other debris 110 deg field of view
Rear Camera	CCD color camera Rain and road water resistant or within water resistant enclosure Protected from road rocks and other debris 70 deg field of view
GPS	Must be capable of maintaining constant measurements through a leaning turn Position accuracy = Speed accuracy =
Inertial Measurement Unit (IMU)	Acceleration accuracy Gyroscope accuracy
Radar	Num of targets > 3 Speed accuracy = Range accuracy =
Brake Status Sensor	Use a non-obtrusive measurement method Must indicate status regardless of how speed or duration of brake application by rider
RPM Sensor	Use a non-obtrusive measurement method (e.g. inductive loop) 2% accuracy over a 1 to 20,000 rpm range
Vacuum sensor	2psi accuracy over a 0 to 20 psi range

2. SOFTWARE REQUIREMENTS

The DAS software must adhere to the following requirements.

- DAS software must
    - NOT affect rider safety
    - Have no impact on the motorcycles functions or rider experience
    - Collect and store specified variables in a efficient and reliable manner
- DAS software should
    - Reliably collect and store specified variables for at least 200 hours before retrieving data
    - Reliably collect and store specified variables for at least 3 consecutive hours without ignition cycle
    - Require no maintenance or calibration for 1 year
    - Provide a mechanism for unobtrusively downloading data

2.1 DATA COLLECTION SOFTWARE SPECIFICATIONS

Parameter	Specification	Justification
Interface	Must be able to attach an engineering display for monitoring DAS, collection status, and sensors outputs INCLUDING video. Display must be removed prior to naturalistic data collection.	The diagnostic display ensures that a system is working, provides troubleshooting interface, and calibration interface. The video portion is necessary to focus the cameras after installation.
Data Collection	The software must choreograph the sensor suite such that data accuracy and precision is retained in the recorded data. Data shall be collected as specified in the "collection status" specification in the hardware table.	A precise and accurate dataset is required for analysis
Data Format	Parametric data shall be recorded asynchronously in a format compatible with VTTI's current generation data viewing software.	During the study, data must be rapidly moved from the hardware to the appropriate tool for analysis.
Data Preprocessing	The software shall perform the pre-processing necessary to translate raw sensor inputs to meaningful measures for collection.	To mitigate misuse of the data conversions of the raw data to relevant units is best performed within the DAS when possible
Unit System	All measures shall be recorded using the SI standard	Standardization of the variable units will help mitigate confusion
Data Retrieval	Software must support data retrieval method specified in the Hardware Specifications table	

2.2 HEADER SPECIFICATIONS

Variable	Units	Range	Operational Definition
Motorcycle ID	n/a	1 to 10,000	ID of the motorcycle on which the DAS is installed. This value must be entered during DAS installation
Software Package Version	n/a	TBD	Version of the software used to during the data collection. This value should change anytime the software is updated.
DAS Unit ID	n/a	1 to 10,000	The ID of the DAS installed in the cycle. This value must be entered during DAS installation.

2.3 VARIABLE SPECIFICATIONS

Group	Variable	Units	Range	Operational Definition	Hardware Required
Frame	Frame	#	0 to TBD	Frame counter that begins at each trip and increments once for every data collection frame	Main Unit
	Video_Frame	#	0 to TBD	Frame of the video that begins at each trip and increments once for every video frame. This value MUST be in the data stream and also be present as an overlay on the video itself.	Main Unit
Video	Forward_View	n/a	n/a	Video of the forward driving scene	Camera
	Left_Side_View	n/a	n/a	Video of the side of the bike and scene including rider body position and clutch hand	Camera
	Right_Side_View	n/a	n/a	Video of the right side of the bike and scene including rider body position and brake hand	Camera
	Rear_View	n/a	n/a	Video of the reward driving scene	Camera
	Helmet_View	n/a	n/a	Video of the rider's helmet	Camera
Time	Week	#	1490-1600	Week number that is ensured accurate by syncing with GPS when GPS signal is good	GPS
	Time_of_Week	ms	0 to 604799999	Time of Week number that is ensured accurate by syncing with GPS when GPS signal is good	GPS
Helmet Tracker*	X_Helmet_Pos	m	0 to 3	Smoothed X position on the screen	Camera
	Y_ Helmet _Pos	m	0 to 3	Smoothed Y position on the screen	
	Z_ Helmet _Pos	m	0 to 3	Smoothed Z position on the screen	
	X_ Helmet _Rot	Deg	0 to 180	Smoothed Rotation around the X axis	
	Y_ Helmet _Rot	Deg	0 to 180	Smoothed Rotation around the Y axis	
	Z_ Helmet _Rot	Deg	0 to 180	Smoothed Rotation around the Z axis	
	Gaze_Zone	n/a	On Road Instrument Panel Driver Mirror Driver Side Passenger Mirror Passenger Side	Zone where the driver is looking based on the smoothed values.	
	Confidence	%	0 to 100	Indication of data quality based on machine vision object match quality	

Group	Variable	Units	Range	Operational Definition	Hardware Required
Eye Tracker*	X_Eye_Pos	n/a	0 to 1	Normalized eye gaze location	Dual eye cameras and scene camera
	X_Eye_Pos	n/a	0 to 1	Normalized eye gaze location	
	X_Eye_Pos	n/a	0 to 1	Normalized eye gaze location	
Lane Tracker	Status	n/a	Lost	Road scout cannot find any lane lines to report.	Camera
			Lane	The vehicle lies in the lane between the painted lines.	
			Right	The vehicle is crossing a line on the right.	
			Left	The vehicle is crossing a line on the left.	
			Abort	The driver aborted crossing a line. A line was crossed then the driver crossed back over it.	
			Shift	The driver successfully crossed a line completely and settled in the adjacent lane. (lane change)	
			Nightime	The car is driving in nighttime condition (darkness).	
			Exit_R	There is an exit on the right side of the road.	
			Exit_LT	There is an exit on the left side of the road.	
	Lane_Offset	m		Distance between center line of vehicle and imaginary centerline of roadway lane	
	Lane_Width	m		Estimated width of roadway lane	
	Gamma	Deg		Angle between center line of vehicle and center line of lane markings in radians at the camera position.	
	Rho_Inverse	Deg		Inverse curvature of the roadway.	
	Incline	Deg		Change in incline angle of the road.	
	L1_Marking_Type	n/a	0 = none 1 = double line 2 = single line 3 = road gutter 4 = road edge 5 = reflector	Type of Marker	
	L1_Marking_Shade	n/a	0 = white or yellow marking 1 = black marking	Shade of the marking line (does not apply to edges or gutters).	
	L1_Left_Dash	n/a	0 = solid 1 = dash 2 = unsure if solid or dash	Left most marking if double line. Otherwise marking dash status for single line:	
	L1_Right_Dash	n/a	0 = solid 1 = dash 2 = unsure if solid or dash	Right most marking if double line only	
	L1 Probability	n/a	Max is 1024. Probability of marking increases as marker is found from one frame to the next. Max value is 1024. A minimum value of 4 indicates that the marker is fabricated.	Probability that marking exists.	
	L1_Left_Distance	m		Distance to left side (outside) of left line.	
	L1_Right_Distance	m		Distance to right side (inside) of left line.	
	L2_Marking_Type	n/a	0 = none 1 = double line 2 = single line 3 = road gutter 4 = road edge 5 = reflector	Type of Marker	

Group	Variable	Units	Range	Operational Definition	Hardware Required
	L2_Marking_Shade	n/a	0 = white or yellow marking 1 = black marking	Shade of the marking line (does not apply to edges or gutters).	
	L2_Left_Dash	n/a	0 = solid 1 = dash 2 = unsure if solid or dash	Left most marking if double line. Otherwise marking dash status for single line:	
	L2_Right_Dash	n/a	0 = solid 1 = dash 2 = unsure if solid or dash	Right most marking if double line only	
	L2 Probability	n/a	Max is 1024. Probability of marking increases as marker is found from one frame to the next. Max value is 1024. A minimum value of 4 indicates that the marker is fabricated.	Probability that marking exists.	
	L2_Left_Distance	m		Distance to left side (outside) of left line.	
	L2_Right_Distance	m		Distance to right side (inside) of left line.	
GPS	Latitude	Deg	0 to 180	Current Latitude	GPS
	Longitude	Deg	0 to 180	Current Longitude	
	Heading	Deg	0 to 180	Current Heading	
	Altitude	M	0 to 5,000	Current Altitude	
	Speed	m/s	0 to 70	Current Speed	
	Week	#	1490-1600	GPS week value	
	Time_of_Week	ms	0 to 604799999	GPS time of week value	
	Distance_Traveled	m	0 to 5,000	COMPUTED: Distance traveled since last ignition cycle.	
IMU	X_Accel	g	0 to TBD	Longitudinal acceleration	IMU
	Y_Accel	g	0 to TBD	Lateral Acceleration	
	Z_Accel	g	0 to TBD	Vertical Acceleration	
	Roll_Rate	Deg/s	TBD	Roll rate	
	Pitch_Rate	Deg/s	TBD	Pitch rate	
	Yaw_Rate	Deg/s	TBD	Yaw rate	
Controls	Front_Brake_Status	n/a	0 to 1	Indicates brake on/off rather than brake status. If necessary, the front and rear brake status variables could be combined into a single brake status variable.	Switch or network
	Rear_Brake_Status	n/a	0 to 1	Indicates brake on/off rather than brake status. If necessary, the front and rear brake status variables could be combined into a single brake status variable.	Switch or network
Other	Engine_Speed	RPM	0 to 20,000	Engine Revolutions Per Minute	TBD
	Engien_Vacuum	Psi	0 to 100	Engine vacuum is a measure of power requested by rider	Vacuum sensor
Radar	Object ID(Track 1-TBD)	n/a	0-255	Unique ID for the track	Radar sensor
	X_Range(Track 1-TBD)	m	0-500	Longitudinal range to objects	
	Y_Range(Track 1-TBD)	m	0-500	Lateral range to objects	
	X_Speed(Track 1-TBD)	m/s	0 to 70	Longitudinal speed of object	
	Y_Speed(Track 1-TBD)	m/s	0 to 70	Lateral speed of object	
	Type(Track 1-TBD)	n/a	0-TBD	Type of object	

*Helmet and eye tracking systems may not both be implemented depending on the research questions and goals of future efforts.

Appendix C - NSTSCE DAS Design Questionnaire

There are two purposes for this questionnaire. Your answers will assist designers of systems that will be used in motorcycle-related research. When combined with the responses of other individuals, your answers will also provide information on a number of topics related to motorcycle use. Summaries of these data will be published. This research is funded by the National Surface Transportation Safety Center for Excellence operated by the Virginia Tech Transportation Institute and has been reviewed by the Virginia Tech Institutional Review Board. If you have questions, please contact [redacted].

Questionnaire instructions

This questionnaire takes 15-20 minutes to complete.

Questionnaire Instructions: This questionnaire takes 15-20 minutes to complete.

<u>Section A</u>

1. **Gender:**
   ○ Male
   ○ Female

2. **Year of Birth:** _______

3. **Do you have a valid motor vehicle driver's license?**
   ○ Yes
   ○ No

4. **Do you have a motorcycle operator's license (NOT a permit)?**
   ○ Yes
   ○ No

5. **In what State do you ride most often?** ________________

6. **How old were you when you obtained your motorcycle license?**
   ____

   ○ Do not have my motorcycle license.

7. **How old were you when you began riding STREET/ON-ROAD motorcycles?**
   ____

   ○ I never rode on the street.

8. **How old were you when you began riding motorcycles OFF-ROAD?**
   ____

   ○ I never rode off-road.

9. **How many different STREET motorcycles have you ridden regularly *in the last 12 months*?**
   ____

10. **How many motorcycles do you currently own or lease?**
    ____

11. **List the year, make, model, and displacement of the STREET/ON-ROAD motorcycles you own in order of annual use (Bike 1 being the most frequently used). *Please skip this question if you do not own a STREET/ON-ROAD motorcycle.***
    Example:

    Bike 1

    Year: 2003

    Make: Yamaha

    Model: XT 225

    Displacement (cc): 225

    Bike 1

    Year: ________

    Make: ________

    Model: ________

    Displacement (cc): ________

Bike 2

Year: _________

Make: _________

Model: _________

Displacement (cc): _________

Bike 3

Year: _________

Make: _________

Model: _________

Displacement (cc): _________

Bike 4

Year: _________

Make: _________

Model: _________

Displacement (cc): _________

12. **Approximately how many miles did you ride motorcycles *in the last 12 months*?**

    ____

<u>Section B</u>

For the motorcycle you ride most frequently (Bike 1 above), please answer the following:

13. **What year did you purchase this motorcycle?**

    ____

14.What is the odometer reading on this motorcycle?

____

15.Did you purchase this motorcycle new or used?

○ New
○ Used

16.If you purchased this motorcycle used, what was the odometer reading when you purchased it?

____

***The following set of questions will help determine options for mounting systems and accessing data during future research projects*.**

17.When at home, where do you store this motorcycle?

○ Garage/house
○ Driveway
○ Parking lot
○ Street
○ Other: ________

18.What type of internet access do you have at home?

○ Dial-up
○ High speed without wireless
○ High speed with wireless
○ None

19.Is there an electrical outlet near the motorcycle?

○ Yes
○ No

20.When at home, how often do you cover this motorcycle?

○ Always
○ Almost Always
○ Sometimes
○ Rarely
○ Never

21.On this motorcycle, how often do you use a windshield?

○ Always
○ Almost Always
○ Sometimes

○ Rarely
○ Never

22. On this motorcycle, how often do you use luggage carriers or saddle bags?

○ Always
○ Almost Always
○ Sometimes
○ Rarely
○ Never

If you use luggage carriers or saddle bags:

23. What items do you carry in it? ***(Select all that apply)***

○ Books
○ Computer
○ Clothing
○ First Aid Kit
○ Food/Beverages
○ Papers:
○ Other: __________

24. How often is the storage (e.g., luggage carriers or saddle bags) more than half full?

○ Always
○ Almost Always
○ Sometimes
○ Rarely
○ Never

25. Do you use any of the following aftermarket accessories on this motorcycle? ***(Select all that apply)***

○ Back rest
○ Bagger skirts (alternative to a saddle bag)
○ Chain guard
○ Rear hugger (keeps the undertail from getting damaged from debris)
○ Engine control chips or jets
○ Exhaust/muffler modification
○ Fly Screen (smaller than a wind screen that protects clocks and offers some wind protection)
○ Front mudguards
○ Gas tank bib
○ Motorcycle trailer
○ Saddle bag guards (providing extra support to your saddlebags)
○ Suspension modification
○ Tail skirts
○ Tinted windshield
○ Do not use any of these

26. Do you use any of the following bike-to-bike radio systems on this motorcycle? *(Select all that apply)*
- ○ Intercom
- ○ CB
- ○ FRS Radio
- ○ None
- ○ Other: __________

27. Do you use a GPS on this motorcycle?
- ○ Yes
- ○ No

28. Do you use a cell phone while riding this motorcycle?
- ○ Yes
- ○ No

Section C

The following section pertains to how you ride Bike 1 from above. A trip is defined as the travel period from the place you started to your final destination (which may be the same place you started). Stops along the way, like breaks or for fuel, are included in one trip.

29. How often do you ride this motorcycle?

Days: _______

per (week, month, or year): _______

30. Approximately how many miles did you ride this motorcycle on the road *in the last 12 months*?

____

31. Approximately how many miles did you drive a car *in the last 12 months*?

____

32. Do you have a riding season?
- ○ Yes
- ○ No, I ride all year. *(Please skip to Question 35.)*

33. Approximately what month do you begin your riding season, if any?
- ○ January
- ○ February
- ○ March

○ April
○ May
○ June
○ July
○ August
○ September
○ October
○ November
○ December

34. Approximately what month do you end your riding season, if any?

○ January
○ February
○ March
○ April
○ May
○ June
○ July
○ August
○ September
○ October
○ November
○ December

35. Do you spend more time riding on weekdays or weekends?

○ Weekdays
○ Weekends
○ I ride on weekends and weekdays equally.

36. Which of the following best describes your riding?

○ I commute on a motorcycle at least once a week during my riding season; I do not ride specifically for pleasure.
○ I commute on a motorcycle at least once a week during my riding season; I also ride for pleasure.
○ I sometimes ride to commute, but not consistently. I also ride sometimes for pleasure.
○ I ride mostly for pleasure; I rarely commute on a motorcycle.

37. How often do you ride after dark?

○ Very frequently
○ Frequently
○ Sometimes
○ Rarely
○ Never

38. Which of the following describes most of the miles in which you typically ride?

○ Mostly urban (frequent stop lights, turn lanes, traffic entering from side streets, interacting with other traffic while riding)
○ Mostly rural (generally one lane in each direction, infrequent stop lights, some stop signs, other traffic occasionally)
○ Suburban (miles are a roughly equal mix of urban and rural)

39. What type of roads do you ride most frequently?

○ 2-way roads (one lane in each direction)
○ Multilane roads (multiple lanes in each direction)

40. During your last riding season (or last year if you ride all year), how many of your rides were for commuting to and from work, running errands, etc?

○ All
○ Most
○ Some
○ Few
○ None

41. During your last riding season(or last year if you ride all year), how many of your rides were for pleasure only?

○ All
○ Most
○ Some
○ Few
○ None

For work-related commute:

42. How many days a week do you commute on your motorcycle? *(If you select "0", please skip to question 47.)*

○ 0
○ 1
○ 2
○ 3
○ 4
○ 5
○ 6
○ 7

43. How long is your commute (one way)?

Minutes: _______

44. How many miles is your commute (one way)?

____

45. Where do you park your motorcycle at work?

○ Garage
○ Parking structure/deck
○ Ground level parking lot
○ Street parking
○ Other: __________

46. Do you cover your bike at work?

○ Yes
○ No

For pleasure trips:

(Note: A trip is defined as the travel period from the place you started to your final destination (which may be the same place you started). Stops along the way, like breaks or for fuel, are included in one trip.)

47. For the trips you take most frequently, how long does it take you to get to your destination?

○ Less than ½ day
○ ½ day to 1 full day
○ Multiple days

48. For a common trip you took for pleasure, how many miles do you ride?

____

On the longest trip you took for pleasure during your last riding season:

49. How many days did you ride?

____

50. On average, how many miles did you ride each day?

____

51. How many miles is the most you rode in one day?

____

52. What is the longest ride you expect to do in the next year?

Days: _______

Miles: __________

53. How long do you normally ride for before taking a break?

○ 30 minutes
○ 1 hour
○ 1.5 hours
○ 2 hours
○ 2.5 hours
○ 3 hours
○ 3.5 hours
○ 4 hours
○ 4.5 hours
○ 5 hours or more

54. How often do you have a passenger on your motorcycle when taking trips for pleasure?

○ Always
○ Almost Always
○ Sometimes
○ Rarely
○ Never

Section D

55. How did you learn to ride? *(Select all that apply)*

○ Taught self
○ Taught by family member/friend
○ Training course
○ Other: __________

56. Have you taken a motorcycle training course (e.g., Motorcycle Safety Foundation)?

○ Yes
○ No

57. Estimate how many separate occasions in the last year you practiced hard braking or swerving on your street bike (e.g., going to a parking lot and practicing hard braking)?

○ 0
○ 1
○ 2
○ 3
○ 4
○ 5

○ 6
○ 7
○ 8
○ 9
○ 10
○ 11
○ 12
○ 13
○ 14
○ 15
○ 16
○ 17
○ 18
○ 19
○ 20 or more

58. Estimate how many stunt type maneuvers you did in the last year (e.g., wheelies, stoppies, burnouts) on your street bike?

○ 0
○ 1
○ 2
○ 3
○ 4
○ 5
○ 6
○ 7
○ 8
○ 9
○ 10
○ 11
○ 12
○ 13
○ 14
○ 15
○ 16
○ 17
○ 18
○ 19
○ 20 or more

59. Which of the following best describes your motorcycle maintenance?

○ I perform all the maintenance on my motorcycle.
○ I perform the maintenance up to my ability and bring my motorcycle to a shop when necessary.
○ I always bring my motorcycle to the shop for maintenance.

60. How often do you charge your motorcycle battery?

○ During long breaks (e.g., winter)
○ Occasionally for other reasons (e.g., trouble starting, left lights/ignition on)
○ Never

61. How often do you examine the braking system before you ride?

- ○ Always
- ○ Almost Always
- ○ Sometimes
- ○ Rarely
- ○ Never

62. How often do you examine the tire condition before you ride?

- ○ Always
- ○ Almost Always
- ○ Sometimes
- ○ Rarely
- ○ Never

63. How often do you examine the function of the headlight, turning signal, and braking light before you ride?

- ○ Always
- ○ Almost Always
- ○ Sometimes
- ○ Rarely
- ○ Never

64. What type of protective gear do you wear on a regular basis? *(Select all that apply)*

- ○ Helmet
- ○ Face shield
- ○ Goggles
- ○ Gloves
- ○ Jacket
- ○ Pants
- ○ Riding suit
- ○ Do not wear any of these

How often do you wear the following:

65. Bright/colorful clothing?

- ○ Always
- ○ Almost Always
- ○ Sometimes
- ○ Rarely
- ○ Never

66. Reflective clothing?

- ○ Always
- ○ Almost Always
- ○ Sometimes

○ Rarely
○ Never

67. Boots?

○ Always
○ Almost Always
○ Sometimes
○ Rarely
○ Never

68. Helmet?

○ Always
○ Almost Always
○ Sometimes
○ Rarely
○ Never

69. How many helmets do you own?

____

70. What type of helmet do you wear most often while riding?

○ Full-face
○ Three quarter shell
○ Half shell
○ Do not wear a helmet

71. Do you wear a helmet when riding in States that don't require helmet use?

○ Yes
○ No

72. **Have you ever crashed (i.e., any type of crash -- accidently laid your bike down while moving or ran into something or struck by another vehicle/animal)? *(Please skip to Question 81 if you answer "No.")***

○ Yes
○ No

73. If so, how many times?

____

The following questions pertain to your most recent crash.

74.How many vehicles, besides your own, were involved?

____

75. Did it involve a pedestrian?

○ Yes
○ No

76.If so, how many?

____

77.Who was at fault?

○ You, as the motorcycle rider (i.e., motorcycle driver)
○ Other driver
○ Pedestrian
○ Road condition (includes wet, gravel, potholes)
○ No-fault crash

78.Where did it take place?

○ Intersection
○ Curve/bend
○ Other: __________

79.Were you speeding?

○ Yes
○ No

80.Please provide any other useful details that are not included above.

____

____

____

Section E

The following questions are to estimate interest among riders. You will not be contacted for participation based on your answers.

81. **What is your level of interest in participating in an on-road study exploring motorcycle riding behaviors and rider performance?**
0 Wouldn’t do it under any circumstances

1

2

3

4

5 I would probably be willing

82. **What is your willingness to let a research institute temporarily install small sensors and cameras on your motorcycle for a period of time (e.g., weeks or months)?**
0 Wouldn’t do it under any circumstances

1

2

3

4

5 I would probably be willing

83. **Would you be willing to wear a helmet provided by a research institute?**
0 Wouldn’t do it under any circumstances

1

2

3

4

5 I would probably be willing

84. **Would you be willing to allow a research institute to temporarily attach small sensors or cameras to your helmet?**
0 Wouldn’t do it under any circumstances

1

2

3

4

5 I would probably be willing

85. Would you be willing to have a detachable cable from your helmet to your motorcycle similar to what is used for motorcycle intercoms?
0 Wouldn’t do it under any circumstances

1

2

3

4

5 I would probably be willing

86. Please list any reasons why you would *not* be interested in this type of study:
____

____

87. What pay would be acceptable *per month* to attain your participation in research in which small data acquisition hardware was mounted on your motorcycle for one riding season?
$ __________

88. If some other compensation or accommodations would be required, what would they be?
____

89. Where did you hear about this survey?
○ Pamphlet left on my motorcycle.
○ It was forwarded to me by an individual
○ I received it in an e-mail from a group

- ○ I read about it on a website
- ○ Other: _________

90. Please list any motorcycle-related certifications in addition to your rider's license/permit/endorsement. Examples include training or maintenance certifications?

____

This research institute is considering conducting an on-road study exploring motorcycle riding behaviors and rider performance. If you are possibly interested in participating, would it be okay to contact you?

- ○ Yes, I would possibly be interested. Please contact me at the number or email address I have provided below.
- ○ No, I am not interested. Please do not contact me.

If yes, please contact me at the following number (or email address) to provide more details.

____

Note: Your contact information will only be viewed by VTTI's Principal Investigator and Co-Investigator of this project.

Thank you for your feedback.

Appendix D - Recruiting and Screening Forms

Screening Questionnaire

Note to Researcher:

Initial contact between participants and researchers will take place over the phone. Please, read the following Introductory Statement, followed by the questionnaire. Regardless of how contact is made, this questionnaire must be administered verbally before a decision is made regarding suitability for this study. **Do not place any participant information on this questionnaire**, it should only be used to record participant answers. Once eligibility has been determined (i.e., the participant answers comply with all the screening criteria) and you've recorded the participant information on the last page, discard the rest of this questionnaire.

Introductory Statement:
After prospective participant calls or you call them, use the following script as a guideline in the screening interview.

Hello, my name is ______ and I am a researcher with the Virginia Tech Transportation Institute in Blacksburg, VA. We are currently recruiting people to participate in a research study investigating motorcycle riding.

We are calling to ask if you would have interest in participating. The study involves placing sensors and cameras on your motorcycle and having you ride as you normally do for two to four weeks. During the study, depending on the needs of the study, and of course your willingness, you may use either a helmet we provide, have a small removable sticker placed on your helmet, or you may just use your regular helmet as is. If you have questions during this call, I can answer them. Afterward, if you think you may be interested, we will send you a write up about the study, also known as an Informed Consent, to read and sign if you'd like to participate. If so, you would then come to the Institute to get started.

At this time, I can answer any questions you have or I can read you some more details about the sensor installation, VTTI, and payment for participation.

Answer questions AND read the following.

Sensor Installation and VTTI

If you are willing to participate, you would bring your bike to VTTI and leave it with us for two to three days. Your motorcycle will be started, but will not be ridden by anyone but you. The Institute has many years of experience installing sensors on people's cars and trucks and later removing them without damage. We have developed these sensors and cameras, as well as the garage procedures, specifically for motorcycles.

Pay

You will receive $20.00 an hour for the time you spend at VTTI . This time requirment is expected to be about 2 hours over the course of the entire study. You will also receive $20.00 per week that you ride with the equipment installed on your motorcycle.

Does this sound interesting to you?

If No:
Thank you for your time. If you have any questions in the future related to this study or this call, you may reach me at 540-231-xxxx.

If Yes:
First, I would like to collect some information from you to determine if you are eligible to participate. This will take up to 15 minutes of your time. If there is a question you are uncomfortable with, you do not have to answer it. Do I have your verbal permission to ask you these questions?

○ Yes
○ No *(Ineligible)*

Upon receiving ineligible response, please STOP and tell them they are not eligible for the study based on their answer. Refer to Criteria for Participation for additional information. A sample script is provided at the end of this document once eligibility (or ineligibility) has been determined.

1. Gender
   ○ Male
   ○ Female

2. How old are you? ____ years old *(Ineligible under 18 years of age.)*

3. Do you have a valid motorcycle license?
   ○ Yes
   ○ No *(Ineligible)*

4. Do you have one STREET motorcycle that you own and will own for the next six months and are willing to have it instrumented for this study?
   ○ Yes
   ○ No *(Ineligible)*

5. Do you currently carry at least liability insurance for this motorcycle?
   - ○ Yes *(Mention that we will require proof of insurance during orientation)*
   - ○ No *(Ineligible)*

6. We will require proof of insurance during the orientation. Are you able to provide us with this information?
   - ○ Yes
   - ○ No *(Ineligible)*

7. How would you describe the mechanical condition of this motorcycle?
   - ○ Excellent – Always starts, runs great, like new.
   - ○ Good – Always starts, runs well, has some miles on it.
   - ○ Fair – Occasional minor trouble starting but runs well.
   - ○ Poor– Often trouble starting or requires attention to keep running. *(Ineligible)*

8. Do you expect anyone else will ride this motorcycle regularly during this period?
   - ○ Yes *(Ineligible)*
   - ○ No

9. Are you eligible for employment in the U.S.?   (Please note that we are NOT offering employment to you.)
   - ○ Yes
   - ○ No *(Ineligible)*

10. Please note that for tax recording purposes, the fiscal and accounting services office at Virginia Tech (also known as the Controller's Office) requires that all participants provide their social security number to receive payment for participation in our studies. You do NOT need to provide it now, but are you willing to provide us with your social security number?
    - ○ Yes
    - ○ No *(Ineligible)*

11. (Females only) Are you currently pregnant?
    - ○ Yes *(Ineligible: Please explain that they cannot participate because the Virginia Tech IRB does not allow pregnant women to participate in this type of driving study.)*
    - ○ No

12. What is the make/model/year/displacement of the street motorcycle you ride most frequently?
    Make _______
    Model _______
    Year _______
    Displacement _________

13. How many years have you been riding a street motorcycle? _____ years

14. On average, how many miles *per year* do you ride a street motorcycle? _________miles

Eligibility Determination

If the Participant is NOT Eligible:

Unfortunately, you are not eligible to perform the study because _______________. Thank you for your time.

Criteria for Participation:

1. Must be 18 years or older.
2. Must hold a valid driver's license.
3. Must hold a valid motorcycle license.
4. Must own one motorcycle that they will own for the next six months.
5. Must have liability insurance.
6. Motorcycle must be in fair or better mechanical condition.
7. Must not expect anyone else will ride this motorcycle regularly during the study.
8. Must be eligible for employment in the U.S.
9. Must be willing to provide a valid social security number.
10. Must not be pregnant.
11. Make, Model, Year, Displacement *(to ensure a diverse sample of motorcycles)*
12. Number of years riding *(to ensure a diverse sample of experience)*
13. Miles per year *(to ensure a diverse sample of experience)*

If the Participant IS Eligible:

Thank you for answering these questions. You are eligible to participate in this study. We would like to obtain your contact information so that we can provide you with more information about the study and follow up after you have looked at it. Please note that we will likely not be able to have everyone participate who is interested, so you may end up receiving the material and being willing to participate, but we cannot include you in this study. If this happens, we will hopefully be able to include you in future studies.

1. Name: __________________

2. Do you use e-mail?
   ○ Yes; what is your email address? _________________________________
   ○ No
   If yes, deliver by e-mail.
   If no: In what city do you live? _________________________________

   If local (Blacksburg, Christiansburg, etc): If convenient, we can hand deliver the material to you. Would that be okay or would you prefer we mail it?

If mail:

Mailing address: ____

____

Finally, I'd like to get your phone numbers to follow-up with you.

3. Phone numbers:
    a. Home : _______________________________
    b. Cell Phone: ____________________________
    c. Work Phone: ____________________________

4. Which is the best number to use to contact you? ___________________

5. When would be good to call? Make as soon as convenient. If unsure, suggest three days.?
   ____

After having looked at the materials, feel free to contact me with questions or to accept or decline participation. The best number to reach me at is…

****

Appendix E - Informed Consent Form

Consent Form for Participants Using Privately Owned Motorcycle

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Pilot Study of Instrumentation to Collect Behavioral Data to Identify On-road Rider Behaviors

Investigators: Dr. Shane McLaughlin and Dr. Zac Doerzaph

I. The Purpose of this Research/Project

Over 10% of all fatalities on U.S. roads are motorcyclists. The motorcycle fatality rate has doubled in the last 10 years. This study is a small practice study, or pilot study with approximately 5 participants. The lessons learned in this study will lead up to a larger study to investigate the behavior of motorcyclists and other factors that may contribute to these statistics.

II. Procedures

You are being asked to participate in a naturalistic driving study. The study involves a two to four week data collection period in which a self-contained unit containing sensors and cameras will be installed on your motorcycle to record a variety of driving measures. As a participant, you will be expected to participate in the following activities:

Attend an initial meeting and information session at VTTI

- Review information regarding participation in the study (A researcher will show you where we intend to place the data collection system and show you pictures of what a completed installation looks like).
- Read and sign this Informed Consent Form.
- Show the experimenter your valid driver's license and proof of insurance.
- Complete a paper and pencil questionnaire.
- Complete vision tests.
- Fill out a W9 tax form in order to receive payment for participating.
- Schedule a time to instrument your motorcycle

☐ Allow the researcher to fit you with a helmet that you will wear during the study (Not all study participants will wear a VTTI issued helmet. This box will be checked for participants who are issued a helmet).

Allow VTTI staff to install the instrumentation on your motorcycle

- Instrumentation will normally take 2-3 days.
- If it is convenient for you, this will take place immediately after the information session at VTTI. In this case, VTTI staff will provide you with a ride home and will pick you up again when the bike is ready.
- If it is not convenient for you to leave the motorcycle at the end of the information session, a separate visit will be scheduled and you will be given rides to and from VTTI to accommodate this.

When instrumentation is complete, you will be shown the instrumentation system on your motorcycle. If you are going to use a VTTI issued helmet, a researcher will demonstrate how to connect the helmet to the system using the cord.

Then, you will drive your motorcycle as you normally would to your normal destinations for 2 to 4 weeks. During this time, we ask that you do the following:

- Contact VTTI if you notice any maintenance issues with the system (for example, a camera that comes loose and dangles).
- Permit VTTI researchers to access your motorcycle (at your home or work location) at least once a week to download data. You do not need to be present during the data downloads. Subject to your approval, data downloads will be completed between 7am and 11pm.
- If you are in an accident while in the study, we ask that you do three things:
  a. Call us at [redacted] to notify us of the accident.
  b. Allow us to retrieve the data from your vehicle’s electronic data recorder (EDR or “black box”) and from the data collection system we installed.
  c. Allow us to have access to the police accident report, if any, which results from the accident.
- Do <u>not</u> take the motorcycle into any facilities that do not permit video recording devices.

After your two to four week session is over we will be schedule a date and time for you to come back to VTTI. The following will occur during this one hour session:

- The system will be removed from your motorcycle.
- If you were using a VTTI helmet, you will return it to VTTI.
- Fill out a final questionnaire.
- Receive final payment for participation in the study.

III. Risks

The risk to you is no more than you would normally incur while riding your motorcycle with 31 pounds of luggage. All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard in any foreseeable way. None of the data collection equipment will interfere with any part of your normal field of view. The addition of the data collection systems to the vehicle will affect the operating or handling characteristics of the motorcycle in that a loaded luggage carrier will be mounted behind the seat. This luggage carrier and the equipment inside weigh 31 pounds. Loads mounted behind the rear wheel axle could change cycle balance and braking characteristics. You should only participate if you have experience and are comfortable riding with luggage in this location.

If you are using a VTTI helmet, the cord connecting the helmet to the data collection system will disconnect easily in the event that you separate from the bike. Except for your two visits to VTTI, you are not being asked to alter your daily driving routines in any way.

There is an additional risk not encountered in everyday life. While you are riding the motorcycle, cameras will record video of you, your actions, and surrounding traffic. In the event of an accident, there is a risk that the video could be obtained in conjunction with a government inquiry, or in litigation or dispute resolution. This is discussed in more detail below.

Please note that since you are driving your own motorcycle, Virginia Tech is not liable for the expenses incurred in any accident you may have. In the event of an accident, you are not responsible for damage to the instrumentation VTTI installs on the motorcycle.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation. Under Commonwealth of Virginia law, workers compensation does not apply to volunteers; therefore, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses.

If you should become injured in an accident, whether on or off your motorcycle, the medical treatment available to you would be that provided to any person by emergency medical services in the vicinity where the accident occurs.

IV. Benefits of this Project

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is being made to encourage participation. Participation will help to improve the body of knowledge regarding motorcyclists' behavior and performance. Participation will also help us design the larger study in a way that is acceptable and comfortable for future participants.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after you begin participation, your name and other identifying information will be separated from the data and replaced with a number. That is, your data will not be attached to your name, but rather to a number (for example, Driver 0011).

While driving the vehicle, a camera will record your face and torso. Additionally, cameras will capture views of the forward view. All video will be captured and stored in digital format (no tape copies will exist).

The video, questionnaire, and sensor data will be stored in a specific password-protected project folder. For the purposes of this project, only authorized project personnel will have access to your video data.

It is expected that the data we capture throughout the course of the entire study, including all 5 motorcycle riders, will be a valuable source of data on how motorcyclists respond to certain situations and how the roadway and motorcycle might be enhanced to improve driver safety. Therefore, it is expected that there will be follow-on data analyses conducted using all of the data. These follow-on analyses will be conducted by qualified researchers who may or may not be part of the original project team. In every case, the researchers who obtain access to the data will be required to sign a data sharing agreement which specifies the ways in which they may use the data, and which will continue to protect your anonymity and confidentiality. The confidentiality protection provided to you by these data sharing agreements will be as great as or greater than the level provided and described in this document. Data that can identify you (e.g. video data of your face) will not be released to any researchers outside of VTTI. Any further research efforts will also require additional approval by the Institutional Review Board (IRB), but will not require anything further of you.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

If you are involved in a crash while participating in this study, the data collection equipment on your motorcycle will likely capture the events leading up to the event. The data collection equipment SHOULD NOT be given to police officers or any other party.

We will do everything we can to keep others from learning about your participation in the research. We may disclose information about you as required by law, in conjunction with a government inquiry, or in litigation or dispute resolution.

You should understand that this informed consent does not prevent you or a member of your family from voluntarily releasing information about yourself or your involvement in this research.

This informed consent also does not prevent the researchers from disclosing matters such as child abuse, or subject's threatened violence to self or others. In terms of a vehicle, this could also include items such as driving under the influence of drugs or alcohol or allowing an unlicensed minor to drive the vehicle. If this type of behavior is observed, we reserve the right to remove you from the study and inform the appropriate authorities of what we have observed. In all cases, we will notify you first of the behaviors we have observed prior to removing you from the study or informing others of our observations. If you are removed from the study, you will be compensated for any time already spent in the study, but will receive no further payments.

VI. Compensation

You will paid at the rate of $20.00 an hour for the initial information session and for completing the final questionnaire at the last VTTI session. These payments will be received at the end of each prospective session. You will receive $20.00 per week for the time you ride your motorcycle with the instrumentation installed. This payment will be received at the final VTTI session. If you choose to withdraw from the study, you will be compensated for your participation up to that point.

VII. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, please notify VTTI staff immediately, and arrangements will be made for VTTI staff to remove the instrumentation from your motorcycle. Circumstances could arise in which VTTI opts to end the study early. These could include, but are not limited to, safety concerns and/or equipment malfunctions. If this occurs VTTI staff will contact you to make arrangements to pick up the test vehicle. If this occurs, you will be compensated for the portion of the study of which you participated in.

VIII. Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained and is valid until the date listed at the bottom of this page.

IX.Participant's Acknowledgements (Please check one)

- ☐ **I have experience and am comfortable riding with at least 31 pounds loaded behind the seat and rear axle.**
- ☐ **I do not have experience and/or I am NOT comfortable riding with at least 31 pounds behind the seat and rear axle. (Participants that check this box, should not participate in this study).**

X.Participant’s Permission

I understand what is being asked of me. My questions have been answered. I freely agree to participate and have not been coerced into participation. I understand that participation is voluntary and that I may withdraw at any time without penalty.

I hereby acknowledge the above and give my voluntary consent:

____ Date__________

Participant signature

____ Date __________

Researcher signature

Should I have any questions about this research or its conduct, I may contact:

Shane McLaughlin	Project Principal Investigator	[redacted]
Zac Doerzaph	Co-Principal Investigator	[redacted]

If I should have any questions about the protection of human research participants regarding this study, I may contact :

Dr. David Moore,

Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects

Telephone: [redacted];

Email: [redacted];

Address: Office of Research Compliance, 2000 Kraft Drive, Suite 2000 (0497), Blacksburg, VA 24060.

The Participant Must Be Provided With A Copy Of This Consent Form.

Consent Form for Participant Using VTTI Motorcycle

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Pilot Study of Instrumentation to Collect Behavioral Data to Identify On-road Rider Behaviors

Investigators: Dr. Shane McLaughlin and Dr. Zac Doerzaph

I. The Purpose of this Research/Project

Over 10% of all fatalities on U.S. roads are motorcyclists. The motorcycle fatality rate has doubled in the last 10 years. This study is a small practice study, or pilot study with approximately 5 participants. The lessons learned in this study will lead up to a larger study to investigate the behavior of motorcyclists and other factors that may contribute to these statistics.

II. Procedures

You are being asked to participate in a naturalistic driving study. The study involves a two to four week data collection period in which you will be provided with a motorcycle equipped with a self-contained unit containing sensors and cameras that record a variety of driving measures. As a participant, you will be expected to participate in the following activities:

Attend an initial meeting and information session at VTTI

- Review information regarding participation in the study (A researcher will show you the data collection system and show you the motorcycle).
- Read and sign this Informed Consent Form.
- Show the experimenter your valid driver's license.
- Complete a paper and pencil questionnaire.
- Complete vision tests.
- Fill out a W9 tax form in order to receive payment for participating.

☐ Allow the researcher to fit you with a helmet that you will wear during the study (Not all study participants will wear a VTTI issued helmet. This box will be checked for participants who are issued a helmet).

If you are going to use a VTTI issued helmet, a researcher will demonstrate how to connect the helmet to the system using the cord.

Then, you will drive the motorcycle as you normally would your own to your normal destinations for 2 to 4 weeks. During this time, we ask that you do the following:

- Contact VTTI if you notice any maintenance issues with the system (for example, a camera that comes loose and dangles).
- Permit VTTI researchers to access the motorcycle (at your home or work location) at least once a week to download data. You do not need to be present during the data downloads. Subject to your approval, data downloads will be completed between 7am and 11pm.
- If you are in an accident while in the study, we ask that you do the following:
  - Follow the instructions listed on the orange envelope located under the seat on the motorcycle.
  - Call us at [redacted] to notify us of the accident.
  - Allow us to retrieve the data from the vehicle's electronic data recorder (EDR or "black box") and from the data collection system we installed.
  - Allow us to have access to the police accident report, if any, which results from the accident.
- Do <u>not</u> take the motorcycle into any facilities that do not permit video recording devices.
- You must receive verbal permission from the researchers prior to allowing any mechanical work to be performed on the motorcycle.
- You are responsible for purchasing fuel for the motorcycle, and for all tickets and violations received for the duration that the vehicle is assigned to you.

After your two to four week session is over we will be schedule a date and time for you to come back to VTTI. The following will occur during this one hour session:

- Return the motorcycle to VTTI..
- If you were using a VTTI helmet, you will return it to VTTI.
- Fill out a final questionnaire.
- Receive final payment for participation in the study.

III. Risks

The risk to you is no more than you would normally incur while riding a new motorcycle. All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard in any foreseeable way. None of the data collection equipment will interfere with any part of your normal field of view. The addition of the data collection systems to the vehicle will in no way affect the operating or handling characteristics of the motorcycle. If you are using a VTTI helmet, the cord connecting the helmet to the data collection system will disconnect easily in the event that you separate from the bike. Except for your two visits to VTTI, you are not being asked to alter your daily driving routines in any way.

There is an additional risk not encountered in everyday life. While you are riding the motorcycle, cameras will record video of you, your actions, and surrounding traffic. In the event of an accident, there is a risk that the video could be obtained in conjunction with a government inquiry, or in litigation or dispute resolution. This is discussed in more detail below.

In the event of an accident or injury in a vehicle owned or leased by Virginia Tech, the automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage (unless the other party was at fault, which would mean all expenses would go to the insurer of the other party's vehicle) would apply in case of an accident for all volunteers and would cover medical expenses up to the policy limit. For example, if you were injured in a vehicle owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by this policy. Any coverage of the participant is limited to the terms and conditions of the insurance policy.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, worker's compensation does not apply to volunteers; therefore, if not in the automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses.

For example, if you were injured while you are not riding the motorcycle provided by the research project, the cost of transportation to the hospital emergency room would not be covered by insurance associated with this research.

If you should become injured in an accident, whether on or off the motorcycle, the medical treatment available to you would be that provided to any person by emergency medical services in the vicinity where the accident occurs.

IV. Benefits of this Project

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is being made to encourage participation. Participation will help to improve the body of knowledge regarding motorcyclists' behavior and performance. Participation will also help us design the larger study in a way that is acceptable and comfortable for future participants.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after you begin participation, your name and other identifying information will be separated from the data and replaced with a number. That is, your data will not be attached to your name, but rather to a number (for example, Driver 0011).

While driving the vehicle, a camera will record your face and torso. Additionally, cameras will capture views of the forward view. All video will be captured and stored in digital format (no tape copies will exist).

The video, questionnaire, and sensor data will be stored in a specific password-protected project folder. For the purposes of this project, only authorized project personnel will have access to your video data.

It is expected that the data we capture throughout the course of the entire study, including all 5 motorcycle riders, will be a valuable source of data on how motorcyclists respond to certain situations and how the roadway and motorcycle might be enhanced to improve driver safety. Therefore, it is expected that there will be follow-on data analyses conducted using all of the data. These follow-on analyses will be conducted by qualified researchers who may or may not be part of the original project team. In every case, the researchers who obtain access to the data will be required to sign a data sharing agreement which specifies the ways in which they may use the data, and which will continue to protect your anonymity and confidentiality. The confidentiality protection provided to you by these data sharing agreements will be as great as or greater than the level provided and described in this document. Data that can identify you (e.g. video data of your face) will not be released to any researchers outside of VTTI. Any further research efforts will also require additional approval by the Institutional Review Board (IRB), but will not require anything further of you.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

If you are involved in a crash while participating in this study, the data collection equipment on your motorcycle will likely capture the events leading up to the event. The data collection equipment SHOULD NOT be given to police officers or any other party.

We will do everything we can to keep others from learning about your participation in the research. We may disclose information about you as required by law, in conjunction with a government inquiry, or in litigation or dispute resolution.

You should understand that this informed consent does not prevent you or a member of your family from voluntarily releasing information about yourself or your involvement in this research.

This informed consent also does not prevent the researchers from disclosing matters such as child abuse, or subject's threatened violence to self or others. In terms of a vehicle, this could also include items such as driving under the influence of drugs or alcohol or allowing an unlicensed minor to drive the vehicle. If this type of behavior is observed, we reserve the right to remove you from the study and inform the appropriate authorities of what we have observed. In all cases, we will notify you first of the behaviors we have observed prior to removing you from the study or informing others of our observations. If you are removed from the study, you will be compensated for any time already spent in the study, but will receive no further payments.

VI. Compensation

You will paid at the rate of $20.00 an hour for the initial information session and for completing the final questionnaire at the last VTTI session. These payments will be received at the end of each prospective session. You will receive $20.00 per week for the time you ride the motorcycle with the instrumentation installed. This payment will be received at the final VTTI session. If you choose to withdraw from the study, you will be compensated for your participation up to that point.

VII. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, please notify VTTI staff immediately, and arrangements will be made for VTTI staff to pick up the motorcycle. Circumstances could arise in which VTTI opts to end the study early. These could include, but are not limited to, safety concerns and/or equipment malfunctions. If this occurs VTTI staff will contact you to make arrangements to pick up the test vehicle. If this occurs, you will be compensated for the portion of the study of which you participated in.

VIII. Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained and is valid until the date listed at the bottom of this page.

IX.Participant’s Responsibilities

If you voluntarily agree to participate in this study, you will have the following responsibilities regarding the research motorcycle:

1. To refrain from driving the motorcycle while impaired by any substances.
2. To conform to the laws and regulations of driving on public roadways.
3. To maintain reasonable security of the research motorcycle.
4. To allow experimenters to gain reasonable access to the research motorcycle in your possession for the purposes of diagnosing difficulties and downloading data.
5. You may not allow anyone else to drive the motorcycle.
6. You may not use the motorcycle for illegal activities.
7. You are responsible for fuel purchase and for paying all parking tickets issued to the research motorcycle, during the time the vehicle is in your possession. You are also responsible for any traffic violations, and tolls.
8. To notify VTTI staff if you encounter any difficulties or have questions.
9. To not take the motorcycle into any facilities that do not permit video recording devices.

X.Participant’s Acknowledgements (Please check one)

☐ **I am comfortable operating a 650cc motorcycle**
☐ **I am not comfortable operating a 650cc motorcycle**

XI.Participant’s Permission

I understand what is being asked of me. My questions have been answered. I freely agree to participate and have not been coerced into participation. I understand that participation is voluntary and that I may withdraw at any time without penalty.

I hereby acknowledge the above and give my voluntary consent:

____ Date__________

Participant signature

____ Date __________

Researcher signature

Should I have any questions about this research or its conduct, I may contact:

Shane McLaughlin	Project Principal Investigator	[redacted]
Zac Doerzaph	Co-Principal Investigator	[redacted]

If I should have any questions about the protection of human research participants regarding this study, I may contact :

Dr. David Moore,

Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects

Telephone: [redacted];

Email: [redacted];

Address: Office of Research Compliance, 2000 Kraft Drive, Suite 2000 (0497), Blacksburg, VA 24060.

The Participant Must Be Provided With A Copy Of This Consent Form.

Appendix F - Commercially Available Eye-tracking Alternatives

Name	Web site	Location
Eye link 1000/2K	www.sr-research.com	Head supported
EyeLink II	www.sr-research.com	Head mounted
EyeLink Arm Mount	www.sr-research.com	Arm mounted
Eyelink remote	www.sr-research.com	Head free
FaceLab4 (v4.5)	http://www.seeingmachines.com/facelab.htm	Head free
Eyebox2	https://secure.xuuk.com	Eye counter
Tobii T60/T120	www.tobii.com	In a monitor
Tobii x120	www.tobii.com	Head free
ViewPoint scene camera	http://www.arringtonresearch.com	Head mounted (used outdoors)
Remote Camera system	http://www.arringtonresearch.com	Head free
VisionTrak	http://www.polhemus.com/?page=Eye_VisionTrak	
iView X Hi-Speed 1250	www.smivision.com/en/eye-gaze-tracking-systems/products	Head supported
iView X HED	www.smivision.com/en/eye-gaze-tracking-	Head mounted: indoor/outdoor

Name	Web site	Location
	systems/products	
TOPAZ	www.smivision.com/en/eye-gaze-tracking-systems/products	
Vision Systems International, LLC	http://www.vsi-hmcs.com/	Helmet mounted for military aviation.

Appendix G - Event Reduction Questions and Possible Responses

Reduction Question	Sub	Categories recorded
Rider: Safety / Protective Attire	Head protection	No Helmet | Half-Shell | Three quarter Shell | Full Face | Other
	Helmet Color	Light colored | Dark colored | Combination: light/dark | Unable to determine | NA - No helmet | Unable to determine
	Face Shield	Yes, face shield in use | Face shield present, but not in use | No face shield present | Unable to determine | Unable to determine
	Torso Protection	Jacket Worn | No jacket | Long-sleeve shirt | Short sleeve shirt | Other | Unable to determine | Short sleeve shirt
	Torso clothing color	Light colored | Dark colored | Combination: light/dark | Unable to determine | Unable to determine
	Hand protection	Full-finger gloves | Open-finger gloves | Other | No hand protection | Unable to determine | No hand protection
	Sunglasses	Yes | No | Tinted/Mirrored Visor | Unable to determine | Unable to determine
Passenger presence		Yes | No | Unable to determine
Passenger: Safety / Protective Attire	Head protection	No Helmet | Half-Shell | Three quarter Shell | Full Face | Other | Full Face
	Helmet Color	Light colored | Dark colored | Combination: light/dark | Unable to determine | NA - No helmet | Unable to determine
	Face Shield	Yes, face shield in use | Face shield present, but not in use | No face shield present | Unable to determine | Unable to determine
	Torso Protection	Leather Jacket worn | Textile jacket worn | No jacket | Long-sleeve shirt | Short sleeve shirt | Other | Unable to determine | Long-sleeve shirt

Reduction Question	Sub	Categories recorded
	Torso clothing color	Light colored | Dark colored | Combination: light/dark | Unable to determine | Unable to determine
	Hand protection	Full-finger gloves | Open-finger gloves | Other | No hand protection | Unable to determine | No hand protection
Ambient lighting at start of trip		Daylight | Dawn/Dusk | Night (not lighted) | Night (lighted) | Night (lighted)
Daytime Sun Position (in forward view)		Yes | No | N/A: Nighttime
Nighttime Headlight Glare		Yes | No | N/A: Daytime
Other Visual Obstructions		Trees | Road Curvature/slope | Building/billboard | Other | N/A | Other
Head Alignment		Yes | No, head leans farther than body | No, head tilted away from body lean | Unable to determine | Unable to determine
Body Alignment		Yes | No, body tilted farther from bike | No, body tilted away from bike lean | Unable to determine | Unable to determine
Handlebar - Hand Position		Both hands on handlebars | Left hand only on handlebars | Right hand only on handlebars | No hands on handlebars | Unable to determine | No hands on handlebars
Brake lever - hand position		Covering brake lever | Two fingers on brake | No fingers on brake | Unable to determine | Unable to determine

Reduction Question	Sub	Categories recorded
Relation to Junction		Non-junction | Intersection | Intersection-related | Interchange area | Entrance/exit Ramp | Driveway, alley access, etc. | Railroad crossing | Parking lot | Other (includes crosswalks) | Unknown | Interchange area
Road Alignment		Straight | Right curve | Left curve
Road Profile		Level | Incline | Decline | Dip | Hillcrest
LOS		Level of Service A (LOS A) | Level of Service B (LOS B) | Level of Service C (LOS C) | Level of Service D (LOS D) | Level of Service E (LOS E) | Level of Service F (LOS F) | Level of Service D (LOS D)
Locality		Residential | Business/Industrial | Interstate | Open country | Construction Zone | School Zone | Parking lot | Other | Highway | Unknown | Open country
Traffic Flow		Not Divided (2 way trafficway) | Not Divided (w/ center 2-way left turn lane) | Divided | One-way traffic | No-lanes (e.g. parking lot) | Unknown One-way traffic
Travel Lanes		
Weather		No adverse conditions | Rain | Rain & Fog | Fog | Sleet | Snow | Sleet & Fog | Other | Fog
Road Surface Condition		Dry | Wet | Snow/slush | Ice | Gravel/sand/dirt/oil | Other | Unknown | Ice

Reduction Question	Categories recorded
Intersection Type	At Grade | Interchange
Intersection Scenario	Left | Right | Straight | Left Exit | Right Exit | Merge
Sync of Collision Zone Entrance	

Reduction Question	Categories recorded
Traffic Control Device	Signal controlled | Stop sign controlled | Thru, but stop sign controlled | N/A - Merge
Appropriate gap with cross traffic	Yes | Yes, but no cross traffic present | No, inappropriate gap with cross traffic |
Adherence to traffic signal	Yes | No, entered intersection on red light (with no complete stop if right turn) | No, light turned red while in intersection | N/A - no signal present
Adherence to Stop Sign	Yes, complete stop. | No (Stop Sign), rider rolled through (<5 mph), NO traffic present | No (Stop Sign), rider rolled through (>5 mph), traffic present | No (Stop Sign), speed (>5 mph), NO traffic present | No (Stop Sign), speed (>5 mph), traffic present | Unknown | No stop sign present.
Number of travel lanes (before Intersection)	1 | 2 | 3 | 4 | 5 | 6 | 7
# of dedicated Left Only lanes	1 | 2 | 3
# of dedicated Right Only lanes	1 | 2 | 3
Travel lane position number (at collision zone entrance)	1 | 2 | 3 | 4 | 5 | 6 | 7
Number of travel lanes (after Intersection)	1 | 2 | 3 | 4 | 5 | 6 | 7
Travel lane position number (after)	1 | 2 | 3 | 4 | 5 | 6 | 7
Lane Position at Collision Zone Entrance	Right | Middle | Left
Did the rider exit the intersection in the appropriate lane?	Yes | No - rider changed lanes during intersection | No - rider changed lanes on approach | No - rider changed lanes on approach AND in the middle of the intersection
Task 1	1) No secondary task | 2) Cell phone: locating/reaching answering | 3) Cell phone: looking at cell phone display | 4) iPod: Locating/reaching for iPod | 5) iPod: Operating ipod | 6) iPod: Viewing iPod | 7) Adjusting other known motorcycle device | 8) Adjusting unknown device | 9) External: Pedestrian | 10) External: Animal | 11) External: Object | 12) External: Construction zone | 13) Other (describe in comments)

Reduction Question	**Categories recorded**
Task 1 Timing	N/A - No secondary task | During the Approach ONLY | While crossing the intersection ONLY | BOTH during and while crossing
Task 2	1) No secondary task | 2) Cell phone: locating/reaching answering | 3) Cell phone: looking at cell phone display | 4) iPod: Locating/reaching for iPod | 5) iPod: Operating ipod | 6) iPod: Viewing iPod | 7) Adjusting other known motorcycle device | 8) Adjusting unknown device | 9) External: Pedestrian | 10) External: Animal | 11) External: Object | 12) External: Construction zone | 13) Other (describe in comments)
Task 2 Timing	N/A - No secondary task | During the Approach ONLY | While crossing the intersection ONLY | BOTH during and while crossing
Other secondary tasks	
Appropriate speed	Yes, matching surrounding traffic | No, faster than surrounding traffic | No, slower than surrounding traffic | N/A - no traffic present
Lead vehicle	N/A - No lead vehicle | Yes - Lead vehicle 15-150 feet | No - Lead vehicle <15 feet | Unknown
Rider Hands on Handlebars at start sync	Both hands on handlebars | Left hand only on handlebars | Right hand only on handlebars | No hands on handlebars | Unable to determine
Rider Hand on Brake at start sync	Covering brake lever | Two fingers on brake | No fingers on brake | Unable to determine
Event	Crash | Near-crash | Minor conflict | No event
Weather	No adverse conditions | Rain | Rain & Fog | Fog | Sleet | Snow | Sleet & Fog | Other
Road Surface Condition	Dry | Wet | Snow/slush | Ice | Gravel/sand/dirt/oil | Other | Unknown
Ambient lighting	Daylight | Dawn/Dusk | Night (not lighted) | Night (lighted)

Appendix H - Independent Evaluator Report

Independent Evaluation of the "Pilot Study of Instrumentation to Collect Behavioral Data to Identify On-road Rider Behaviors"

By

John Campbell

Battelle
The Business of Innovation

November 6, 2009

Table of Contents

Introduction

This report to the Virginia Tech Transportation Institute (VTTI) describes the activities and findings associated with an independent evaluation (IE) of the methods and procedures associated with VTTI's "Pilot Study of Instrumentation to Collect Behavioral Data to Identify On-Road Rider Behaviors" project.

The objectives of this independent evaluation are to assess: (1) if the motorcycle instrumentation described and demonstrated to Battelle seems to be capturing the data as intended, and (2) if a future field study of on-road rider behavior using the planned instrumentation and experimental methods can answer NHTSA's research questions.

The methods, results, and recommendations associated with this independent evaluation are presented below.

Evaluation Methods

The independent evaluation has consisted of four related activities:

1. Prepare for the Site Visit
2. Conduct the Site Visit
3. Review and Analyze Relevant Materials
4. Develop Evaluation Report

Each of these activities is described below.

Prepare for the Site Visit

Prior to the site visit, VTTI project staff provided Battelle with a set of background material on the project. This material contained a draft agenda for the site visit, as well as a summary of the: background, objectives, research questions, general instrumentation approach, and instrumentation details associated with the project. They also included an excerpt of the Statement of Work between VTTI and NHTSA.

Though only a summary, these background materials provided a useful introduction to the project and were sufficient to familiarize the independent evaluator with the project's goals and prospective technical approach. Using these materials, Battelle was able to generate an initial set of questions and comments about the project that were used throughout the subsequent site visit.

Conduct the Site Visit

The site visit was conducted on October 15-16, 2009. The entire day of the 15th was devoted to a review of the project by VTTI staff, interspersed by a number of questions, demonstrations, and discussions about progress to-date. For VTTI, Shane McLaughlin (Project PI) and Zac Doerzaph

(Co-PI) provided most of the briefing, Brad Cannon participated throughout the day, and Julie McClafferty provided a briefing on data reduction.

The original agenda for the 15th is shown below and, although the actual timing of specific agenda items varied slightly, the agenda provides a good summary of the site visit activities:

Start	Duration	Description
8:00	0:30	Discuss agenda, initial questions, and adjust agenda as appropriate
8:30	0:30	Overview of motorcycle research and crash types
9:00	0:60	Descriptions of instrumentation development and lessons learned
10:00	0:45	Walk around of instrumented motorcycle/helmet
10:45	0:15	Overview of data collection processes as it relates to feasibility
11:00	0:30	Description of the video reduction process
11:30	0:30	Introduction to data and data reduction software
12:00	0:15	Break
12:15	0:60	Working lunch /overview of data integration and data analysis
1:15	1:30	Detailed discussion of data collected, by variable
2:45	2:00	Review and discussion of demonstration analyses
4:45	0:30	Review of work referenced to project objectives

A brief discussion on the morning of the 16th allowed Battelle to follow-up from the previous day with additional questions about the effort, and to clarify or confirm specific details about the study. As another follow-up to the visit, VTTI project staff provided Battelle with a number of documents, slides, screen captures, etc., that were requested by Battelle to provide general context for the study or to answer specific questions.

At all times - both before and during the site visit – VTTI staff provided complete and valuable support to this independent evaluation. As noted above, the pre-visit material were very helpful in setting the stage for the actual site visit and in familiarizing the independent evaluator with the effort. VTTI answered all questions posed by the independent evaluator promptly and in full, and have provided all material that were requested to support this evaluation.

Review and Analyze Relevant Materials

Following the site visit and the receipt of additional study material, the Battelle evaluator reviewed all of the documentation in-hand, as well the notes taken throughout the evaluation process. Reviewed documentation included:

- Pre-Visit Material

- Demonstration Analysis Discussion
- Motorcycle Researcher Dictionary for Video Reduction Data
- Screen Grab of the VTTI Data Analysis Reduction Tool
- A Selection of Slides from the Site Visit Presentations
- Pre-Drive Questionnaire
- Post-Drive Questionnaire
- Post-Crash Interview Form
- Summary Document on the Feasibility of Collecting Data to Identify On-Road Rider Behaviors

Based on the site visit, as well as a review of the documentation provided by VTTI, Battelle first developed a short summary that reflects the evaluator's understanding of the goals and methods of the on-road study. The summary is presented below, establishes the basis for the evaluation, and may provide some context to the evaluation results.

Understanding of the Goals and Methods of the On-Road Study. The on-road study intends to use a naturalistic approach to collecting and analyzing on-road riding behaviors. The overall goal of the effort is to obtain a better understanding of riding behaviors and their contribution to crash risk. These data are expected to provide insights into the relative contributions of various factors (the roadway environment, weather, individual rider characteristics, rider behaviors, traffic conditions, etc.) on safe/unsafe behaviors, as well as such as near-misses and crashes. Such insights could also aid in the identification, development, and assessment of countermeasures.

The technical approach includes:

1. Recruiting a reasonably representative group of motorcycle riders as study participants who will be paid for their participation in the study,
2. Instrumenting participants' motorcycles with a series of brackets, housings, sensors, and data storage devices,
3. Instructing participants to ride when and how they normally would, with no special instruction or restrictions associated with riding frequency, routes, or behaviors, and
4. Processing data and identifying events (crashes, near-misses, incidents) using VTTIs custom software and the associated procedures for reducing and analyzing naturalistic driving data.

The instrumentation package includes:

- Main unit – a (approximately) 7.5 cm x 28 cm x 19 cm box that houses key hardware/software and is located behind and to one side of the rider. Includes the primary board/CPU for the instrumentation, as well as a solid state hard drive,
- Cameras (5 total: forward, rear, and a "puck" with 3 cameras (rider head[1], left rearward, and right rearward).
- Inertial measurement unit that measures roll, pitch, yaw, and acceleration in 3 axes,
- Forward-looking radar unit with +/- 16 degrees field-of-regard (32 degrees total), and an effective range of about 150 yards,
- Lane Tracking – achieved by running the front camera image through a machine vision system and then generating a computer-generated "birds-eye" view of the motorcycle relative to the roadway, including representations of the centerline and lane edges.
- GPS – the module is integrated into the main unit and includes an antenna attached via cable.
- Sensors to record the state of the turn signals and braking status.[2]
- Various brackets and housing to attach the instrumentation to the motorcycle and protect the instrumentation from the elements.

The pilot study has included three participants to-date. Importantly, the instrumentation suite used on the three motorcycles instrumented so far has been developed iteratively throughout the pilot study. Thus, there have been a number of differences across the pilot subjects with respect to the precise instrumentation used on their individual motorcycles.

The full study will include 50-60 motorcycle riders, with individual motorcycles instrumented for a full "riding season" that could be as long as twelve months. Motorcycle usage varies considerably across riders; e.g., from those who use a motorcycle exclusively in their day-to-day trips, to those who may only ride on weekends or in good weather. Thus, the amount and nature of the data obtained will vary considerably from rider to rider.

Develop Evaluation Report

This report reflects Battelle's output from the independent evaluation activities. The discussions below provides a general assessment of the proposed methodology, a review of advantages and

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[1] The "rider head" camera is an OptiTrack device that uses infrared and machine vision technologies to capture and analyze head motions.

[2] For the pilot, braking status was recorded as only ON or OFF. For the full study, VTTI is exploring several options for measuring brake force applied, as well as options for distinguishing between the riders' application of the forward versus rear brakes.

disadvantages of the proposed methodology relative to the NHTSA research questions for the effort, and ideas or recommendations for improving the study.

Evaluation Results

As noted earlier, the objectives of this independent evaluation are to assess: (1) if the motorcycle instrumentation described and demonstrated to Battelle seems to be capturing the data as intended, and (2) if a future field study of on-road rider behavior using the planned instrumentation and experimental methods can answer NHTSA's research questions. An assessment of both of these questions is provided below.

Overview

In general, the planned on-road study uses an appropriate methodology to learn more about real-world riding behaviors and their contribution to crash risk. The overall approach – as summarized above – is technically sound and reflects "lessons learned" from previous naturalistic driving studies; low-cost, state-of-the-art options with respect to instrumentation suitable for motorcycles; the rigors of the motorcycle riding environment; and an appreciation of the differences between motorcycle riders and passenger vehicle drivers.

The VTTI team understands the complexities associated with collecting on-road data and have made reasonable trade-offs between competing requirements, including trade-offs among costs, schedules, operational realities, and the limits of the technologies used to instrument the motorcycles. However, the motorcycle instrumentation described and demonstrated to Battelle seems to be capturing the data as intended, and VTTI's approach to data analysis and reduction is systematic, rigorous, and appropriate, given the study's objectives.

Assessment of Specific Research Questions

Of considerable concern to NHTSA and a focus of this independent evaluation is whether or not the planned on-road study can answer the specific NHTSA's research questions of greatest interest to NHTSA. The Statement of Work (SOW) between NHTSA and VTTI notes that the study should answer some of the following research questions:

1. Where are riders looking when they have conflicts, near-crashes, and crashes? Do riders who have sufficient sight distance (i.e., looking 6+ seconds ahead of them) have fewer crashes and near-misses than riders who are overriding their sight distance?
2. How does exposure among the study participants affect involvement in crashes or near-misses? Do the number of conflicts, near-crashes and crashes increase with exposure, or is there an inverse relationship?

3. What is the study participants' riding exposure over a riding season? Where do they ride most often and how does this compare to the fatality data?
4. What is the interaction between experience and exposure?
5. Are there differences between riders who have near-misses and/or crashes and riders who experience none? What are they?
6. How does lane placement affect a rider's ability to avoid crashes and detect hazards?
7. Are riders who avoid crashes and near-misses less likely to travel over the posted speed limit?
8. How many instances occur in which the driver appears to fail to see the motorcycle rider (i.e., turning in front of the rider when there really isn't enough time to do so)?

In the discussion below, we have evaluated VTTI's proposed methodology for the on-road study with respect to each of these questions. In particular, we present (as appropriate) the advantages and disadvantages of the proposed methodology, an overall assessment of the likelihood that the future on-road study will provide useful answers to the questions, and recommendations for revising the methodology to perhaps provide more complete and accurate answers.

1. Where are riders looking when they have conflicts, near-crashes, and crashes? Do riders who have sufficient sight distance (i.e., looking 6+ seconds ahead of them) have fewer crashes and near-misses than riders who are overriding their sight distance?

By "sight distance", we assume that NHTSA is referring to the time required for the rider to travel from a given point on the road to the future point on the road corresponding to a rider's instantaneous point-of-gaze (this is a bit different than the meaning of "sight distance" as used in the context of roadway design). Given the unique vulnerability of motorcycles relative to passenger vehicles and trucks (see also Horswil and McKenna, 2001), additional information about hazard perception would be of great value to countermeasure development in this area.

In general, the ability of the planned on-road study to answer this question seems limited. The current instrumentation suite does not include an eye tracker or high-resolution point-of-gaze measurement system, and is therefore unable to directly and precisely determine where riders are looking.[3] Analysis of the head camera data will allow VTTI to provide estimates of gaze location (e.g., left side of roadway, right side of roadway, instrument cluster, left rear, right rear, etc.), and perhaps eyes-on-the-road time. It seems unlikely that these gaze estimates can be made at a resolution that is finer than such coarse areas of interest.

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[3] Of course, even expensive, intrusive eye/head tracking devices will only be accurate to within 1 or 2 degrees in an on-road environment, and are associated with a number of operational drawbacks as well.

In the documentation provided to this independent evaluation, VTTI describes a method for estimating sight distance that involves: identification of objects that can serve as absolute points of reference, cuing the forward video to the point at which this object is just visible, advancing the video until the rider reaches that point, and then calculating sight distance based on the resulting time interval. Such an approach would require integration of multiple data sources including, the driver's gaze, the forward camera or radar, the speed of the motorcycle, and (perhaps) other driver's inputs into the motorcycle. Taken together, these data elements could be used in an effort to make informed inferences about where riders are looking and it may be possible to use this approach to estimate gaze relative to specific roadway elements (curves, intersections, signs) or hazards such as on-coming vehicles. Perhaps such data could support a determination that the rider was likely looking on the roadway ahead (or not) before and during crashes, near-miss, or other incidents. However, a key challenge to this approach is the independence of eye and head movements (head movements will be recorded, but eye movements will not), and uncertainties about eye height relative to the roadway and the forward camera.

Overall, the VTTI approach to gaze determination has the advantage (versus an eye tracker or high-resolution point-of-gaze measurement system) of being: (1) relatively low cost, and (2) transparent and non-intrusive from the perspective of the rider. The chief disadvantage of the planned approach is a lack of precision and accuracy, as compared to NHTSA's goals of obtaining precise sight distance values.

It would be helpful if VTTI could demonstrate proof-of-concept for their approach through a small pilot study. The study could assess the team's ability to use their current gaze measurement approach to provide both coarse estimates of gaze location and, through the integration of multiple data sources, more precise estimates of sight distance.

2. How does exposure among the study participants affect involvement in crashes or near-misses? Do the number of conflicts, near-crashes and crashes increase with exposure, or is there an inverse relationship?

The notion of exposure is inherently complicated, and could include a number of measures and constructs when assessing riding risk (see also Evans, 1991). For the current study, measures of exposure could potentially include: miles travelled, speeds, time-of-day, time-of-year, traffic volumes, road class, weather conditions, and general characteristics of the roadway. Overall, the planned on-road study should be capable of assessing the effects of exposure on conflicts, near-crashes and crashes.

However, some measures of exposure will be easier to obtain than others, with associated differences in accuracy and precision. For example, accounting for miles travelled when assessing the risk of conflicts, near-crashes and crashes can be readily accomplished using the GPS data. Similarly, accounting for time-of-day (e.g., daytime vs. nighttime comparisons) or time-of-year effects can be done using the DAS time stamp. Including other measures of exposure such as traffic volumes or roadway characteristics are possible, but will require manual reviews of video data. Such exercises will be more difficult, time-consuming, and – perhaps – more prone to uncertainties due to the quality of the video data (e.g., under nighttime, rainy, or foggy conditions), differences of opinion across raters, or errors in judgment. Measures of exposure such as road class and weather conditions are possible through either a review of the video data (with associated difficulties and possible errors), or perhaps through geospatial databases or county/State/national databases that provide road class and historical weather data as a function of GPS and time/date information.

It may be helpful for NHTSA to specify the precise measures of exposure of greatest interest during the planning phase of the on-road study. This would help VTTI generate better time and budget estimates for including measures of exposure in their data analysis activities, and give NHTSA a better understanding of what to expect from the study. If county/State/national databases are required to generate exposure estimates, VTTI should confirm that the desired data are available and summarize any relevant characteristics of the databases.

3. What is the study participants' riding exposure over a riding season? Where do they ride most often and how does this compare to the fatality data?

The planned on-road study should be capable of assessing the effects of exposure over a riding season, including assessments of where study participants ride most often. As noted above, obtaining such measures will require "matching" obtained GPS data with geospatial data and State or county databases (to the extent that they are available) that provide roadway information such as posted speed, road class, and infrastructure characteristics.

4. What is the interaction between experience and exposure?

The planned on-road study should be capable of assessing interactions between rider experience and exposure, subject to the caveats and discussion provided above.

It may be useful for NHTSA to specify key variables of interest and the interactions of interest among these variables, and for VTTI staff to conduct power analyses and calculate desired sample sizes for small, medium and large effects (as defined by Cohen, 1988) accordingly. Broadly speaking, the power of statistical comparisons among riders with different experience levels in the planned on-road study will depend on the number of participants assigned to each experience level defined for the study, variability within each rider and within groups of riders defined by the experimental design.

Overall, the proposed sample size of the on-road study (50 to 60 riders) seems adequate if the study focuses on highly targeted subgroups of riders, but inadequate if the study is intended to be used as a foundational study relevant to the rider population as a whole. For example, if rider experience is the only independent variable used in the study (with other variables such as age, gender, training, motorcycle type, trip type, etc. held constant between subgroups defined by levels of experience), then 50 to 60 riders corresponding to – for example – high and low experience levels may be adequate. Fifty to sixty riders does not seem to be enough participants if the sample as a whole is segmented out into subgroups corresponding to age, gender, etc. Thus, it would seem useful for NHTSA to clearly define the variables on interest and for VTTI to conduct power analyses to calculate desired sample sizes reflecting those variables.

5. Are there differences between riders who have near-misses and/or crashes and riders who experience none? What are they?

The planned on-road study should be capable of identifying near-misses and crashes, and of making comparisons between riders with varying levels of near-misses and crashes. The software tools and the data dictionaries that VTTI will use to identify and code both near-misses and crashes seem clear and comprehensive. Some of the measures of exposure discussed above can be used to make and support these comparisons.

However, VTTI's ability to make such comparisons would be improved by the addition of measures corresponding to personality, attitudinal, and other individual factors that may be relevant to a rider's propensity to engage in risky behaviors. In this regard, the pre-drive questionnaire currently planned for the on-road study should be expanded to include questions focused on sensation seeking, propensity for risk taking, etc.

6. How does lane placement affect a rider's ability to avoid crashes and detect hazards?

In the planned on-road study, lane tracking measures will be obtained by running the front camera image through a machine vision system and then generating a computer-generated "birds-eye" view of the motorcycle relative to the roadway, including representations of the centerline and lane edges. Through VTTI's approach to data mining and event detection/analysis, overt crash avoidance maneuvers and hazard detection behaviors should be recorded and identified (several such events were examined and discussed during the site visit). Participant reports may also be helpful in identifying and characterizing events. To the extent that events such as "avoiding a crash" or "detecting a hazard" can be consistently extracted from the data, the planned on-road study should be capable of answering this question.

7. Are riders who avoid crashes and near-misses less likely to travel over the posted speed limit?

The planned on-road study should be capable of answering this question. As noted above, obtaining posted speed limits will require "matching" the obtained GPS data with geospatial data and State or State or county databases that provide posted speed. If county/State/national databases are required to identify posted speed limits, VTTI should confirm that the desired data are available and summarize any relevant characteristics of the databases.

8. How many instances occur in which the driver appears to fail to see the motorcycle rider (i.e., turning in front of the rider when there really isn't enough time to do so)?

Through analyses of the radar, camera data, and participant reports, VTTI should be able to identify at least some near-misses that seem to be the fault of other drivers. These near-misses could include drivers making left or right turns in front of the motorcycle rider, drivers changing lanes or merging in ways that put the motorcycle at risk, and others.

However, it seems unlikely that these data will be sufficient to draw any strong causal inferences from the near-misses. That is, it will be unclear if the drivers, for example, failed to see the motorcycle rider, saw the rider but misjudged speed and distance, were avoiding some other hazard, etc. In the interests of clarity, NHTSA should perhaps specify the "other driver" errors that they are most interested in capturing during the planned-on-road study, and then VTTI should describe if and how they expect to obtain measures corresponding to these errors.

Recommendations

Based on the evaluation results provided above, we have generated the following recommendations for the planned on-road study:

1. *Validate sight distance estimation method.* The lack of high-resolution, high-accuracy, point-of-gaze information seems to be a key weakness in the planned study, relative to NHTSA's research questions. Though VTTI has developed a method for estimating sight distance, it would be useful if VTTI could demonstrate the efficacy of this approach through a small pilot study. The pilot study should use the proposed method to obtain an independent assessment of point-of-gaze/sight distance for on-road data collected under controlled conditions.

2. *Specify exposure measures and confirm the availability of required data.* Incorporating the effects of exposure on safety outcomes is a key theme these across NHTSA's research questions for the planned on-road study. However, "exposure" could potentially include a large number of measures, with some measures being easier to obtain than others. To improve VTTI's ability to plan the on-road study, and clarify the goals and outcomes of the effort, NHTSA should specify the precise measures of exposure of greatest interest. If external data sources (e.g., county/State/national databases) are required to generate exposure estimates, VTTI should confirm that the desired data are available and summarize any relevant characteristics of the databases.

3. *Specify key variables of interest and conduct power analyses.* NHTSA has indicated an interest in analyzing interaction effects between exposure and experience. This raise a broader question about the statistical power associated with the planned on-road study,

given the (relatively) small proposed sample size of 50-60 riders. In general, 50-60 riders seems adequate if the study focuses on highly targeted subgroups of riders, but inadequate if the study is intended to be used as a foundational study relevant to the rider population as a whole. NHTSA should specify the key variables of interest and the interactions of interest among these variables, and VTTI staff should conduct power analyses and calculate desired sample sizes for small, medium and large effects accordingly.

4. *Expand the pre-drive questionnaire to include measures associated with personality, attitudes, and other individual factors.* NHTSA is specifically interested in examining differences between those riders who experience near-misses and crashes, and those who do not. VTTI's ability to make such comparisons would be improved by adding measures to the pre-drive questionnaire that correspond to personality, attitudinal, and other individual factors that may be relevant to a rider's propensity to engage in risky behaviors.

5. *Specify "other driver" errors of interest and confirm the availability of required data.* NHTSA is interested in determining how often the driver's appears to fail to see the motorcycle rider, based on overt behaviors such as turning in front of the motorcycle when there is not enough time to do so safely. Though the study will be able to identify such events, it will be generally unable to determine the precise nature of the "other driver errors." NHTSA should specify the "other driver" errors they are most interested in capturing in the planned-on-road study, and then VTTI should describe if and how they expect to obtain measures corresponding to these errors.

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Appendix I - Research Questions and Instrumentation Groupings

Q#	Questions	Average Priority	Base	Enhanced brake/throttle	Radar	Gaze
1.1	Where are riders looking when they have conflicts, near-crashes, and crashes? Is this the same between trained and untrained riders?	3.0	2		3	1
2.1	Do riders who have sufficient sight distance (i.e., looking 6+ seconds ahead of them) have fewer crashes and near-misses than riders who are overriding their sight distance?	3.0	2		3	1
3.1.1	How does exposure among the study participants affect involvement in crashes or near-crashes?	3.0	1		2	
3.1.2	How does exposure affect where riders are looking?	3.0	1		3	2
4.1	Does the number of conflicts, near-crashes and crashes increase with exposure, or is there an inverse relationship?	3.0	1		2	
5.1	What is the study participants' riding exposure over a riding season?	3.0	1			
7.1	What is the interaction between experience and exposure?	3.0	1			
15.1	Defensive riding - General	3.0	2		3	1
16.3	Do crashes and near-crashes arise during curve negotiation?	3.0	1	3		2
17.1	What are the trajectories (speed, direction, time-to-collision, etc) of the subject motorcycle and other involved vehicle?	3.0	2		1	
18.1	Evasive maneuvers - General	3.0	1	2	3	
19.5	What is the relationship between riding style (braking, leaning, etc) and pre-incident speed?	3.0	1	2		
19.6	What is the relationship between riding style (braking, leaning, etc) and rider experience?	3.0	1	2		
19.7	What is the relationship between riding style (braking, leaning, etc) and weight:power ratio?	3.0	1	2		
20.7	How often do one or both wheels skid?	3.0	1	2		
21.1	Lateral control - General	3.0	2	1		
23.1	What is the sequence of events/precipitating factors in crashes and near-crashes?	3.0	1	3	4	2

Q#	Questions	Average Priority	Base	Enhanced brake/throttle	Radar	Gaze
23.2	What is the sequence of events/precipitating factors in crashes and near-crashes involving a second vehicle (leading, following, crossing, oblique crossing, adjacent)?	3.0	1	4	2	3
24.3	Is there a difference in riding characteristics (brake bias, braking force, countersteering, lean angle) between trained and untrained riders during crash or near-crash events? Does this correlate to the same differences above?	3.0	1	2		
24.4	Are trained riders more effective in evasive maneuver choices? Execution?	3.0				
31.1	What loss of control mode occurs leading up to the event (e.g., capsize, slide out, high side, wide on turn, end over, wobble, weave, lost wheelie)?	3.0	1	2		
32.2	What is the timing and cause of rider separation from bike?	3.0	1			
8.1	Are there differences between riders who have near-crashes and/or crashes and riders who experience none? What are they?	2.7	1	2	3	
11.1	How often do adjacent drivers appears to fail to see the motorcycle rider (i.e., turning in front of the rider when there really isn't enough time to do so)?	2.7	2		1	
14.1	How much riding is done in mixed traffic versus open road?	2.7	1		2	
15.3	How is speed controlled at different types of intersections (T, angled, alley, signaled, unsignaled)?	2.7	1			
15.4	How is speed controlled at different types of intersections in the presence and absence of potentially encroaching traffic?	2.7	1	2	3	
16.1	In what scenarios do crashes and near-crashes arise (e.g., following, intersection approach, curve taking, lane change)?	2.7	1		2	
18.3	What evasive maneuvers are used? Braking, swerving, both?	2.5	1	2		
18.4	What is the sequence of braking, steering, leaning?	2.5	1	2		
18.5	What distances are consumed for different evasive maneuvers (braking, swerving).	2.5	1	2	3	
20.3	What following distances and TTCs do riders employ?	2.5	1		2	
20.4	How effective are riders at controlling deceleration?	2.5	1	2	3	

Q#	Questions	Average Priority	Base	Enhanced brake/throttle	Radar	Gaze
24.2	Is there a difference in riding characteristics (brake bias, braking force, countersteering, lean angle) between trained and untrained riders in baseline conditions?	2.5	1	2		
25.1	What is the interaction between rider age and exposure?	2.5	1			
27.4	Differences between rider types (trained, untrained, experienced, inexperienced)	2.5	1			
28.1	What decelerations are achieved for different braking systems (ABS, Combined Brake Systems (CBS), Conventional Hydraulic)?	2.5	1	2		
28.4	For similar time-to-collision scenarios, does braking profile differ across braking systems?	2.5	1	3	2	
6.1	Where do riders ride most often and how does this compare to the fatality data?	2.3	1			
9.1	How does lane placement affect a rider's ability to avoid crashes and detect hazards?	2.3	1			
11.2	How often do adjacent drivers appears to fail to see the motorcycle rider (i.e., turning in front of the rider when there really isn't enough time to do so) when other vehicle's view is obstructed?	2.3				
12.4	How does recreational riding compare to riding for transport in terms of crashes and near-crashes?	2.3	1			
15.2	Does lane position vary with road geometry? Curves, blind intersections, passing parked cars, merging?	2.3	1			
10.1	Are riders who avoid crashes and near-crashes less likely to travel over the posted speed limit?	2.0	1			
11.3	How often do adjacent drivers appears to fail to see the motorcycle rider (i.e., turning in front of the rider when there really isn't enough time to do so) in limited visibility (fog, rain, glare)?	2.0				
12.1	How does recreational riding compare to riding for transport in terms of event rates, acceleration event rates, lean angles?	2.0	1			
18.2	How familiar are riders with near-evasive maneuvers?	2.0	1			
19.2	What is the relationship between riding style (braking, leaning, etc) and engine displacement?	2.0	1			

Q#	Questions	Average Priority	Base	Enhanced brake/throttle	Radar	Gaze
19.3	What is the relationship between riding style (braking, leaning, etc) and motorcycle type?	2.0	1			
20.2	Longitudinal control performance distributions (decelerations, accelerations)?	2.0	1			
20.5	Which brake is applied first?	2.0		1		
21.4	How effective are riders in maintaining their lane?	2.0	1			
21.5	How often do riders cross into an oncoming lane?	2.0	1			
23.5	What is the sequence of events/precipitating factors in crashes and near-crashes involving animals?	2.0	1			
23.7	What is the sequence of events/precipitating factors in crashes and near-crashes gravel or similar?	2.0	1			
27.2	Does rider torso position vary during curve negotiation?	2.0	1			
27.3	Does rider torso and head position vary during evasive maneuvers?	2.0	1			
28.3	Is time between start of braking and maximum deceleration different?	2.0	1			
29.2	Do people practice braking?	2.0	1			
29.3	Do people practice swerving?	2.0	1			
29.5	How frequently do people practice?	2.0	1			
32.1	Rider separation from bike?	2.0	1			
33.1	Prevalence of secondary tasks in crashes, near-crashes and related to other safety-related measures	2.0	1			
12.2	How does recreational riding compare to riding for transport in terms of speeds, traffic, road class, duration, environment?	1.7	1			
13.2	How does car driving frequency relate to motorcycle skills in terms of compatibility / negative transfer?	1.7	1			
15.5	How does rider clothing conspicuity (helmet and clothing color, retroreflective markings) relate to other safety-related measures?	1.7	1			
21.2	Lateral control performance distributions (lean, lateral accelerations)?	1.5	1			
21.3	What range of lateral velocities do riders achieve at different speeds?	1.5	1			

Q#	Questions	Average Priority	Base	Enhanced brake/throttle	Radar	Gaze
21.6	What type of steering is used (counter steering vs. standard steering) to initiate lean?	1.5	1			
21.7	How often are wheel lockup or low CoF precipitating factors in lateral control events?	1.5	1			
21.8	Does bike cornering clearance relate to other safety-related measures?	1.5	1			
22.1	How does exposure versus incidents compare for time of day, day of week, month of year?	1.5	1			
23.6	What is the sequence of events/precipitating factors in crashes and near-crashes from wheelies etc?	1.5	1			
26.1	What is the relationship between off-road experience and other safety-related measures?	1.5	1			
29.4	What levels of braking and swerving are achieved in practice?	1.5	1			
29.6	Are there relationships between practice and riding styles?	1.5	1			
30.1	How often are passengers on bikes?	1.5	1			
12.5	How does recreational riding compare to riding for transport in terms of safety/protective attire?	1.3	1			
19.4	What is the relationship between riding style (braking, leaning, etc) and motorcycle modifications?	1.0	1			
23.3	What is the sequence of events/precipitating factors in crashes and near-crashes involving a roadway defect or design hazard?	1.0	1			
23.4	What is the sequence of events/precipitating factors in crashes and near-crashes involving a pedestrian?	1.0	1			