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NSTSCE

National Surface Transportation Safety Center for Excellence

Rocky Mountain Naturalistic Driving Study

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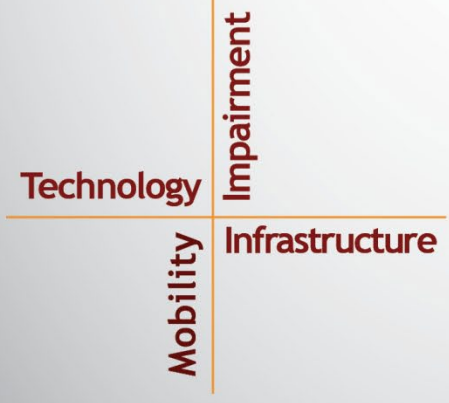

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EXECUTIVE SUMMARY

The Rocky Mountain Naturalistic Driving Study (RMNDS) was, at the time of data collection, the first attempt to use the NDS methodology to conduct research on the effects of cannabis on driving performance. The resulting dataset comprises over 14,000 trips made by 23 participants who self-reported medium to heavy cannabis use and who also reported they had a history of driving under the influence of cannabis. A unique aspect of the study was the collection of quantitative and qualitative drug use data. Qualitative drug use data was collected via an online journal, while quantitative drug use data was collected using a Quantisal oral fluid collection device prior to one driving trip each week. Samples were sent to a toxicology laboratory for analysis, which produced quantifiable test results for the National Institute on Drug Abuse 5 drug panel, including delta-9-THC. Out of the 14,000+ trips, there were a total of 178 verified drug test results along with 1,549 drug use journal entries. While the study proved successful for collecting naturalistic driving data and both objective and subjective drug use data, the difficulty comes in linking the drug use data to the driving data in order to identify periods of driving that may be impacted by the consumption of cannabis and/or other drugs. Further analysis of the RMNDS data, including identification of trips linked to drug use, would provide invaluable information about the impact of cannabis and/or other drugs on driving performance.

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LIST OF ABBREVIATIONS AND SYMBOLS

DAS	data acquisition system
DUIC	driving under the influence of cannabis
NDS	naturalistic driving study
RMNDS	Rocky Mountain naturalistic driving study
THC	delta-9-tetrahydrocannabinol

CHAPTER 1. INTRODUCTION

The wave of cannabis legislation in the U.S. began in 1996 with the legalization of medical cannabis use in California. A number of states followed suit by legalizing medical use, but it was not until 2012 that Colorado and Washington became the first two states to legalize recreational cannabis use. Since then, the legalization wave has rapidly picked up pace and, as of 2023, a total of 23 states have enacted laws legalizing recreational cannabis use for adults (Figure 1).[1] Public support for cannabis legalization has also increased dramatically over the last two decades, with twice as many adults expressing support for legalization in 2019 compared to survey results from 2000. Indeed, nearly 9 out of 10 Americans surveyed by the Pew Research Center in 2022 said cannabis should be legal for medical or recreational use.[2] These momentous shifts in cannabis legislation and public opinion pose a number of challenges for several critical health domains and have significant implications for road safety. While a recent roadside driver survey found cannabis to be the most commonly detected drug after alcohol, the accompanying research aimed at determining the impact of cannabis on driving performance has produced inconclusive or inconsistent results.

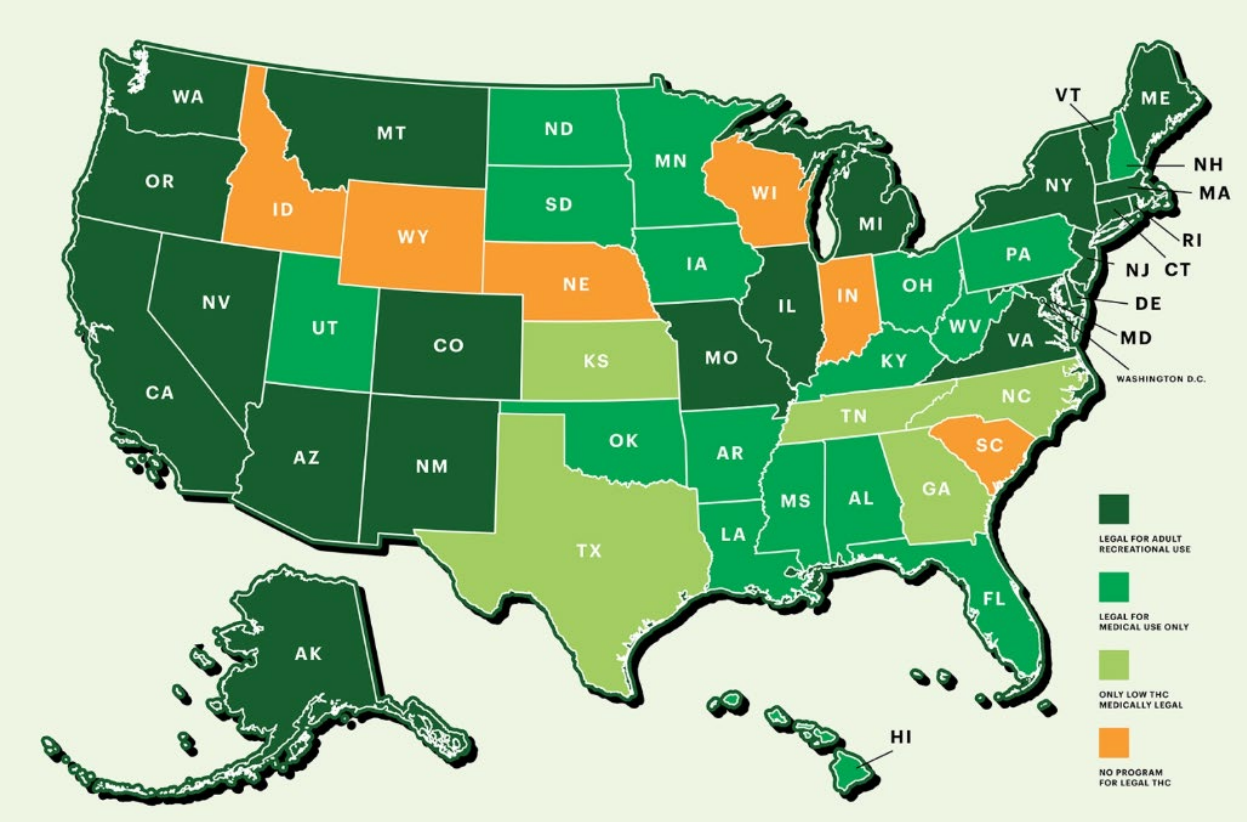


Figure 1. Map. Cannabis legalization status by state (Bort et al., 2023).

In terms of adverse consequences, cannabis use has been empirically linked to psychosis,[4] addiction,[5,6] altered brain development,[7-9] depression,[10] cognitive deficits,[11] lower income,[12,13] and decreased life satisfaction.[12] Cannabis is not only the most widely consumed illicit substance worldwide,[15] but also the most common illicit drug quantified in drivers' blood or oral fluid according to the 2007 National Roadside Survey.[16,17] Possibly indicative of the

growing prevalence of cannabis use among drivers, driver fatalities where cannabis was detected nearly tripled in the last decade to 12.2%.[18] However, it is unknown whether this change in cannabis detection is representative of the growing prevalence of cannabis, if it is an artifact of increased testing for cannabis in fatal crashes, or if there is a causal link between cannabis use and crash risk.

Unfortunately, the absence of a research consensus on the impact of cannabis on driving performance prevents informed policy decisions regarding driving under the influence of cannabis (DUIC) and limits the public's understanding of the potential risks of DUIC. Indeed, even the most basic questions regarding the relationship between cannabis and driving remain unanswered or cannot be conclusively answered due to contradictory research findings.[3,19] At a fundamental level, consensus is even lacking on whether cannabis impairment increases crash risk. While cannabis has been shown to cause impairment in nearly every performance area connected to driving,[19] it has only been shown to have a modest impact on driving in simulator and on-road tests.[3,19-21] Several studies have even shown that delta-9-tetrahydrocannabinol (THC), the primary active component of cannabis, has no effect on driving performance in either simulator or on-road tests.[22-24] These contradictory and modest findings have been linked to several factors. First, many of these previous studies used dependent measures that lacked sensitivity or were not tailored to the known effects of THC impairment.[25,26] Moreover, cannabis users may be aware of their impairment and not only increase their driving effort[27] but may also attempt to compensate by driving more slowly and taking fewer risks.[21,23,27-29] Additionally, there is no reliable association between THC concentrations in the blood and impairment from cannabis. In fact, research has shown there is a time lag between peak THC concentration and subjective impairment, with cannabis users experiencing maximum impairment approximately 20 minutes after peak THC concentration in the blood. THC concentrations decrease rapidly in the blood; however, cannabis metabolites (i.e., the byproduct of the body breaking down the drug into a different substance) are detectable for a significantly longer window of time than THC and will likely be present long after an individual is no longer impaired.[30,31]

These inconsistencies in study results are likely tied to differences in study designs.[3] Indeed, task complexity is a critical aspect of these studies.[3,32,33] Impairment is most readily observed when divided attention is necessary to complete multiple subtasks.[3,21,30,34] Thus, driving simulators, which lack the true task complexity of driving, may allow for cannabis users to compensate for their impairment. For example, many driving simulators do not have realistic interfaces (e.g., a single driver scene projected on a wall); require minimal task switching and multitasking; require less than 360° monitoring; do not examine the distracting effects of passengers; and cannot simulate the added seriousness of driving consequences on an actual road. In contrast, naturalistic driving studies (NDSs) utilize unobtrusive in-vehicle instrumentation within a participant's own vehicle as they go about their daily routines, allowing researchers to assess the effects of impairment in real-world conditions under the true task complexity of driving. Unlike artificial testing scenarios, NDSs also capture the additive effects of the driver's motivation and mental state. Participants in a simulator study may be motivated to perform well when a researcher is present, and they are engaged in a novel artificial driving experience. For example, the "driving" experience of driving a simulator in a dark room with an experimenter nearby is very different than the real driving experience of an individual returning from a party with a group of friends after smoking a joint. Indeed, research shows that the effects of cannabis are more significant during long, monotonous drives.[3] Thus, NDSs may hold the

key to resolving discrepant research findings regarding the effect of cannabis impairment on driving performance.

Colorado provides an ideal environment for a cannabis related NDS due to the legal status of recreational and medicinal cannabis use in the State. A recent survey reported that 9% of the population regularly used cannabis,[35] and 21% of these individuals reported driving after cannabis usage.[36] Rates of cannabis prevalence in fatal traffic crashes have also risen in Colorado since the legalization of cannabis for medicinal use in 2009.[37] However, this may be due to changes in toxicology testing protocols and capabilities rather than increased cannabis use by drivers or its impact on driving safety.

This study was the first NDS investigating the impact of cannabis use on driving and served as a pilot study to test new methods for conducting research on cannabis-impaired driving. The resulting dataset will provide insight into the effects of cannabis use on driving through the naturalistic collection of video and kinematic data from the vehicle, video of the driver's face and the forward roadway, quantitative toxicology test results, and self-reported drug use data. These data can be analyzed by researchers to investigate a host of research questions related to cannabis use and driving.

CHAPTER 2. METHOD

PARTICIPANT RECRUITMENT

The legal age for cannabis use in the U.S. is 21; thus, the participants recruited in Colorado for this study were required to be at least 21 years of age. Additionally, in order to target the population that most commonly engage in cannabis-impaired driving, the maximum age of participants was capped at 50 years. A total of 23 participants were recruited, all of whom reported they were moderate to heavy cannabis users with a history of driving under the influence of cannabis.

Participants were recruited by placing ads in newspapers, on Craigslist, and on social media. Flyers and business cards were posted in targeted business locations that sell cannabis. Participants were also recruited through word-of-mouth, and these individuals initiated contact with the research team. Potential participants were provided with basic information about the study via email or a phone call and invited to participate in a detailed screening to determine eligibility.

Eligibility Criteria & Screening

The screening questionnaire (Appendix A) was administered verbally to determine if a potential participant was suitable for enrolment in the study. Participants were required to meet the following criteria to be eligible:

- Must have a valid U.S. driver's license allowing independent, unsupervised driving.
- Must drive at least 3 days per week on average.
- Must own their own vehicle.
- The vehicle to be instrumented must be a vehicle model year 1996 or newer and be in good mechanical condition.
- The participant must plan on driving the vehicle to be instrumented as their main vehicle for the duration of their scheduled participation.
- Must be able to provide proof of insurance for the vehicle.
- Must not routinely share their vehicle with other drivers and must not routinely let others drive their vehicle while they are enrolled in the study.
- Must report a history of driving under the influence of cannabis.
- Must not have a need to drive their vehicle into areas where cameras are not allowed (including locations such as some military bases, international border crossings, etc.).
- Must be a U.S. citizen or eligible to work in the U.S. (for payment purposes).
- Must be willing to provide their Social Security Number (for payment purposes).
- Must have a personal email address that is checked daily.
- Must not have a history of brain damage from stroke, tumor, head injury, recent concussion, disease or infection of the brain, respiratory disorder/disease requiring oxygen.
- Must not have had an epileptic seizure or lapse of consciousness within the past 12 months.
- Must not have current problems with the inner ear issues with dizziness, vertigo, or balance.
- Must drive at least 50 miles/week.

- Must be able to drive without glasses.
- Must not be an identical twin.

After completing the screening questionnaire, those deemed eligible were scheduled for a study orientation session to complete the consent process, fill out initial questionnaires, and have the data collection equipment installed in their vehicle.

Study Orientation Session

Participants were asked to drive their vehicle to the installation facility, where they met with a member of the research team and an equipment installer. As a final eligibility step, the participant was asked to present the researcher with a valid driver's license, proof of vehicle liability insurance, and the vehicle registration to verify ownership. The consent form was reviewed and signed, and the vehicle was inspected for any existing damage, which was documented on a vehicle inspection checklist. The participant watched a short instructional video about the oral fluid drug testing procedure and completed an oral fluid drug test to establish preliminary drug use results. This also provided an opportunity for the participant to experience how to correctly self-administer the drug test. Participants were given a hard copy of detailed instructions on the self-administration procedure for the oral fluid test (Appendix B) and received an email containing a link to the instructional video for testing procedures.

The study orientation session provided an opportunity for participants to complete the introductory, online questionnaire while the data collection equipment was being installed in their vehicle. The questionnaire comprised a variety of questions focusing on participant demographics, driving history, driving knowledge, drug use, frequency of risky behavior, medical conditions, current medications, perception of risk, sensation seeking, and sleep hygiene. The questionnaire was designed to take less than an hour to complete.

The study orientation session also provided details of compensation for participation, which was paid after completion of each of the following stages of the study:

1. Participants received $50 for completing all introductory procedures. This included $30 for vehicle instrumentation and an additional $20 for completion of the initial online questionnaire.
2. In the event the participant was requested to return to the installation facility for a maintenance appointment, they received $30 for each maintenance visit.
3. Participants received $20 per week for completing the weekly oral fluid drug test and daily self-report drug use journal.
4. Participants received an additional $150 for completing the entire study.

Completion of all tasks and participation in the entire 3-month data collection period resulted in a total maximum payment of $440. Payments were prorated if the participant withdrew from the study prior to completion. Towards the end of the data collection period, participants were notified of the opportunity to extend their participation for an additional 2–14 weeks. Those who decided to extend were consented in person by a member of the research team during the course of routine maintenance activity (i.e., data drive swap). Compensation for remaining in the study was kept at the rate of $20 per week for completion of the weekly drug test and daily journal.

VEHICLE INSTRUMENTATION

The data acquisition system (DAS) installed in each participant's vehicle was mounted such that it did not pose a hazard or obstruct the driver's view at any point in time. Video and vehicle sensor data were collected while the vehicle was on and running (i.e., the system was active from key on to key off) and stored on the DAS's hard drive. Vehicle data of interest included longitudinal and lateral acceleration, yaw, GPS speed, position, and heading, distance to the right and left lane line, and speed data. The MiniDAS, which was developed internally by VTTI, provided two camera views: one of the driver's face and the other of the forward roadway (Figure 2).

Figure 2. Video screen capture. MiniDAS camera views.

The MiniDAS was equipped with a critical incident button for drivers to use in the event of a crash or the occurrence of a safety-critical event. When the red button on the windshield-mounted unit was pressed, a microphone was activated for 30 seconds, which allowed the driver to provide more detailed information about what happened. Pressing this button also flagged the incident in the database after the data were collected. Additionally, the critical incident button provided another way for participants to report drug use, as they were instructed to press the button after starting the vehicle, but before driving, to verbally report the last time they consumed or inhaled cannabis. Participants were also asked to provide any other relevant drug-use information (e.g., if they believed they were under the influence of any other substance).

Audio was only recorded after pressing the critical incident button and continuous audio data was not collected.

Vehicle instrumentation also included an ambient atmospheric analyzer made up of three separate sensors. The first sensor was designed to detect the presence of alcohol within the vehicle cabin. This sensor was likely not able to distinguish whether the alcohol was imbibed or applied (e.g., hand sanitizer), and also was not able to determine whether the alcohol was emanating from the driver or a passenger. The second sensor was designed to detect the presence of smoke within the vehicle, including smoke originating from smoked tobacco or cannabis. The final sensor was a prototype sensor to detect the presence of marijuana smoke, specifically. These two smoke detecting sensors were not able to differentiate where the smoke was originating from, but it would be possible to infer the source from video evidence, similar to witnessing someone imbibing alcohol while driving. All of these sensors were used to flag the data for possible indications of impaired driving.

DATA COLLECTION

Data collection commenced in April 2016 and continued through to August 2017. Data were collected throughout the duration of the study using several different methods. Participants were requested to track and report their drug use in two ways. Firstly, participants were asked to complete an oral fluid drug test once per week, prior to driving. Drug test results provided information on which drugs were present in the participant. Secondly, participants were asked to complete an online daily drug use journal, which included details about which drugs were consumed, as well as when, where, and how such was consumed. Video and driving data were collected via the MiniDAS installed in the participant's vehicle.

Oral Fluid Drug Test

Participants used the Quantisal oral fluid testing device from Immunalysis to collect an oral fluid sample once per week. Prior to self-administering the drug test, the participant was instructed to start their vehicle and conduct the drug test procedure in front of the in-vehicle camera aimed at the driver so the procedure was recorded and could be verified. In terms of when to conduct the drug test, participants were asked to randomly pick a trip that was safe and convenient and that allowed at least 15 minutes beforehand to perform the drug test procedure. If participants were regular drug users, they were instructed to randomly choose trips that represented a range of their drug use (e.g., do not always choose to conduct the drug test prior to a Monday morning commute or a return trip from a bar after having one alcoholic beverage). Participants were not required to change their drug use or driving patterns during the course of the study.

To complete the weekly drug test, participants were provided with a package for each drug test that provided all necessary sample collection items, including a factory packaged Quantisal saliva collection device, participant identification sticker, and stamped envelope addressed to the drug testing facility, along with instructions on how to collect a specimen (Figure 3). The saliva collection device required participants to place the device under their tongue for approximately 2 minutes. Once the indicator turned blue, participants placed the collection device into the transport tube containing a buffer fluid that stabilized the sample then affixed the ID sticker. Participants were instructed to show the transport tube in view of the driver-aimed camera with the sticker visible (Figure 4) so the specific trip could be identified and correlated to drug test results. Participants then sealed the drug test in the pre-addressed envelope and mailed it to the laboratory for analysis.

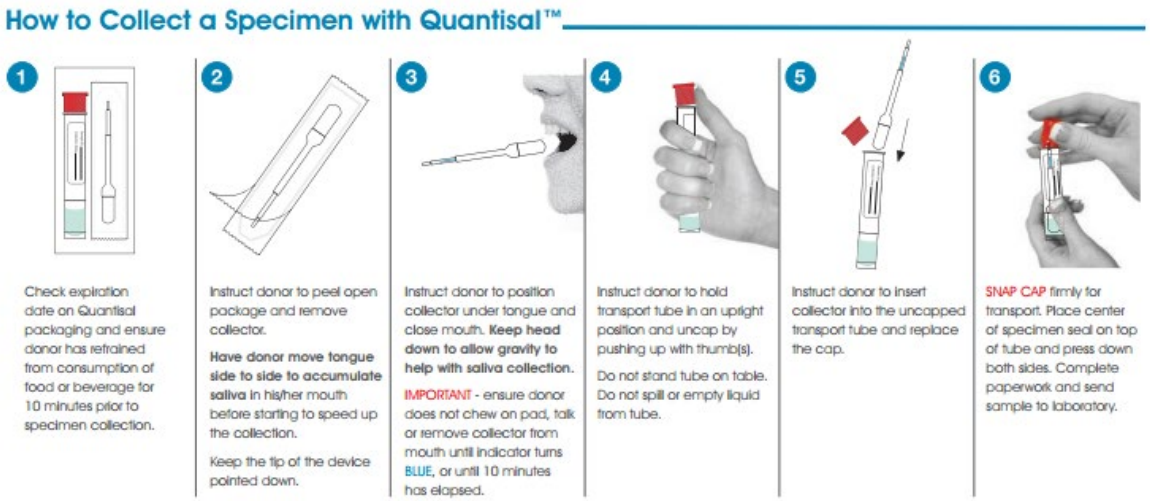


Figure 3. Illustration. Manufacturer's drug test specimen collection steps.

Figure 4. Video screen capture. Example of a MiniDAS recording of a drug test.

Toxicology analysis of the oral fluid samples detected concentrations of many different drugs, including THC, alcohol, amphetamine, cocaine, opiates, barbiturates, benzodiazepines, methamphetamine, PCP, and several other common drugs. Table 1 shows the data elements provided for each participant's oral fluid sample.

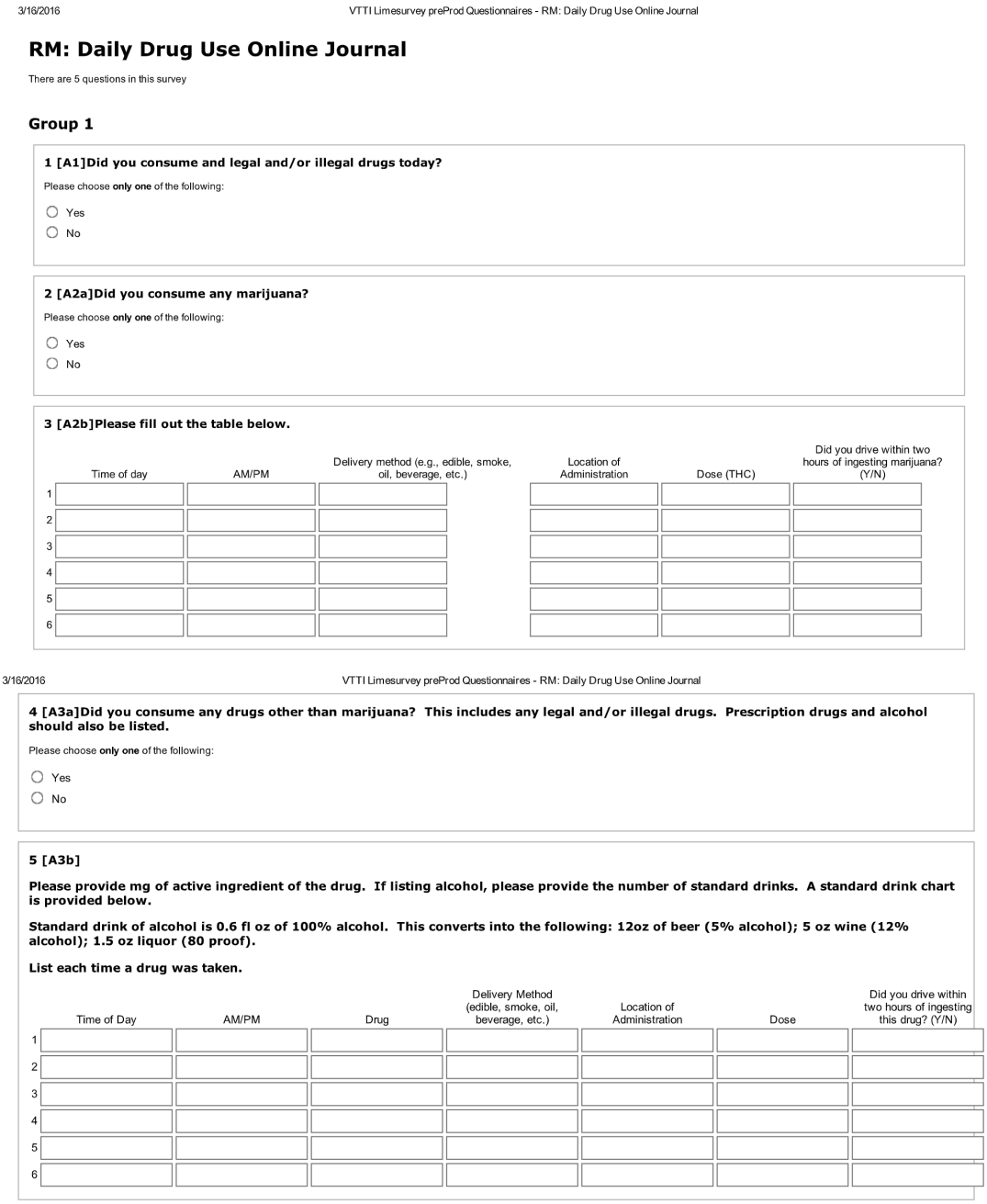
Table 1. Drug test results data elements.

Variable	Description
ParticipantID	Identifier for participant in database
SpecimenID	Identifier for the drug test specimen
SpecimenRxTimestamp	Timestamp when the drug test was received
Alcohol mg/dL	Drug test result alcohol value
THC	Drug test THC value

Variable	Description
THC-COOH	Drug test THC-COOH value
Cocaine	Drug test cocaine value
BZE	Drug test BZE value
AMP	Drug test amphetamines value
METH	Drug test methamphetamines value
Morphine	Drug test Morphine value
Codeine	Drug test codeine value
6-AM	Drug test 6-AM value
HYC	Drug test HYC value
HYM	Drug test HYM value
OXYC	Drug test OXYC value
OXYM	Drug test OXYM value
PCP	Drug test PCP value

Daily Drug Use Journal

As noted above, participants also reported their daily drug use via an online journal (Figure 5). Participants were requested to complete the online journal each night at 7 p.m. Mountain Time using a link embedded in the Rocky Mountain Daily Journal Email. The survey was intended to take less than 5 minutes each night to complete. Details were collected regarding what drug/s were consumed, the time of day, the delivery method (e.g., edible, smoke, oil, etc.), the dose, and where the drug was consumed. Participants were also asked if they drove within 2 hours of consuming the drug. Although cannabis was the specific drug of interest, participants were asked to report any other drugs they consumed, including alcohol, with specifics regarding the time of day, location, the type, and the dose (i.e., amount). These details allow for analysis of polydrug use. See Appendix C for a complete list of the journal data elements available for analysis.


3/16/2016 VTTI Limesurvey preProd Questionnaires - RM: Daily Drug Use Online Journal

RM: Daily Drug Use Online Journal

There are 5 questions in this survey

Group 1

1 [A1]Did you consume and legal and/or illegal drugs today?

Please choose **only one** of the following:

○ Yes
○ No

2 [A2a]Did you consume any marijuana?

Please choose **only one** of the following:

○ Yes
○ No

3 [A2b]Please fill out the table below.

	Time of day	AM/PM	Delivery method (e.g., edible, smoke, oil, beverage, etc.)	Location of Administration	Dose (THC)	Did you drive within two hours of ingesting marijuana? (Y/N)
1						
2						
3						
4						
5						
6						

3/16/2016 VTTI Limesurvey preProd Questionnaires - RM: Daily Drug Use Online Journal

4 [A3a]Did you consume any drugs other than marijuana? This includes any legal and/or illegal drugs. Prescription drugs and alcohol should also be listed.

Please choose **only one** of the following:

○ Yes
○ No

5 [A3b]

Please provide mg of active ingredient of the drug. If listing alcohol, please provide the number of standard drinks. A standard drink chart is provided below.

Standard drink of alcohol is 0.6 fl oz of 100% alcohol. This converts into the following: 12oz of beer (5% alcohol); 5 oz wine (12% alcohol); 1.5 oz liquor (80 proof).

List each time a drug was taken.

	Time of Day	AM/PM	Drug	Delivery Method (edible, smoke, oil, beverage, etc.)	Location of Administration	Dose	Did you drive within two hours of ingesting this drug? (Y/N)
1							
2							
3							
4							
5							
6							

Figure 5. Screen shot. Self-report drug use journal questionnaire.

DATA MINING PROTOCOL

The multiple different data sources provide a variety of options for subsequent data mining efforts and analysis. Initial analyses followed the workflow presented in Figure 6. The first step involved identifying trips for which there was an associated drug test as verified by a video record from the MiniDAS. Information recorded for each drug test was used to identify the exact trip within the database matching that drug test, resulting in a total number of 179 trips with verified drug tests.

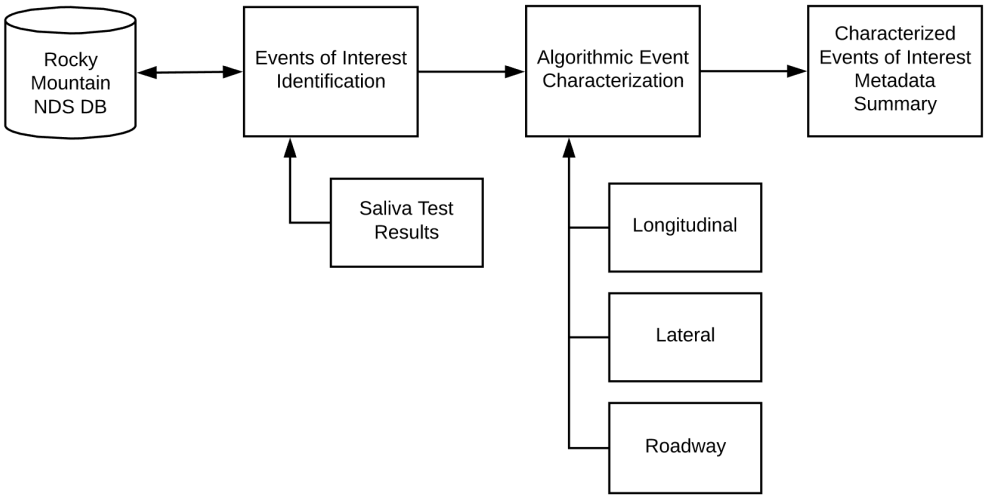


Figure 6. Flowchart. Overview of the data analysis protocol.

Using the list of identified events of interest, algorithmic characterization steps were performed on these trips to disseminate the collected kinematic data into a form that could be used for analysis. In particular, the focus was on finding kinematic driving events that could be used to assist in answering questions pertaining to cannabis use and its influence on the following:

- Crash risk
- Defensive driving
- Overcorrecting
- Reduced response time

For each event identified, data mining techniques were conducted to extract and identify the data elements listed in Table 2.

Table 2. Data elements extracted from trip data.

Data of Interest	Units
DAS Recorded Timestamp	ms
Longitudinal Acceleration	m/s^2
Lateral Acceleration	m/s^2
Yaw	deg/s
GPS Speed	kph
GPS Position	dec deg
GPS Heading	deg
Left Lane Distance	mm
Right Lane Distance	mm
Speed Limit	kph
Speed Phase	a) Stopping b) Coasting c) Accelerating

Figure 7 provides an example of various plots generated to support analysis activities. In the top right corner, a color-coded plot identifies sections of data where the speed signal was in a stopping (i.e., red), accelerating (i.e., green), or coasting (i.e., yellow) phase. Speed limit zone information (i.e., black) is also shown to provide a frame of reference for the driver's speed. Using this known speed limit and exact speed of the vehicle, speed-limit-exceeding events were identified. Other plots of interest in Figure 7 include a map showing the trip from start to finish, longitudinal and lateral acceleration, yaw, lane position, heading, and output from the three atmospheric sensors.

Additionally, initial calculations were conducted using the algorithmically determined Speed Phase data, specifically:

- The maximum, minimum, mean, and standard deviation of the longitudinal acceleration were calculated for all Stopping regions detected in a trip.
- The maximum, minimum, mean, and standard deviation of the difference between the driver's speed and the speed limit of the roadway were calculated for all Coasting regions where the vehicle was traveling over 10 mph.

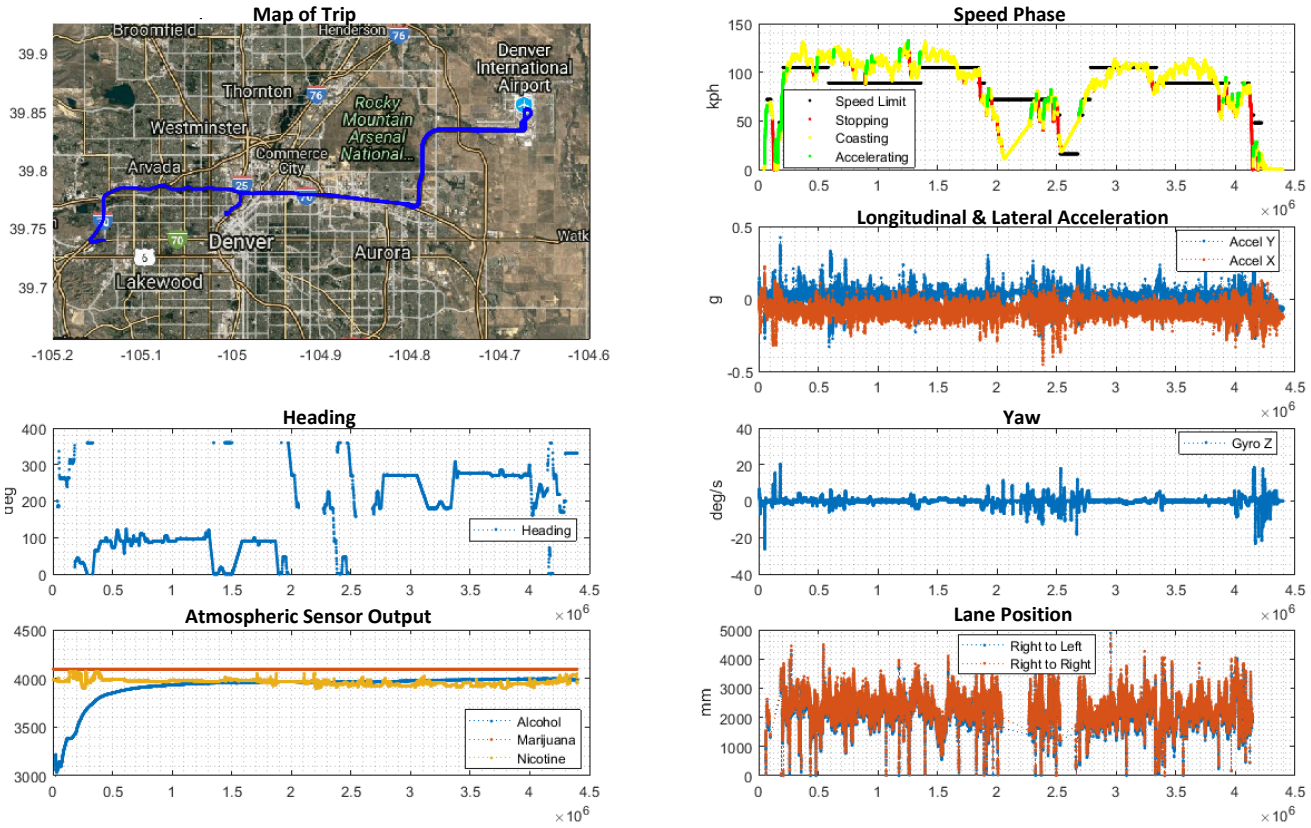


Figure 7. Plots. Various kinematic trip data elements.

The final step of data mining involved extracting and compiling all relevant data elements of interest, which resulted in an extensive list of variables, including information related to the participant, the specific trip, kinematic data, and the associated drug test results that could be used to assess cannabis use and the influence of cannabis use across a number of factors. See Appendix D for the complete list of variables used to characterize events of interest.

CHAPTER 3. RESULTS

PARTICIPANT DEMOGRAPHICS

There were 23 participants in the study. The average age was 32.2 years and average driving experience was 14 years. Participants were 55% females, 90% white, 4.5% African American and 4.5% Hispanic. All participants had at least a high school diploma, while 77% had a college degree or higher. Sixty-eight percent had a full-time job, 18% had part-time employment, and 14% were not working. Participants reported medium to heavy cannabis use.

SUMMARY TRIP DATA

Table 3 provides a summary of the participant vehicle trip data collected by the MiniDAS over the duration of the study.

Table 3. Summary of trip data.

Trip Variables	Total	Minimum	Maximum
Total Number of Trips	14,475	-	-
Total Trip Time Data Collected	2,402 hrs	-	-
Average Number of Trips per Participant	629.3	10	4,982
Average Trip Duration	9.96 mins	4.02 mins	24.8 mins
Average Trip Time Data per Participant	104.5 hrs	4.14 hrs	265.51 hrs
Average Length of Participation	90.1 days	1 day	153 days

ORAL FUID DRUG TEST SUMMARY

Participants submitted 266 oral fluid samples for toxicology testing to identify the presence of drugs. Of those samples, 118 tested positive for the presence of at least one drug, with 11 testing positive for two drugs, 14 testing positive for three drugs, and 1 sample testing positive for four drugs. Table 4 shows the number of positive test results for each drug included in testing. Any drug not listed in the table did not produce any positive test results. Since some samples tested positive for more than one drug (i.e., indicative of polydrug use), the numbers in the table are higher than the total number of positive tests.

Table 4. Summary of positive drug test results.

Drug	Count of Positive Drug Test Results
Alcohol	6
THC	109
BZE	1
AMP	22
METH	14
Morphine	1
Codeine	1

DRUG USE JOURNAL SUMMARY

Participants completed a total of 1,549 drug use journals. Each journal entry may have contained reported drug use of more than one drug; thus, the total count of drugs reported is greater than the number of journals submitted. Additionally, each journal entry could be used to log up to six separate instances of cannabis consumption in a day. Nine hundred seventy-five of the journal entries reported at least one instance of cannabis consumption. Approximately one quarter of those journal entries reported two or more instances of cannabis consumption, while another quarter reported three or more instances of cannabis use. Table 5 shows the total count of each drug that was self-reported during the study.

Table 5. Summary of self-reported drug use data.

Drug	Total Count
Cannabis	1,593
Alcohol	702
Illegal	58
Over the counter	91
Prescription	748

INITIAL ANALYSIS OF TRIP DATA

In order to identify potential events of interest, trigger algorithms were deployed across all collected trips to flag aggressive kinematic events that could be indicative of a near-crash or crash event. These trigger values can be adjusted as needed depending on the type of events of interest and the severity of the desired event. For instance, increasing the value of the longitudinal trigger will flag increasingly severe hard braking events. Since this was an initial exploratory search of the associated kinematic data, the trigger values were relatively low to identify as many potential events of interest as possible. The trigger algorithms resulted in the identification of 26,557 trigger events of interest (Table 6).

Table 6. Total number of kinematic trigger events.

Kinematic Event (Gs)	Count
Yaw Rate < -4	1,087
Longitudinal < -0.3	6,576
Lateral < -0.3	7,404
Lateral > 0.3	7,966
Longitudinal > 0.3	2,567
Yaw Rate > 4	957

After initial identification, these triggers were further refined and classified according to the criteria in Table 7.

Table 7. Classification of kinematic trigger types.

Trigger Type	Description
Longitudinal Deceleration	Occurs when a threshold deceleration of 0.65 g in the X direction is reached or exceeded at any point in time.
Highway Longitudinal Deceleration	Occurs when a threshold deceleration of 0.30 g in the X direction is reached or exceeded while a speed threshold of 40 mph is reached or exceeded.
Longitudinal Acceleration	Occurs when a threshold acceleration of 0.5 g in the X direction is reached or exceeded at any point in time.
Swerve Evasive Maneuver	Occurs when yaw rate completes one complete cycle of a sine waveform and exceeds 15 deg/sec/sec within 2000 ms with min. speed 5 m/s.
Steering Evasive Maneuver	The abs. value of derivative of lateral acceleration is greater than -1.0 g/s for 800 ms while the vehicle travels at 5 m/s or higher speeds.
Lateral Acceleration	Occurs when a threshold acceleration of 0.75 g in the Y direction is reached or exceeded for at least 0.2 seconds.
Longitudinal Jerk	The derivative of longitudinal acceleration is less than -1.0 g/s for 250 ms while the vehicle travels at 5 m/s or higher.
Yaw Rate	Occurs when yaw rate oscillates from ±8 deg/sec to the same magnitude in the opposite direction within 0.75 sec.

To illustrate how these triggers can be further analyzed, longitudinal deceleration, or hard braking trigger events, were selected (i.e., Longitudinal Deceleration and Highway Longitudinal Deceleration trigger types). These trigger events were validated by trained data analysts and categorized according to the outcome of the event, meaning the event resulted in a crash, near-crash, crash-relevant conflict, or it was a non-conflict (see Appendix E) for event type definitions). Although no crashes were identified in the data, there were near-crashes and crash-relevant conflicts. Table 8 provides a summary of the event type by kinematic trigger type.

Table 8. Event type by kinematic trigger type.

Kinematic Trigger Type	Event Type			
	Crash	Near-crash	Crash-relevant Conflict	Non-Conflict
Longitudinal Deceleration	0	40	20	98
Highway Longitudinal Deceleration	0	22	32	1,252
All Other Trigger Types	0	5	5	376
Totals	0	67	57	1,726

Additional information associated with these events can be analyzed to investigate factors present in the lead up to, and during the occurrence of, each event. These include factors such as:

- Precipitating event (e.g., the vehicle ahead was decelerating, pedestrian in roadway)
- Incident type (e.g., turn into path of oncoming vehicle, rear-end, striking, or sideswipe)
- Driver behavior (e.g., distraction, signal violation, delayed braking, following too closely)
- Secondary task engagement (e.g., cell phone use, talking to a passenger)
- Environmental factors (e.g., weather, lighting)
- Infrastructure/roadway factors (e.g., traffic flow and density, intersection influence).

Periods of baseline driving, which refers to general periods of driving that do not include a safety critical event or incident, can also be analyzed to get an understanding of how cannabis users typically drive, what behaviors they engage in while driving, and any other driving patterns. Combining the driving data with the toxicology results and/or drug use journal entries allows for the identification and analysis of trips taken when the driver was under the influence of cannabis and may have been impaired.

CHAPTER 4. DISCUSSION AND CONCLUSIONS

This study provides insight into the use of the NDS methodology for conducting research on cannabis use and the resulting impact on driving. The overall methodology was successful in collecting quantifiable oral fluid drug test data, self-reported drug use data, and naturalistic vehicle driving data for 23 moderate to heavy cannabis users. This resulted in over 14,000 trips, many of which may be linked to a verified drug test in which the participant tested positive for cannabis or a drug use journal entry in which the participant reports they drove after consuming cannabis. Further analysis is needed to investigate the extent to which the drug use data can be linked to the trip data in order to identify and analyze periods of cannabis-positive driving.

Participant drug use can be characterized by analyzing both objective measures (i.e., oral fluid drug tests) and subjective measures (i.e., self-report daily journals). Objective measures provide confirmation not just of the presence of various drugs in the participant's system, but also quantifiable information regarding the amount of each drug in the participant's system. Additionally, instances of polydrug use can be confirmed and further investigated. Cannabis and alcohol are the most commonly reported drugs consumed at the same time, and the additive effect has been shown to negatively impact driving performance in a simulator (i.e., increased weaving and reaction time), despite participants being unaware of the increased effect on their driving ability.[38] These data present an opportunity to identify trips involving cannabis and alcohol use to determine the impact on driving performance.

The vehicle driving data comprises roughly 2,400 total driving hours, with an average of 104 driving hours per participant (ranging from 4 hours to 266 hours). No crashes were observed in these data; however, the use of kinematic trigger events allowed for the identification of other driving events of interest, such as hard braking events. Additional analysis is needed to map the driving data onto the objective and subjective drug use data in order to identify specific trips that may have been impacted by drug consumption. This study has shown the NDS methodology to be an innovative and unique way to study drug-positive driving. While the methodology is feasible and effective to investigate driving performance on any number of trips, the difficulty lies in identifying specific trips associated with drug consumption and potential impairment. Compliance with instructions for collecting both objective and subjective drug use data was not perfect; however, preliminary analysis of the data identified a number of trips that were associated with a verified oral fluid drug test. The self-report drug data could also undoubtedly be mapped onto the trip data to identify periods of driving that may be impacted by drug use (albeit, self-reported drug use). One lesson learned regarding the self-report drug data from the online journal entries was related to the use of text box fields to collect the information. Using text boxes allows participants to freely enter information in non-standardized formats. This resulted in numerous issues such as spelling mistakes, slang being used, and use of a wide variety of time formatting and consumption units from participant to participant. Researchers had to spend a significant amount of time restructuring these data and standardizing user input in multiple manual cleaning steps. Future studies choosing to use a similar methodology would benefit from providing a more structured response format and limiting the use of text box response questions.

There are many opportunities for further in-depth investigation and analysis of these data, including characterization of video data, that may provide invaluable insight into cannabis-positive driving behavior. There may also be interest in investigating drugs other than cannabis,

such as amphetamines, or drugs taken in addition to cannabis (i.e., polydrug trips). Other opportunities to build on existing work include characterizing events of interest based on external environmental roadway characteristics or distracted driving behavior (e.g., eye glance and secondary task engagement). These data may also be useful in developing an impaired driving detection algorithm. Various data markers that may be helpful to detect cannabis-impaired driving could include time of day, lane center adherence (i.e., lateral lane position), speed/headway adherence, acceleration and deceleration events, and eye glance/gaze tracking. Each of these markers would generate a probability-based score to indicate if the driver was impaired.

APPENDIX A. SCREENING QUESTIONNAIRE

Note:
Initial contact between participants and researchers may take place over the phone. If this is the case, 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.

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'm with the Virginia Tech Transportation Institute, in Blacksburg, VA. We are currently recruiting people who use cannabis or marijuana to participate in a research study in the Front Range area of Colorado. If you are eligible, we will add your name to the list of potential participants; we will not be scheduling you for participation today, only determining your eligibility. Your responses will be recorded and stored throughout the duration of the research. If you are not eligible, or if you are not selected for participation, you may elect to have your information saved in our participant database for consideration in future research opportunities. Should you not wish to do so, your contact information will be removed from our database and any record of responses you provide today destroyed.

This research is funded by the National Surface Transportation Safety Center for Excellence and the purpose is to learn more about safe driving behaviors by understanding how people actually drive. You should know that this study is being done in cooperation with the National Institute of Health and as such, the research team has secured a Certificate of Confidentiality. The research team understands that you may have concerns about the protection of your data and therefore has taken the steps to acquire this Certificate. This provides an extra layer of protection for you and your data. With this Certificate, neither the researchers nor study sponsors can be forced to disclose identifying information related to you in any civil, criminal, administrative, legislative, or other proceeding. At no time are you being judged or evaluated, and the research team will not be disclosing your participation in the study to police, job supervisors, or any other personnel not directly related to the study.

If you are eligible and choose to participate, a monitoring system will be temporarily installed in your vehicle for up to 3 months. VTTI has been doing studies of this sort for over 15 years, with cars, tractor trailers, and even motorcycles. The system has GPS and other sensors that will record your speed, acceleration, and location. It will also have cameras that look out the front windshield and at the driver. There will be a number of prototype sensors that are designed to detect the presence of alcohol and smoke within the vehicle. These sensors may not be able to differentiate between imbibed alcohol and non-imbibed alcohol such as hand sanitizer or perfume. The sensors themselves are also not able to determine if the alcohol presence is coming from a driver or passenger. The sensor data will only be available to researchers after your participation ends (it will not alert the researchers of any findings while you are in the study). Overall, the monitoring system will be unobtrusive - it won't affect your car's performance and you won't have to interact with it at all. The only thing you will notice is the small cameras and possibly some wires that will be fastened out of the way. The system will be installed and removed by trained professionals. Installation is expected to take about 1-2 hours, and will take place at our research facility in the Front Range area of Colorado. Due to the

cameras involved, this study is not suitable for people who frequent areas where video recordings are not allowed, for example military installations or high security facilities.

As part of this research, we would like to monitor your use of cannabis/marijuana, by asking you to complete a brief, daily questionnaire and provide a mouth swab once per week. We will ask you to swab some saliva from your mouth using sterile cotton applicators provided by us; then ask you to mail them to a secure lab site in a self-addressed envelope also provided by us. You will also be asked to push a button attached to the research equipment installed in your vehicle to verbally state your recent drug usage. This will include the type and quantity of drug. Your lab results and all of the information recorded by the monitoring system during this research will be treated as confidential and will only be accessible by the research team.

The data collected from your vehicle will be encrypted as it is collected and can only be decrypted by VTTI. From the start of your involvement, your name will not be associated with any recorded data or lab results; you will be assigned a participant #, for example, participant # 10. As the data are decrypted, VTTI will store it while preventing true identification of participants. In addition, your participation will be covered by a National Institutes of Health Certificate of Confidentiality. With this certificate, researchers and study sponsors cannot be forced to disclose information that may identify you, even by a court subpoena, in any federal, state, or local civil, criminal, administrative, legislative, or other proceedings.

If you participate, you will receive payments with a MasterCard; payments will be electronically loaded onto the MasterCard throughout the study. Payment will occur in the following increments: 1. $50 at installation 2. $20 per week once saliva tests and daily drug use surveys are provided 3. $150 at the end of 3 months of participation, when the equipment is removed. For those who participate fully, the maximum payment for the entire study would be $440.

Any questions yet?

If you are interested in possibly participating, I need to go over some screening questions to see if you meet all the eligibility requirements of this study. Any information given to us will be kept secure and confidential.

Do I have your consent to ask the screening questions? [If yes, continue with the questions. If no, then thank him/her for their time and end the phone call.]

Participant Eligibility Questions:

1. Do you currently hold, a valid U.S. driver's license, which you can present at the time of the study? YES _____ NO _____ If yes, how long have you held a license? _____

Criterion: they are ineligible to participate if unable to present a VALID U.S. driver's license at their appointment and they must be an experienced driver (at least 2 years).
NOTE: They will be reminded they must present a driver's license at their appointment if scheduled.

2. Over the past 6 weeks, how many times, on average, have you smoked marijuana each week? _____

Criterion: Must report smoking an average of once or more per week.

3. Do you have an active prescription for medical marijuana? YES _____NO _____

Criterion: While the preference for this study is for recreational users, medical users may be included in the sample. As such we would like to note this information from the screening.

4. Have you ever driven while under the influence of cannabis (marijuana)?
   YES _____NO _____

Notes:_____

Criterion: Must report they have driven under the influence of cannabis.

5. On Average how many days a week do you drive? _____

Criterion: Must drive, on average, at least 3 days per week.

6. On average, how many miles do you travel in a normal week? _____

   Criterion: Must drive at least 50 miles per week, on average, in the vehicle they sign up for the study.

7. As a part of this study, the research team will send you a link to a daily survey each evening by email. The survey is expected to take less than five minutes. Are you willing to complete this survey each night, 7 days a week, using a personal email address?
   Yes_____ No_____

This survey link must be emailed directly to you at a personal email address. Do you have a personal, non-work, email that you currently check, or are willing to check, on a daily basis?

Yes_____ No_____

We also need to ensure participants are able to complete the survey using a reliable internet connection on a personal computer. The survey will not be easily viewable on a mobile phone device. Do you have an internet-connected personal computer at your personal residence?

Yes_____ No_____

Criterion: Must be willing to take a daily survey and have a personal (i.e., non-work) email that they check on a daily basis. This includes having a personal computer with internet access at his or her personal residence.

8. What is your current age? _____ YOB_____

Criterion: Must be 21 - 50 years old to participate.

9. What is your gender? Male _____ Female _____

Criterion: the total number of participants will be gender balanced if possible

10. Are you a U.S. Citizen or eligible to work in the U.S.?
    YES _____NO _____

**Note: participant will need to bring their SS # to the study for W-9 paperwork for payment. (the card is not needed if they have their ss# memorized)

Must be a U.S. citizen or eligible to work in the U.S.

11. If selected to participate in this study, will you provide your SSN at the time of participation? YES _____ NO _____

Must be willing to provide SSN number and complete a W-9 at their first appointment; this is for payment purposes as required by Va Tech.

12. Do you own, co-own, or lease the primary vehicle you drive? YES _____ NO _____

NOTE: The registration must have your name on it in order to participate and you will be asked to provide the documentation at the time of the installation.

Criterion: Must own, co-own, or lease the primary vehicle that will be used during the study. (If they are paying on a loan for the vehicle or leasing the vehicle in their name, these are accepted)

13. What is the make, model and year of the primary vehicle you usually drive?

Make: _____ Model:_____ Year:_____

NOTE: Upon inspection, the research team may determine the vehicle is not eligible to instrument, for example, if looks to be in poor mechanical condition or if the vehicle cannot accommodate the data collection equipment.

Must be a 1996 or newer model vehicle such as a truck, car, SUV, or van. No motorcycles or convertibles.

14. Are you willing to provide proof of insurance on the vehicle? YES _____ NO _____

Notes:_____

Must provide proof of insurance on the vehicle being used in the study.

15. Do you plan to trade or sell this vehicle within the next 6 months? YES _____ NO _____

Criterion: Must plan to keep their primary vehicle for the entire duration of the study.

16. Does anyone else drive this vehicle on a regular basis? YES _____ NO _____

Notes:_____

Criterion: The participant must be the primary driver of the vehicle they enroll in the study. Cannot have other drivers on a regular basis (Should not have others driving the vehicle more often than the participant does on a weekly basis).

17. Are you an identical twin? YES_____ NO_____

If yes, Does your twin live in your household? YES _____ NO _____

If no, Would you be willing to agree not to let your twin drive the vehicle for the duration of the study?

YES _____ NO _____

Criterion: Identical twins who share housing are not enrolled due to difficulties with driver identification. If participants have a twin, not living with them, they agree to not allow the twin to drive the vehicle at any time during the study.

18. Do you live in the Front Range region of Colorado?

YES _____ NO _____

If no, where do you live? _____

We have installation facilities in Longmont, CO. Are you willing to bring the vehicle to the facility for instrumentation?

YES _____ NO _____

Criterion: Must live or work in the Front Range area of CO area and be willing to bring the vehicle to the agreed upon installation site.

19. Do you plan to stay in this area over the next 12 months? YES_____ NO_____

Criterion: Must plan to reside in study area for duration of study instrumentation.

20. Do you drive in areas where videotaping is not allowed, for example, military installations?

YES _____ NO _____

Notes:_____

Criterion: Cannot drive in areas where videotaping is not allowed.

We need to ask a few questions about your medical history…

Do you have a history of any of the following medical conditions? If yes, please explain.

21. Any Head Injury, Stroke, or illness or disease affecting the Brain?

YES _____ NO _____

If yes, please explain:_____

Cannot have a history of brain damage from stroke, tumor, head injury, recent concussion, or disease or infection of the brain.

22. Current respiratory disorder/disease or any condition which requires oxygen?

YES _____ NO _____ Notes:_____

Cannot have current respiratory disorder/disease or disorder/disease requiring oxygen.

23. Any epileptic seizures or lapses of consciousness within the past twelve months?

YES _____ NO _____ Notes:_____

Cannot have had an epileptic seizure or lapse of consciousness within the past 12 months.

24. Current problems with inner ear problems, dizziness, vertigo, or balance problems?
YES _____ NO _____

Cannot have current problems with inner ear problems, dizziness, vertigo, or balance problems.

25. Are you recovering from any major surgery or illness within the past six months, including any eye procedure which limits how much you may drive? YES _____ NO _____

If yes, explain:_____

Cannot be suffering from any condition which may limit how much they drive. For example someone going through or beginning chemo or radiation treatments would not be a good candidate for fear of relapse or worsening condition.

26. Do you anticipate any life event during the next six months which may alter your normal driving pattern, causing you to drive less? For example, an upcoming surgery, having a baby, going out of town for an extended period of time, a major illness, etc.

YES _____ NO _____

Notes:_____

Must not anticipate any life event during the next 6 months (including eye procedures) which would alter their normal driving habits/patterns/frequency for more than a week. (going on vacation for one week is acceptable, a minor procedure that only affects them for a few days is ok, etc)

27. You will be asked to drive without sunglasses when safe to do so. Will this present a problem should you be eligible to participate?

Yes _____
No _____

Do you wear eyeglasses that tint or darken in the sunlight while sitting inside a vehicle?

Yes _____
No _____

Criterion: Must be able to drive without sunglasses or w/o lenses that darken while inside a vehicle.

28. If selected to participate, you will be asked to provide mouth swabs and mail them, every week, to a lab in a stamped envelope we will provide. Would you have any problem complying with these instructions?

NOTE: If samples are not sent as instructed on the agreed upon schedule, you may be dropped from the study.

YES _____ NO _____

Comments, if any: _____

Must be able to provide and mail mouth swabs in a timely manner.

How did you hear about this project? _____

Recruiting Others:

Do you know anyone else with that may be interested in hearing about this study?
If yes, may we send you the information so you can forward it to them? (Or they can provide our phone #, email, website address to others; we will be happy to speak to anyone interested in hearing more)

Do you prefer we send you the info by Email: _____ or USPS mail (address):_____

If Eligible:
Name: _____
Availability: _____
Home Phone #: _____ Cell#_____ Work #_____
We encourage you to read a copy of the Informed Consent prior to coming in for your scheduled appointment. Please review it ahead of time and contact us with any questions or concerns. You will be asked to read & sign a copy of this document upon arrival at VTTI prior to participating. Do not bring this document with you to the appointment; we simply ask for you to review the document ahead of time and to let us know you received it. Do you prefer we send as an email attachment or by USPS?
E-mail or mailing address: _____
Scheduled on (date & time):_____
Availability: _____
Town or city you live & approximate travel time to Denver._____

Would you like to be contacted for future studies? Yes: _____No: _____

If yes, collect the following:

Last Name: _____ First Name: _____
Y.O.B. _____
Home Phone #: _____ Cell#_____ Work #_____
Town or city: _____ State: _____

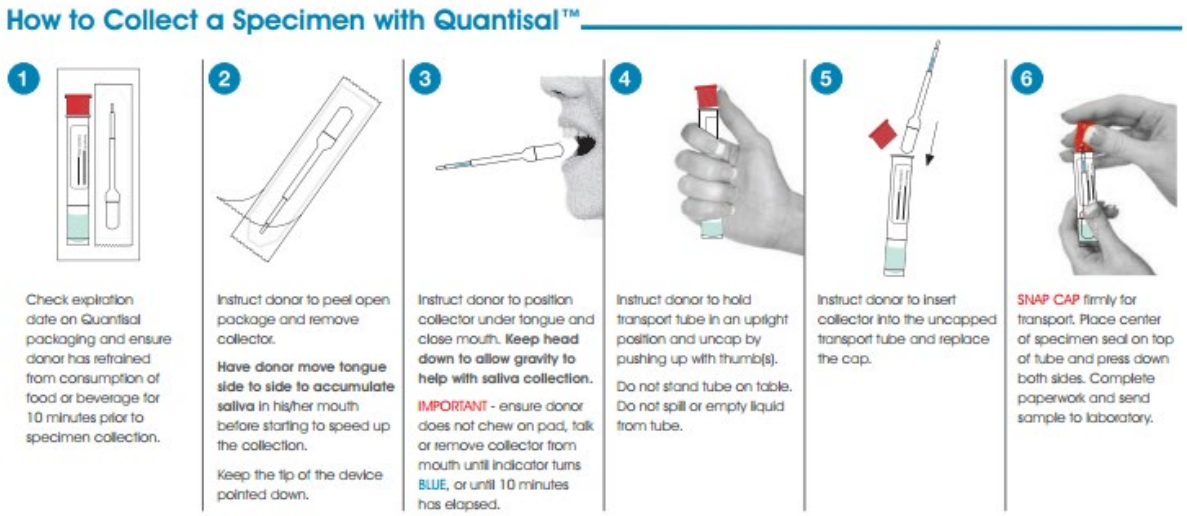
Specialty Driver's License_____
if CDL, endorsements/restrictions_____
Make and Model of Primary Vehicle (light) _____**If Ineligible:**
May we retain your information in case you may be eligible for other studies in the future?
____ *Yes* _____ *No*
If no,
Thank you so much for your time today. Let me remind you that your contact information, as well as any additional information you may have provided during our conversation, will be removed from our database.

If yes,
Thank you so much for your time today and your interest in being contacted for future studies. Please allow me to confirm that the contact information we have for you is the best way to get in touch with you.
Name: _____
Home Phone #: _____ Cell#_____ Work #_____
E-mail or mailing address: _____

APPENDIX B. ORAL FLUID TESTING PROCEDURE

For this study you will be asked to perform a weekly oral fluid drug test prior to a drive. This document provides you with information on study procedures and how to successfully complete the collection. You will specifically be using the Quantisal™ Oral Fluid Collection Device.

1. **Select your trip.** Once a week, you will be asked to complete the oral fluid drug test at the beginning of your trip. We ask that you anticipate a trip of 15 minutes or longer. Also, try to randomize the time of day and day of the week when you take this weekly test. For example, do not take every test on a Tuesday afternoon. Also, you may want to vary trips based on how recently you inhaled or consumed marijuana. As a condition of participation, remember that you are agreeing to not specifically drive under the influence of marijuana as a result of your participation in this study.
2. **Turn on the vehicle** (but do NOT start driving). The vehicle needs to be turned on in order for the data collection equipment to begin working.
3. **Take the oral fluid device out of the pre-arranged package.** This package will contain the drug collection device, pre-stamped envelope, and sticker.
4. **Provide an oral fluid sample.** While seated normally on the driver-side of the vehicle, please take the oral fluid drug test. Specific instructions are provided below. Instructions are also provided on the packaging of the oral fluid collection device.



5. **Place the sticker on the transport tube.** Place the provided sticker cleanly onto the transport tube so that all writing can be read. Again, make sure the cap is securely snapped onto the tube.
6. **Show the sticker to the miniDAS camera.** Please show the driver-view camera the sticker after it has been placed on the transport tube. As shown to the right, please place the test tube, with the sticker facing the miniDAS, approximately one foot away from the camera. This will confirm the time of the test.
7. **Place the labeled transport tube into the stamped envelope.** Seal the envelope once the oral fluid collection device
8. **Mail the sealed envelope within 24 hours of taking the test.**
9. **Please contact the research team with any questions.**

APPENDIX C. SELF-REPORTED DRUG USE JOURNAL DATA ELEMENTS

Variable	Description
MJ Time	Participant reported cannabis use time
MJ Time of day	Participant reported cannabis use time of day
MJ Type	Participant reported cannabis use drug type
MJ Intake	Participant reported cannabis use intake method
MJ Dosage (mg)	Participant reported cannabis use intake dosage
MJ % THC Content	Participant reported cannabis use % THC content
MJ Location	Participant reported cannabis use location
MJ Drove w/in 2hrs	Participant reported driving within 2 hours of reported use
MJ # of inhalations	Participant reported cannabis inhalations
MJ Device	Participant reported cannabis smoking device
MJ Form	Participant reported cannabis form
MJ Strain	Participant reported cannabis strain
MJ # of bowl packs	Participant reported cannabis # of bowl pack(s) smoked
MJ # of joints	Participant reported cannabis # of joint(s) smoked
MJ 2 Intake	Participant reported 2nd cannabis type used
MJ 2 Digestion	Participant reported 2nd cannabis type digestion method
MJ 2 Drove w/in 2hrs	Participant reported driving within 2 hours of reported use
Drug 1 Time	Participant reported other drug 1 use time
Drug 1 Time of Day	Participant reported other drug 1 use time of day
Drug 1 Type	Participant reported other drug 1 use type
Drug 1 Alcohol Type	If drug 1 is alcohol, the alcohol type consumed (e.g., beer, liquor)
Drug 1 Alcohol Dose	If drug 1 is alcohol, the number of drinks consumed
Drug 1 Name	Participant reported other drug 1 use name
Drug 1 Dose (mg)	Participant reported other drug 1 use intake dosage
Drug 1 Location	Participant reported other drug 1 use location
Drug 1 Drove w/in 2 hrs	Participant reported driving within 2 hours of reported use
Drug 2 Time	Participant reported other drug 2 use time
Drug 2 Time of Day	Participant reported other drug 2 use time of day
Drug 2 Type	Participant reported other drug 2 use type
Drug 2 Name	Participant reported other drug 2 use name
Drug 2 Dose (mg)	Participant reported other drug 2 use intake dosage
Drug 2 Location	Participant reported other drug 2 use location

APPENDIX D. CHARACTERIZED EVENTS OF INTEREST METADATA

Variable ID	Definition
FileID	Identifier for trip file in database
VehicleID	Identifier for vehicle in database
ParticipantID	Identifier for participant in database
TripTimestamp	Timestamp in which trip started
TripLength	Length of the trip
SpecimenID	Identifier for the drug test specimen
SpecimenRxTimestamp	Timestamp when the drug test was received
SpecimenTripTimestamp	Timestamp of when the drug test recording took place
SpecimenTripNotes	Notes regarding the specimen
TimeSinceLastDrugTest	Time in seconds when last drug test was taken
TimeStampSinceLastDrugTest	Timestamp when last drug test was taken
NumOfTripsSinceLastDrugTest	Number of trips taken since last drug test
TotalNumOfTrips	Total number of trips participant had during study
TotalTripDuration	Total trip duration in seconds participant had during study
FirstTripTimestamp	First trip participant had during study
LastTripTimestamp	Last trip participant had during study
TotalNumOfTripsWithDrugTests	Total no. of trips participant had with verified drug test
NumOfTriggersInTrip	Number of kinematic triggers in this particular trip
PeakNegYawRate	Peak negative yaw rate
PeakNegLongAccel	Peak negative longitudinal acceleration
PeakNegLatAccel	Peak negative lateral acceleration
PeakPosLatAccel	Peak positive lateral acceleration
PeakPosLongAccel	Peak positive longitudinal acceleration
PeakPosYawRate	Peak positive yaw rate
TotalNumOfTriggers	Total number of triggers participant had during study
Alcohol mg/dL	Drug test result Alcohol value
THC	Drug test THC value
THC-COOH	Drug test THC-COOH value
Cocaine	Drug test Cocaine value
BZE	Drug test BZE value
AMP	Drug test Amphetamines value

Variable ID	Definition
METH	Drug test Methamphetamines value
Morphine	Drug test Morphine value
Codeine	Drug test Codeine value
6-AM	Drug test 6-AM value
HYC	Drug test HYC value
HYM	Drug test HYM value
OXYC	Drug test OXYC value
OXYM	Drug test OXYM value
PCP	Drug test PCP value
SpeedLimit	Speed limit of event
StartTimestamp	Start timestamp of the speed limit
SpeedMax	Maximum speed of the trip
SpeedMin	Minimum speed of the trip
SpeedMean	Average speed of the trip
SpeedStdev	Standard deviation (SD) of speed of the trip
DecelMax	Maximum acceleration of stopping speed phase region
DecldMin	Minimum acceleration of stopping speed phase region
DecelMean	Average acceleration of stopping speed phase region
DecelStdev	SD of acceleration of stopping speed phase region
SpeedLimitDeltaMax	Maximum speed difference between the driver's speed and the speed limit of the roadway
SpeedLimitDeltaMin	Minimum speed difference between the driver's speed and the speed limit of the roadway
SpeedLimitDeltaMean	Average speed difference between the driver's speed and the speed limit of the roadway
SpeedLimitDeltaStdev	SD of speed difference between the driver's speed and the speed limit of the roadway
RightLaneDistanceMax	Maximum distance from center of vehicle to right lane
RightLaneDistanceMin	Minimum distance from center of vehicle to right lane
RightLaneDistanceMean	Average distance from center of vehicle to right lane
RightLaneDistanceStdev	SD of distance from center of vehicle to right lane

APPENDIX E. EVENT TYPE DEFINITIONS

Event Type Category	*Event Type Definitions*	*Examples and Hints*
Crash	Any contact that the subject vehicle has with an object, either moving or fixed, at any speed. Also includes non-premeditated departures of the roadway where at least one tire leaves the paved or intended travel surface of the road. For motorcycles, this also includes any contact between the ground and the bike (other than tires) or ground and rider (other than foot). Events classified as Crashes generally undergo further analysis.	Includes contact with other vehicles, roadside barriers (including curbs), objects on or off of the roadway, pedestrians, cyclists, or animals. Roadway departures resulting from evasive maneuvers are considered non-premeditated and are also classified as crashes.

Event Type Category	*Event Type Definitions*	*Examples and Hints*
Near-Crash	Any circumstance that requires a rapid evasive maneuver by the subject vehicle or any other vehicle, pedestrian, cyclist, or animal to avoid a crash. Near Crashes must meet the following four criteria: 1. Not a Crash. The vehicle must not make contact with any object, moving or fixed, and the maneuver must not result in a road departure. 2. Not pre-meditated. The maneuver performed by the subject must not be pre-meditated. This criterion does not rule out Near Crashes caused by unexpected events experienced during a pre-meditated maneuver (e.g., a premeditated aggressive lane change resulting in a conflict with an unseen vehicle in the adjacent lane that requires a rapid evasive maneuver by one of the vehicles). 3. Evasion required. An evasive maneuver to avoid a crash was required on the part of either the subject or another vehicle, pedestrian, animal, etc. An evasive maneuver is defined as steering, braking, accelerating, or combination of control inputs that is performed to avoid a potential crash. 4. Rapidity required. The required evasive maneuver must also require rapidity. Rapidity refers to the swiftness of the response required given the amount of time from the beginning of the subject's reaction and the potential time of impact.	Evasive maneuvers can occur with varying degrees of severity and thus will not always seem extreme. Also, evasive maneuvers are sometimes made that are greater in severity that what is really required to avoid a collision. The Near Crash classification is concerned with the type of maneuver that is required, not the type of maneuver that is made. If the driver over-reacts with a rapid maneuver when a less severe maneuver would have been sufficient, the event would NOT be a Near Crash unless the evasive maneuver itself contributed further to the event (e.g., leading to a loss of control or creating a new conflict with a following vehicle). To distinguish between a Near Crash and Crash Relevant conflict, the deciding factor is the amount of time necessary for the driver to avoid a crash. A braking evasive maneuver reaching -0.3g can be a near crash if the object being avoided is extremely close, whereas a brake reaching -0.8g performed 20 meters away might not meet the rapidity requirement. The required rapidity and urgency depends on a combination of several factors, including proximity, relative speeds, trajectories, and other environmental factors. For light vehicles, a good guideline for determining Near Crashes is a less-than-2-second "Time to Collision" measurement. For example, if the subject is braking behind a vehicle that is 10 meters away and the subject is travelling 6 meters per second faster than the lead vehicle, then there is less than 2 seconds of "time to collision".

Event Type Category	*Event Type Definitions*	*Examples and Hints*
		However not all Time to Collision measurements that are less than two seconds are guaranteed to be Near Crashes. Other vehicle types (e.g., trucks and buses) may require a different guideline. Pre-meditated maneuvers can also lead to a Near Crash if the maneuver creates a new or more urgent situation. For example, the subject maneuvers around a speed bump coming close to a parked vehicle and mid-maneuver the parked vehicle unexpectedly begins to pull into the roadway nearly striking the subject and forcing a rapid evasive maneuver. Or, the subject intentionally takes an aggressive left turn and loses traction or mistakenly over-steers causing a conflict with oncoming vehicles on the new roadway.

Event Type Category	***Event Type Definitions***	***Examples and Hints***
Crash-Relevant	Any circumstance that requires an evasive maneuver on the part of the subject vehicle or any other vehicle, pedestrian, cyclist, or animal that is less urgent than a rapid evasive maneuver (as defined above in Near Crash), but greater in urgency than a "normal maneuver" to avoid a crash. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs. Crash Relevant Conflicts must meet the following four criteria: 1. Not a Crash. The vehicle must not make contact with any object, moving or fixed, and the maneuver must not result in a road departure. 2. Not pre-meditated. The maneuver performed by the subject must not be pre-meditated. This criterion does not rule out Crash Relevant Conflicts caused by unexpected events experienced during a pre-meditated maneuver (e.g., a premeditated aggressive lane change resulting in a conflict with an unseen vehicle in the adjacent lane that requires an non-rapid evasive maneuver by one of the vehicles). 3. Evasion required. An evasive maneuver to avoid a crash was required on the part of either the subject or another vehicle, pedestrian, animal, etc. An evasive maneuver is defined as steering, braking, accelerating, or combination of control inputs that is performed to avoid a potential crash.	Ex. Driver loses control of vehicle in the snow or rain, but regains control with little risk of impact and does not rotate more than 30 degree in either direction. Any conflict with another vehicle, object, pedestrian, etc. that requires a response from the involved parties but the response required is not rapid.

Event Type Category	*Event Type Definitions*	*Examples and Hints*
	4. Rapidity NOT required. The required evasive maneuver must also require rapidity. Rapidity refers to the swiftness of the response required given the amount of time from the beginning of the subject's reaction to the potential time of impact.	
Non-Conflict	Any incident or maneuver that is within the bounds of "normal" driving behaviors and scenarios and is accurately represented by the time series data that created the flagged. The driver may react to situational conditions and events, but the reaction is not evasive and the situation does not place the subject or other involved parties at higher-than-normal risk. Non-Conflict events would not meet the first, third, or fourth criteria listed for a near crash (not a crash, no evasive maneuver is required, maneuver is not required to be rapid). Non-Conflict events may be either pre-meditated or non-premeditated.	Non-Conflict events would not meet the first, third, or fourth criteria listed for a near crash (not a crash, no evasive maneuver is required, maneuver is not required to be rapid). Non-Conflict events may be either pre-meditated or non-premeditated A "normal maneuver" refers to the vast majority of control inputs experienced in the course of driving such as a gradual braking in traffic. Non-conflict events may include hard braking by a driver in the absence of a specific crash threat or a high swerve value from a lane change not resulting in any loss-of-control, lane departure, or proximity to other vehicles. While such situations sometimes reflect at-risk driving habits and styles, they do not result in a discernible crash-relevant conflict. Events resulting from normal driving over normal roadway infrastructure are

Event Type Category	*Event Type Definitions*	*Examples and Hints*
		also classified as Non-Conflict. (e.g., speed bumps, parking lot thresholds, bridge seams, etc.).
Non-subject Conflict	Any incident that gets captured on video, crash-relevant, near-crash, or crash, that does not involve the subject driver.	
Invalid	Any flagged event that resulted from spurious, illogical, or otherwise incorrect sensor readings.	
No Video/Other	Any flagged event that cannot be verified due to missing video. In these events, either the driver ID cannot be confirmed or the Event Severity cannot be assessed because the required video is missing. Keep in mind that a missing video does not automatically mean that the Event Severity cannot be determined. If after careful inspection of the event using the videos that are available, Event Severity is still unknown, then this option can be used.	
Further Review	Any flagged event that the reductionist finds too complex or confusing to be able to determine if it is a SCE or not. This option should not be used for uncertainty between levels of Event Severity (e.g. Near	

Event Type Category	*Event Type Definitions*	*Examples and Hints*
	Crash vs. Crash Relevant), in which case it is better to code up.	

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