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Connected Vehicle Weather Data for Operation of Rural Variable Speed Limit Corridors

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ABSTRACT

Each year thousands of people are killed and injured due to weather-related crashes. While outcomes of many incidents could not be changed, many accidents could be avoided through implementation of intelligent transportation systems. Road Weather Information Systems (RWIS) have been adopted by transportation agencies to provide better information about the impact of current weather conditions on the roadway. However, RWIS can only provide data for a specific location, and there is a need for continuous road weather condition reporting. In response, the Connected Vehicle Initiative proposed using vehicles to communicate current roadway conditions, especially in inclement weather events. The advanced road condition data would allow travelers to better prepare for road conditions. This report illustrates efforts from the University of Wyoming to collect and analyze vehicle CAN-Bus vehicle data to extrapolate road conditions and determine usefulness of this data in providing real-time, weather information acceptable as input to Variable Speed Limit (VSL) algorithms. The results of this research indicate that standardization of vehicle data between vehicle makes and models is required. In addition, current vehicle data manipulation programs are not adequate for providing segmented road weather condition data need for implementation into VSL algorithms.

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EXECUTIVE SUMMARY

Introduction

Over the past decades, technological advancements have been made in all facets of life, including transportation. Transportation technology efforts have been guided through the implementation of Intelligent Transport Systems (ITS) in both urban and rural transportation environments.

Rural and urban areas experience different issues and challenges that require distinctly different transportation planning, design, and operational strategies. Specifically in transportation technology, urban area planners tend to focus their resources and time on improving the mobility and efficiency of roadway systems and alternative transportation systems. However, in rural areas, the need for mobility and efficiency is less an issue than improved safety of rural highways.

One of the largest challenges faced by rural transportation agencies is the impact adverse weather events have on rural highways. The higher speeds, greater distances between destinations, differences in trip purpose, lower traffic volume, and isolated roadway segments with limited access increase the need for ITSs aimed at improving safety on rural networks.

Currently, transportation agencies are implementing Road Weather Information Systems (RWIS) that utilize a roadside environmental sensor that collects point specific weather data. While this information is proving to be highly useful for providing traveler warnings and routing maintenance personnel, the data gathered is not sufficient in areas with isolated weather events, such as Wyoming. In addition, the RWIS stations are expensive to implement and maintain; therefore, many agencies are seeking a solution that could replace the existing system and provide cost-effective and continuous weather data.

The concepts of a "connected environment" and connected vehicles were introduced by the USDOT Connected Vehicle environment. Through this initiative, it is possible that vehicle data from the vehicles' CAN-Bus can be collected and then communicated to affiliated systems, such as road weather condition reporting systems.

The short-term goal of this research is to determine feasibility of collecting and analyzing connected vehicle data to evaluate road weather conditions. In the long-term, the goal of this research is to assist the creation of a real-time connected vehicle road weather condition reporting system that will increase the reliability of VSL corridors, efficiency and effectiveness of winter road maintenance, and safety of the traveling public.

State of Practice Literature Review

The purpose of completing a comprehensive state of practice literature review was to guide research efforts and strategies. Currently there is limited research in detecting road weather conditions through a vehicle's CAN-Bus and communicating that data for use in safety, mobility, and efficiency applications. Significantly more research has been completed regarding intelligent transportation systems, connected vehicles, and road weather management. This broad information is valuable for identifying research opportunities, challenges, constraints, and avenues with respect to connected vehicle applications for road weather management.

The literature review started with an overview of ITS, discussing the processes behind ITS implementation, the history of ITS, efforts made in establishing ITS architecture and standards, existing ITS applications and their benefits, and the future of ITS. Next, a large component of ITS--connected vehicles, was discussed in detail. Institutional issues for CV technology were introduced, the history of CV applications reviewed, and communication technology for CV implementation explained. In addition, current CV applications and test beds were presented with a summary of the benefits and perceived future of CV technology. Then, a brief overview of existing Road Weather Management Strategies were discussed. Specifically, RWIS systems and other detection mechanisms were explained and specific Weather Responsive Traffic Management strategies were outlined. Finally, current research on connected vehicle road weather condition applications was discussed. The three primary components of most existing systems were split and details were provided for each: collection of data, communication or transfer of data, and processing and analysis of data, before current research and implementation efforts were described.

Research Methodology

This research considers rural corridors with variable speed limits (VSLs) implemented due to a high risk of adverse weather conditions. These VSL corridors require real-time road condition data to set speed limits that accurately reflect current road conditions. Currently, this weather information is gathered by RWIS, maintenance personnel, or citizen reporting programs. The purpose of this research is to evaluate the value in using connected vehicle data to supplement or replace RWIS data in VSL decision making algorithms. This research is funded by the Mountain-Plains Consortium.
The research objectives follow:

1. Determine the most effective technology for collecting connected vehicle data from vehicles' CAN-Bus.
2. Investigate the reliability and practicality of ascertaining segmented road condition data from NCAR's Pikalert system.
3. Determine whether connected vehicle CAN-Bus data is suitable for supporting the data requirements of VSL decision-making algorithms.
4. Make recommendations and identify future research needs regarding the prospective use of connected vehicle data in rural roadway corridors subject to significant weather events.

To evaluate these research objectives, a research vehicle was equipped with connected vehicle technology and vehicle data were collected during storm events along a rural VSL corridor. The raw vehicle data were used as input into various algorithms, including NCAR's Vehicle Data Translator (VDT) or Pikalert system, to determine the usefulness of the data as weather observations. The resulting vehicle data were compared with local RWIS data during the storm to determine the usefulness and estimated accuracy of the connected vehicle data for setting variable speed limits. This research does not include real-time data analysis; vehicle data will be collected during winter storm events, then aggregated and analyzed subsequently.

Data Collection

Three steps were followed to create an operational system for collecting and analyzing vehicle data in adverse weather events:

1. Select an adequate vehicle interface and data collection mechanism.
2. Collect vehicle data during storm events using the selected vehicle interface and data collection mechanism.
3. Collect RWIS data corresponding to each test trip for comparison.

The tasks were completed by testing a variety of open-source and off-the-shelf vehicle interfaces and data collection applications and programs. After testing, the OpenXC, CrossChasm C5 was selected in conjunction with an android tablet and the OpenXC Enabler application. Once data collection methods were finalized, 16 test trips were made to evaluate the suitability of using vehicle data to ascertain segmented road weather data.

Data Visualization

The data analysis and visualization for this report is split into three primary components: NCAR's Pikalert analysis, MatLab data visualization, and GIS data visualization. Due to difficulty using NCAR's Pikalert system, the primary analysis was completed qualitatively using the MatLab and GIS data visual representations. Finally, a qualitative analysis combining the vehicle data and RWIS data is provided.

After evaluating the RWIS data for each trip, all vehicle data were implemented into MatLab to provide numeric and graphical representations of each trip considering six vehicle parameters: Vehicle Speed, Engine Speed, Accelerometer Pedal Status, Transmission Torque, Steering Wheel Angle, and Windshield Wiper Status. The Matlab analysis allowed a basis for comparing average vehicle parameter values for each test trip, which provided insight into the impact weather conditions could have on each parameter. In addition, the GIS analysis allowed for better visualization of each parameter along the trip route and identified data collection problems, including periods without data collection and inaccurate GPS readings.

Conclusions and Recommendations

Adverse weather conditions have a significant impact on roadway conditions, vehicle performance, and driver behavior, especially in rural areas. Intelligent Transportation System programs have implemented various applications, such as RWIS, to address dangerous situations caused by adverse weather conditions. Many of these technologically-advanced systems are improving the conditions of rural highways and interstates. In addition, the rise of connected vehicle technology offers a new method for addressing adverse weather conditions. Connected vehicle technology can provide continuous real-time information to better inform drivers and transportation management of current weather and road conditions.

Without standardized vehicle data formats from all vehicles, off-the-shelf CAN-Bus technology is not adequate for collecting a complete and robust vehicle data set. Federal requirements are addressing this issue, however, the circumstances make proactive and advanced research difficult. Even with an adequate data set, this research identifies some concern with translating vehicle CAN-Bus data into mobile weather information. The practicality and usability of NCAR's Pikalert system must be evaluated further to fully comprehend the potential for segmented road weather condition data. The current system appears to be successful in producing and distributing road condition advisories and warnings, but success in producing raw segmented road condition data is unclear. Further, the next steps should be to evaluate complete vehicle data sets during adverse weather events and evaluate the data collection process and Pikalert system to a greater extent.

Due to the current impracticality of collecting firmware for every vehicle make and model, the use of external sensors should be considered for gathering mobile data. Mobile weather sensors present cost-effective solutions for implementing connected vehicle technologies on a fleet of vehicles, regardless of their make or model. These vehicle sensors can determine the vehicle's speed, windshield wiper status, and tire friction, as well as basic atmospheric data, such as ambient temperature, dew point temperature, and barometric pressure.

Further research should evaluate how external and internal vehicle sensors could replace data from a fully-equipped CAN-Bus reader in the interim period before CAN-Bus data standardization is mandated and implemented. Questions to address include: Would these sensors allow more or less data collection? Is their performance as reliable as data from CAN-Bus readers? Would the benefits of uniform data collection hardware and software for every vehicle outweigh any potential data gaps from not collecting CAN-Bus data?

1. INTRODUCTION

Over the past few decades, technological advances have shaped our world and created new opportunities for people to be connected and access massive amounts of information. Smartphones, tablet computers, the Internet, and many other technologies have brought us into the 21st century. These products are used in all facets of everyday life, from paying bills with the click of a button, rather than writing a check, to scanning a cellphone boarding pass instead of printing out the ticket.

Technological advances also have been made in transportation applications. From driverless trains to variable message signs and enroute travel time estimates, transportation has benefitted from advances in technology. However, many of the transportation advances are focused in urban areas rather than in rural areas. While the number of affected drivers may be limited in rural settings in comparison to urban settings, it is crucial that transportation technology also extends to these areas.

Sections 1.1–1.8 provide an introduction to the research conducted for this report.

1.1 Rural versus Urban Transportation Technology

Rural and urban areas experience different issues and challenges that require distinctly different transportation planning, design, and operational strategies. Specifically regarding transportation technology, urban area planners tend to focus their resources and time on improving the mobility and efficiency of roadway systems and alternative transportation systems. However, in rural areas, the need for mobility and efficiency is less an issue than improved safety of rural highways.

The U.S. Department of Transportation's (USDOT) Research and Innovative Technology Administration (RITA) recognizes a number of challenges faced by rural transportation networks. Among these challenges are the safety and operation of rural highway networks (Albert, 2013). The Federal Highway Administration (FHWA) determined that 80 percent of the national road network is comprised of rural roads (USDOT FHWA, 2012). As opposed to urban networks, rural transportation systems provide passage for a wide variety of drivers and vehicles, ranging from commercial, commuter, and personal travelers.

Rural roadways typically experience greater issues with driver expectancy due to severe alignment features and less vehicle traffic, which can cause a decrease in driver attentiveness. The probability of unexpected obstacles along a roadway increases significantly on rural roadways. Because driving on the rural roadways is often done at high speeds, obstacles have the potential to greatly affect the safety of travelers (Albert, 2013). Urban roadways experience a larger number of vehicle crashes than rural roadways, but rural crashes generally are more severe.

One category of obstacles that can have a considerable effect on the safety of rural highways includes poor weather and visibility. In rural areas, drivers typically take longer trips when compared to urban areas. In urban environments, drivers have a greater probability of maintaining caution throughout a trip in inclement weather, due to the short distance. In rural areas, drivers may begin their trips with caution, but over the length of the trip, drivers have a high probability of growing immune to weather conditions and taking more risks, thereby causing more crashes.

Each year more than 7,400 people are killed, and over 673,000 people are injured due to weather-related crashes on highways (Pisano, Lynette, & Michael). While the outcomes of some incidents would not be changed, many of the incidents could have been avoided through implementation of road weather transportation technology.

1.2 Weather Impacts on Rural Highways

Weather has a significant impact on rural highways throughout the world, but especially on highways in areas that experience frequent adverse weather conditions. These adverse weather conditions affect the mobility, safety, and efficiency of roadways, travelers, and oftentimes surrounding businesses and agencies. The mobility of rural highways hindered in poor weather conditions has a widespread effect on commuter, commercial, and personal travelers. Table 1.1 provides a variety of ways in which poor weather can adversely impact the mobility, safety, and efficiency of rural highways.

Table 1.1 Impacts of Adverse Weather on Rural Highway Networks

Mobility	Speed Reductions Non-Reoccurring Delay Poor Vehicle Performance Reduced Roadway Capacity
Safety	Causation or Partial Causation of Serious Crashes Delay Emergency Response Time
Efficiency	Business and Agency Shutdowns Decrease in Retail Sales Significant Reductions in Roadway LOS Increased Operating Costs Delay in Commercial Delivery Schedules Increased Amount and Frequency of Roadway Repairs

As shown in Table 1.1, adverse weather significantly impacts the mobility, safety, and efficiency of roadway networks. Excessive snow and ice can cause increased maintenance and operating costs to clear, close, re-open, and treat affected roadways. Heavy winds, dense fog, and heavy precipitation have the potential to cause and play a role in crashes that result in fatalities, injuries, property damage, and inconvenience. Adverse weather also can affect a vehicle's performance by reducing traction, stability, and maneuverability.

Road closures affect retail sales and delay commercial deliveries, costing businesses crucial time and money. According to the FHWA Office of Highway Policy Information, government and local agencies spend nearly $2.3 billion on snow and ice removal and control operations each year. In some areas, a one day statewide highway network shut-down could cause up to $75 million in lost time, productivity, and wages (USDOT FHWA, n.d.).

Transportation safety in rural areas is an enormous challenge faced by transportation agencies. Over the past decade, improvements have been made to the rural transportation network, incorporating various forms of technology to create a safer and more reliable highway system.

1.3 Existing Transportation Technology on Rural Highways

Urban transportation networks are now required to uphold a certain level of transportation technology to handle heavy loads of traffic and meet critical mobility and efficiency requirements. It hasn't been until recently that transportation technology has spread to rural networks to meet specific challenges, such as adverse weather.

One of the largest improvements in rural transportation technology is the widespread use of Road Weather Information Stations or RWIS. RWIS have been adopted by both federal and state transportation agencies to provide travelers better information regarding the impact of current weather conditions on the roadway. Weather information is gathered by stationary RWIS systems (Arizona Department of Transportation RWIS station shown in Figure 1.1), which are positioned along rural highways. This information typically is sent back to the regional Traffic Management Center (TMC) where it is communicated to travelers on different platforms, including Dynamic Message Signs (DMS) and agency websites.

Figure 1.1 ADOT RWIS

Weather data are updated regularly and used by the TMC to set Variable Speed Limits (VSL) and provide information to drivers, enabling them to plan their trip before entering the roadway. RWIS provides useful information for travelers, commercial agencies, and transportation departments. However, weather data collected from RWIS systems do not fully communicate the state of the roadway because agencies cannot afford to implement and maintain weather stations at frequent intervals along the roadway. Typically, stations are separated by five to ten miles, and road condition data between the stations are interpolated. However, severe alignment features, variant roadway materials, changes in elevation, and localized weather events cause limited reliability and imparts doubt in travelers.

1.4 New Opportunities in Rural Highway Management

Responding to the increasing need for a more reliable system to detect the state of rural roadways, the Connected Vehicles Initiative presented a new concept that could revolutionize the current Rural Highway Management System.

The Connected Vehicles Initiative introduced technology in which vehicles communicate the current roadway conditions directly to the TMC to be analyzed and redistributed. Rather than relying on stationary RWIS systems that only detect local roadway conditions at specific segments of a route, gathering information from vehicle computers could be the answer for providing drivers more accurate and useful road weather information. Travelers could then better prepare for the current and predicted roadway conditions, and in turn, may behave differently or make alternative decisions relating to taking their trip or determining their trip route.

1.5 Introduction to Connected Vehicles

The Connected Vehicles Initiative is a relatively new concept that provides applications for more advanced connectivity among vehicles and between vehicles and roadside infrastructure. The advanced data collected by the increased connectivity could enable crash prevention; increase safety, mobility, and environmental benefits; and provide continuous and more reliable information to all roadway users (Connected Vehicle, 2015). The opportunities from connecting vehicles are endless, however, technology advances, reliability, liability, and privacy concerns have limited current use. Despite the challenges, the opportunities and advantages of connected vehicles are extremely high and will be further implemented into the transportation network in the next couple of decades.

1.6 Connected Vehicle Applications to Improve Road Condition Reporting on Rural Highways

Connected vehicle applications have been explored and tested in efforts to solve various safety, mobility, and efficiency transportation challenges. One such effort involves using vehicle data to better communicate road weather conditions. Strategically placed RWIS systems can be relatively effective in providing an overview of weather conditions along a route, but RWIS systems are unable to illustrate continuous pavement conditions along a route. A connected vehicle road weather application would allow for continuous road condition reporting along a vehicle's route, thereby providing travelers and transportation agencies continuous real-time road condition data with greater certainty.

A connected vehicle road weather application involves four different components: (1) an on board device (OBD) connected to the vehicle's computer through the vehicle's OBD port; (2) communication between OBD and smart device (such as a smartphone, tablet, or computer); (3) translation of raw vehicle data within the smart device to the Traffic Management Center (TMC); and (4) a series of algorithms used to determine the road weather conditions from the raw vehicle data. Once raw vehicle data is analyzed, segmented road weather data can be generated and used for many different applications including setting variable speed limits, more effectively and efficiently removing and treating snow and ice, and maintaining an effective pavement asset management database. The National Center for Atmospheric Research (NCAR) produced an open-source software program called Pikalert (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011) intended to provide segmented road weather condition data from an analysis of vehicle and ancillary weather data.

1.7 Purpose of Research

This research considers rural corridors with variable speed limits (VSLs) implemented due to a high risk of adverse weather conditions. These VSL corridors require real-time road condition data to set speed limits that accurately reflect current road conditions. This weather information currently is gathered by RWIS, maintenance personnel, or citizen reporting programs. This research evaluates the value of using connected vehicle data to supplement or replace RWIS data in VSL decision-making algorithms. This research is funded by the Mountain-Plains Consortium.

The research objectives are to:

1. Determine the most effective technology for collecting connected vehicle data from vehicles' CAN-Bus.
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3. Determine whether connected vehicle CAN-Bus data are suitable for supporting the data requirements of VSL decision-making algorithms.
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To evaluate these research objectives, a research vehicle was equipped with connected vehicle technology and vehicle data were collected during storm events along a rural VSL corridor. The raw vehicle data were used as input into various algorithms, including NCAR's Vehicle Data Translator (VDT) or Pikalert system, to determine usefulness of the data as weather observations (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011). The resulting vehicle data were compared with local RWIS data during the storm to determine usefulness and estimated accuracy of the connected vehicle data for setting variable speed limits. This research does not include real-time data analysis; vehicle data will be collected during winter storm events, then aggregated and analyzed subsequently.

The short-term goal of this research determines feasibility of collecting and analyzing connected vehicle data to evaluate road weather conditions. In the long-term, the goal of this research is to assist the creation of a real-time connected vehicle road weather condition reporting system, which will increase the reliability of VSL corridors, efficiency and effectiveness of winter road maintenance, and safety of the traveling public.

1.8 Introduction to the Remainder of the Report

The remainder of the report is presented as follows: Section 2: State of Practice Literature Review, Section 3: Research Methodology, Section 4: Data Collection, Section 5: Data Visualization, and Section 6: Conclusions & Recommendations.

2. STATE OF PRACTICE LITERATURE REVIEW

In approaching this research, the initial project phase included a detailed state of practice literature review. Transportation technology is an exciting and emerging topic, however, specific topics, such as the use of connected vehicles in road condition applications, are relatively new with less literature on them. For this reason, the comprehensive literature review began with broad topics such as, Intelligent Transportation Systems (ITS), and narrowed down into a more detailed review of connected vehicle applications related to road condition reporting systems.

The state of practice literature review is organized in the following sections, from broad to more specific and detailed topics:

- 2.1 Intelligent Transportation Systems
- 2.2 Connected Vehicles
- 2.3 Road Weather Management Programs
- 2.4 Connected Vehicle Road Weather Condition Application
- 2.5 Summary of Literature Review

2.1 Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) or Transportation Technology refers to the use of technology in advancing transportation networks to solve safety, mobility, and efficiency problems. One of the primary advantages of ITS is that one can solve mobility and efficiency problems without construction of a larger network. Another advantage is that ITS implementation increases safety of all modes of transportation by decreasing crash frequency and severity.

Sections 2.1.1–2.1.7 will provide an overview of ITS.

2.1.1 Introduction to ITS

Intelligent Transportation Systems (ITS) introduced a revolutionary transportation vision that encompasses real-time travel information for every travel mode. ITS applications also increase roadway through-put with constrained roadway capacity, and provide faster and more efficient incident management in day-to-day vehicle collisions and large-scale evacuations and re-entries. ITS technology is currently in use and implemented by a multitude of disciplines and stakeholders to create safe, efficient, and sustainable transportation (Noyes, 2014).

In the past, transportation was single-disciplined, civil engineers designed roadways and interchanges. They created signal timings and supported the increased use of public transportation. Today, transportation networks are significantly more complex and require support of professionals from many fields with a variety of backgrounds and educations. Transportation network complexity has increased significantly due to increasing demand and limited capacity. Agencies do not have the space to continue adding lanes to freeways and arterials. Many urban areas have already reached their roadway footprint limit, yet more and more drivers use the road each year. ITS programs provided a solution to this problem. Regions adopting ITS strategies have experienced reductions in collisions, reduced congestion, and enhanced emergency management (Noyes, 2014).

2.1.2 Systems Engineering

ITS programs are implemented using *Systems Engineering*, which provides a framework for developing and implementing ITS applications (Noyes, 2014). The FHWA Systems Engineering Handbook defines systems engineering: "Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets user needs (USDOT FHWA, 2007)." The definition of systems engineering is broad and can be interpreted in a variety of ways. For this reason, FHWA provided a series of principles to guide system engineering practice for ITS (USDOT FHWA, 2007).

- **Start with Your Eye on the Finish Line.** In other words, the first steps in implementing an ITS project are to determine the end goal of the project and establish metrics to measure project success.
- **Stakeholder Involvement is Key.** To successfully implement an ITS project, stakeholder involvement is crucial at every step and decision point; systems engineering fundamentally encourages stakeholder involvement to ensure that all requirements and needs are met.
- **Define the Problem before Implementing the Solution.** Often, it is simpler to determine a solution for an ill-defined problem; however, the systems engineering approach encourages the formation of a comprehensive problem definition prior to developing a solution.
- **Delay Technology Choices.** In initial project stages, it is best to follow the systems engineering framework of identifying problems, needs, designs, and solutions without specifically selecting technology due to the dynamic nature of technological advances.
- **Divide and Conquer.** ITS projects are often large and complex and best handled by dividing the large project into manageable components.
- **Connect the Dot.** Traceability or connectivity between the user needs and each step within the design and implementation process is an important concept in systems engineering.

To help engineers understand the systems engineering process, the V-Model (shown in Figure 2.1) was adapted to better fit ITS projects. The left wing shows the initial scope identification based on regional needs; the core of the "V" provides the project definition, implementation, and verification processes; and the right wing shows the maintenance and ultimate retirement of the system (USDOT FHWA, 2007). The V-Model emphasizes the need for cradle-to-grave, project life-cycle consideration.

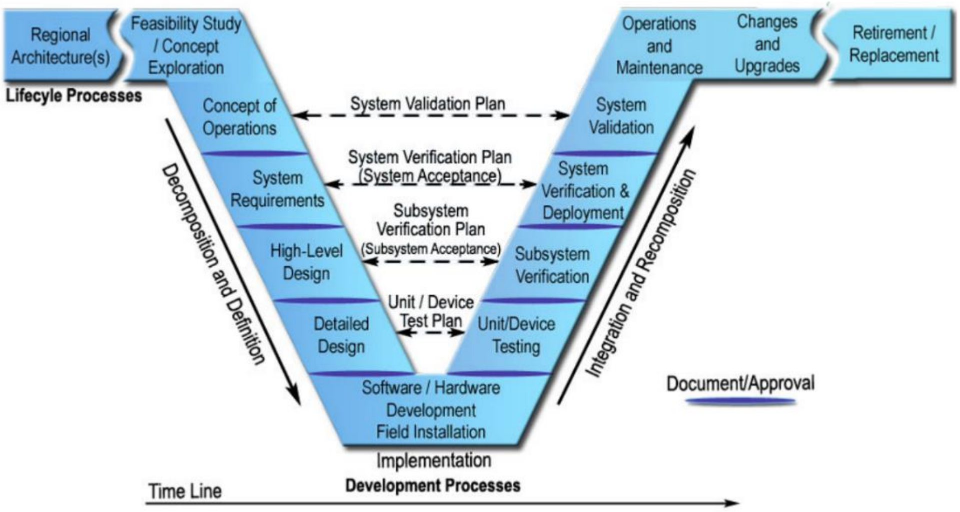


Figure 2.1 ITS Systems Engineering V-Model

The left side of the V-Model indicates broad system needs, requirements, and plans, while the right side shows the specific counterparts to each of those components. A crucial element of systems engineering is ensuring that at each decision point, broad system needs are meeting the end-goal and detailed system components are meeting the broad system needs (USDOT FHWA, 2007).

2.1.3 History of ITS

Over the past 30 years, driver demand on public roads increased by nearly 95%, and the number of public road lane miles increased less than 9% percent (Noyes, 2014). This surge in transportation demand called for a new form of transportation network planning, implementation, and maintenance.

The safety and efficiency of transportation networks have been high priorities in the United States since the mid-1900s, when travel demand started to rise with increasing commuter traffic. Communication and computation technological advances in the 1980s and early 1990s enabled transportation agencies to develop programs that would grow into the ITS applications used today (Noyes, 2014). In 1988, the USDOT’s FHWA created *Mobility 2000,* a working group that focused on developing a national program for transportation technology (Noyes, 2014). The outcome of this working group led to the 1991 *Intermodal Surface Transportation Efficiency Act* (ISTEA) that encouraged the use of new technologies to improve transportation safety, information exchange, system capacity, and travel times (Noyes, 2014). The ISTEA led to development of National and Regional ITS Architecture and standards that provide guidance and support for ITS programs.

In 2012, the surface transportation funding legislation introduced MAP-21, Moving Ahead for Progress in the 21st Century. The MAP-21 legislation transformed the policy and programmatic framework for surface transportation funding, and introduced a performance-based evaluation program (Noyes, 2014). MAP-21 legislation caused many agencies to more seriously consider ITS implementation because ITS systems have the potential to offer greater system efficiencies at smaller capital investments, and are operated through the collection and exchange of performance data, making them highly capable of supporting data-driven, performance-based policies and processes (Noyes, 2014).

MAP-21 legislation requires state and metropolitan transportation agencies to set performance targets and annually report on their progress. To accomplish a systematic approach to setting and recording progress for these goals, states and agencies began creating Regional ITS Architectures, based on the National ITS Architecture, which established the groundwork for ITS project implementation (Noyes, 2014). The following section discusses structure of the National ITS Architecture and briefly reviews Regional ITS Architectures and ITS Standards.

2.1.4 ITS Architecture and Standards

The United States Department of Transportation (USDOT) began developing the National ITS Architecture to support ITS implementation in urban, inter-urban, and rural communities during the mid-1990s in response to the ISTEA (Noyes, 2014). The Architecture includes three layers: (1) Institutional, (2) Transportation, and (3) Communications. The institutional layer outlines program objectives, institutional policies, funding mechanisms, and ensures that user needs are being met. The transportation layer describes both the logical and physical architecture that defines the equipment and service packages needed to implement an ITS program. The communications layer emphasizes the need for system integration and seamless communication between multiple subsystems (Noyes, 2014). Within these three layers, there are five primary components of the National ITS Architecture: (1) User Services, (2) Logical Architecture, (3) Physical Architecture, (4) Equipment Packages, and (5) Service Packages (USDOT). The first component, user services, represents ITS from the perspective of a user, whether the user is an individual traveler or a system operator. The USDOT National Architecture considers thirty-three user services as the foundation of the National Architecture, and grouped those user services into eight bundles (USDOT):

- Travel and Traffic Management
- Public Transportation Management
- Electronic Payment
- Commercial Vehicle Operations
- Emergency Management
- Advanced Vehicle Safety Systems
- Information Management
- Maintenance and Construction Management

The second component of the USDOT National ITS Architecture is the logical architecture. A logical ITS architecture assists transportation agencies in developing and organizing necessary relationships to produce and manage ITS projects. The third component, physical architecture, provides a physical (rather than functional) view of a system (USDOT). The physical architecture provides vague designs representing how the system should be built to provide the required functionality. The physical architecture takes the processes from the logical architecture and creates physical subsystems (USDOT). The final two components are equipment packages and service packages. Both groups function within a subsystem (identified in the logical and physical architectures) to provide an implementable package of hardware and software. Multiple equipment packages make up a service package, which provides implementation design and strategies for addressing specific transportation problems and needs that relate to the identified user services (USDOT).

The National ITS Architecture provides ITS program guidance at the national level and addresses subsystems, technologies, and standards for ITS implementation. Regional ITS architectures, formulated by individual transportation agencies, identify specific plans, programs, goals, and objectives for their region (Noyes, 2014). According to a survey open to all 50 state DOTs, conducted by ITS America, 54 %

of respondents indicated that their department had developed and used a regional or agency specific ITS architecture, and 63 % of state governments have some type if ITS strategy in place (ITS America, 2013). The USDOT's ITS Joint Programs Office (JPO) established the ITS Standards Program to provide clear definitions and standards for all ITS deployments. All private and public agencies implementing ITS deployments are required to follow these standards. The ITS Standards Program works with officials from the American Association of State Highway Transportation Officials (AASHTO), the Institute of Transportation Engineers (ITE), the American Public Transportation Association (APTA), and the Institute of Electrical and Electronics Engineers (IEEE), to formulate technical guidance and requirements for each component of an ITS system (Noyes, 2014).

The formulation of the National ITS and Regional ITS Architectures, combined with the technological standards, aid transportation agencies in implementing ITS programs. The following section provides a concise overview of the existing ITS programs used by state and metropolitan transportation agencies in the United States.

2.1.5 Existing ITS Applications

The purpose of ITS programs are to improve the safety, mobility, efficiency, and environmental impacts of the transportation network. For this reason, all ITS programs and applications strive to meet one or more of these goals. The purpose of this report is not to review every ITS application, but rather to provide a brief introduction to ITS applications currently in use and producing positive impacts. The following ITS applications are discussed:

- Transportation Management Systems
- Freeway Management
- Integrated Corridor Management

Transportation management systems (TMS) can take different forms depending on the size and funding of the implementing agency. TMS can be executed over an entire state or a single location, such as a sports arena or stadium in an urban area. Regardless of size, TMS are expected to implement technology to provide (1) real-time system assessment, (2) pre-determined or real-time strategy determination, (3) strategy execution, and (4) strategy evaluation (Hadi, 2014). To meet these criteria, multiple ITS applications must be implemented and include traffic detectors, closed circuit television (CCTV) cameras, dynamic message signs (DMS), highway advisory radios (HAR), automatic vehicle identification and location (AVI/AVL), and centralized hardware and software at a traffic management center (TMC) (Hadi, 2014).

One component of transportation management systems is freeway management, which increases functionality of freeway systems by reducing congestion, improving safety, and enhancing mobility and reliability. Freeway management systems commonly uses an application called ramp metering to control the rate of vehicles entering a freeway segment (Hadi, 2014). This input control increases the overall throughput of the freeway segment by reducing the density and number of conflicts at the on-ramp. Similarly, traffic safety is improved through reduction in speed variation. After implementing ramp metering in Washington State, the area experienced a 30% reduction in rear-end and sideswipe collisions caused by speed differentials and inappropriate merging actions (Hadi, 2014). Rather than directly affecting a driver's approach to merging onto a freeway, ramp metering decreased the opportunity for a collision by better enabling greater homogeneous traffic conditions.

Another crucial component to freeway management strategies is information dissemination. Providing drivers with advanced warning of downstream congestion allows drivers to choose an alternate route, reduce speeds, or simply recognize a situation ahead. This increased driver awareness prevents secondary crashes caused by inattention and confusion, and reduces the number of at-risk vehicles. Field studies in Europe indicate that between 27 and 44% of drivers diverted to alternate routes when informed of downstream congestion (Hadi, 2014).

Speed harmonization and variable speed limits can provide a valuable alternative for improving traffic safety. Static speed limits are designed to provide speed limits for normal conditions, not considering congestion or weather. In situations with these non-reoccurring delays, variable speed limits provide a constructive tool for increasing safety. Not all variable speed limit installations in the United States are enforceable, but effective implementations have proven to reduce the overall driver speed by five to seven mph, increasing the safety by reducing the frequency and severity of crashes (Hadi, 2014).

Freeway congestion and stopped traffic is the source of many crashes in urban and suburban areas. Drivers often detect decreased traffic speed and attempt to change lanes just upstream of stopped traffic, causing a disturbance in the traffic flow. One ITS application that improves the safety of this situation is freeway queue warnings. These warnings can be static signs with flashing beacons or dynamic messaging signs that inform drivers of downstream queues and the extent of a bottleneck. These queue warning systems can be managed by a traffic management center official viewing CCTV video surveillance of the roadway network, or built-in sensors that automatically turn on the flashing beacons or queue warning message (Hadi, 2014).

Integrated corridor management (ICM) utilizes strategies and technologies to coordinate ITS applications between agencies to increase the overall system benefits including, corridor safety, mobility, and reliability. ICM projects can include interstates, highways, parking facilities, public transportation, and freight facilities (Wallace, 2014). One example of an ICM project is located in San Diego, CA, along I-15. To combat heavy traffic demand and congestion, the San Diego Association of Governments, the California Department of Transportation, the City of San Diego, the City of Escondido, the City of Poway, the Metropolitan Transit System, and the North County Transit District combined forces to implement a variety of ITS applications (Wallace, 2014).

The I-15 corridor’s existing technologies include dynamic route metering, dynamic messaging signs, and variable pricing for managed lanes. New ITS applications include enroute traveler information, pre-trip traveler information, transit signal priority, freeway-coordinated ramp metering, congestion pricing on managed lanes, physical bus priority on arterials, and increased HOV occupancy requirements (Wallace, 2014). Each of these ITS applications were implemented for their potential to increase the safety and mobility of the I-15 corridor.

Today, transportation agencies are hiring professionals to plan and advance their ITS programs for many reasons; however, among the greatest reasons are the incredible safety, efficiency, mobility, and environmental benefits ITS offer.

2.1.6 Benefits of ITS

Often considered the top priority for all transportation agencies, safety is a considerable problem on transportation networks in all transportation modes, and is significantly impacted by ITS programs. Red light running cameras are just one beneficial example of an ITS application that positively affects safety. In some areas, the number of crashes increased with the addition of red light running cameras. On further inspection, the number of rear-end crashes increased and the number of angle and head-on crashes decreased, causing the overall injury severity of the intersection to decrease.

ITS programs implement technologies to better monitor, evaluate, operate, and manage transportation systems (Noyes, 2014). In the past, congestion problems could not be predicted prior to extreme backups, and communication with a massive number of travelers seemed improbable if not impossible. Using ITS programs, congestion can be monitored and evaluated in real-time from Traffic Management Centers (TMCs), and information can be disseminated immediately to provide travel times to drivers on the road. Travelers preparing for a trip are provided with information that could impact the timing of a trip and the route utilized. Increasing information dissemination and communication has proven to increase the mobility and efficiency of transportation networks worldwide.

Another significant benefit reaped from implementation of ITS applications is a decrease in environmental impacts. Vehicle pollution accounts for 5500 million metric tons of CO2 emissions each year (EPA, 2015). Most of the emissions are concentrated in large urban areas where vehicles constantly accelerate and decelerate in stop-and-go traffic due to heavy congestion and traffic control, such as traffic signals, interchanges, and stop signs. A reduction in roadway congestion directly correlates with a reduction in vehicle emissions because vehicles perform less deceleration and acceleration actions, and bottleneck traffic conditions are reduced. As discussed previously, ITS applications increase transportation mobility by decreasing congestion on roadways and reducing the impact transportation networks have on the environment.

2.1.7 Future of ITS

Information Technology Systems are comprised of technology that is growing and changing daily. The United States' public sector investment in ITS grew by $12 billion from 1997 to 2010 (Noyes, 2014). In 2000, approximately 66% of freeway operations agencies used closed-circuit television (CCTV) cameras to monitor traffic movement and disseminate traveler information, and in 2010 nearly 85% of these agencies had similar ITS programs implemented (Noyes, 2014). Advances in technology are making ITS deployments more cost-efficient and cost-effective. These advances are allowing new opportunities for ITS programs to increase transportation safety, mobility, and efficiency, while decreasing the environmental impact of the transportation network.

The future of ITS lies in connected vehicle technology. In 2009, the USDOT's Research and Innovative Technology Administration (RITA) released an ITS Strategic Plan focused on *transforming the nation's transportation system through connectivity* (Noyes, 2014). Since 2009, the connected vehicle program has continued to grow and concepts have transformed into realities for many connected vehicle applications. The following sections provide an overview of the connected vehicle initiative.

2.2 Connected Vehicles

The connected vehicle initiative presents an advanced transportation system comprised of vehicles and infrastructure communicating and sharing data simultaneously to prevent collisions and increase the operation of transportation networks. A world of connected vehicles would significantly expand the capacity of freeways and shorten travel time by enabling short headways, allowing more vehicles on existing roadways. In addition, dynamic traffic assignment would automatically direct travelers to the shortest and best route (Wallace, 2014). Most importantly, a connected vehicle environment would increase safety of the transportation network, and vehicle crashes and crash severity would be limited because adverse driver behavior and performance would be reduced (Wallace, 2014). Self-driving vehicles, operated by computing algorithms and communication with surrounding vehicles and infrastructure, have the potential to further increase safety, mobility, and efficiency of the surface roadway network.

The technology for operating connected vehicles and maintaining a connected vehicle network does exist, and millions of dollars' worth of research is invested into creating developmental test beds and implementing the technology in large systems. Since the 1997 demonstration of automated highways in San Diego, many test beds have proven the connected vehicle concept, and researchers are working to fully understand the technologies to encourage full scale implementation (Wallace, 2014).

Sections 2.2.1–2.2.6 provide an overview of connected vehicle technology and implementation.

2.2.1 Institutional Issues

Institutional issues are not technical, but they take the form of concerns from agencies and users. One of the greatest challenges with connected vehicle technology is liability and privacy concerns from individual drivers (USDOT ITS JPO, 2015). While connected vehicle technology introduces an incomparable world of safety, mobility, and efficiency, there is great concern that the technology is becoming available too quickly for the traveling public and transportation agencies to realize the benefits. Policy makers on all levels—local, state, and federal, are working to create strict technology standards to ensure that all communication between vehicles and infrastructure or vehicles and other vehicles will not cause any privacy breaches or liability concerns for the public or transportation agencies.

The use of connected vehicle technology raises many privacy and liability concerns due to the continuous communication of data between personal vehicles (USDOT ITS JPO, 2004). Drivers often fear that their privacy rights will be violated through the collection of data used for travel time estimates, toll road collection systems, weather data information, or other connected vehicle applications. Public concerns often are voiced about the use of this technology, which tracks individual vehicles without consent. Another concern is the potential for a data security breach, where sensitive and personal information falls into the wrong hands.

To achieve wide-spread CV deployment, a trusted network that confirms validity and intentions of the communications used in CV applications must be established (Hamilton, 2012). A trusted network will be formed using a Public Key Infrastructure (PKI) security system to ensure the privacy and security of the CV environment. The PKI system requires that each message sent through the network is signed with a valid digital certificate. The certificates provide assurance to the receiver that the message is from a legitimate source (Hill, 2013). While institutional issues often can be solved with technological expertise, it is crucial that the traveling public understands the measures in place that protect their privacy and security.

As technology continues to advance, privacy concerns continue to rise and each concern must be satisfactorily addressed and explained to all interested parties. In the case of most connected vehicle applications, the mobile data collected from personal vehicles will be completely anonymous. This means that there will be no way that a device or vehicle could be tracked from segment to segment, or day to day. Second, the data collected will not be stored indefinitely, and high security protocols will be executed to ensure the safety of individual information.

Transportation departments also must be aware of liability risks that exist when executing connected vehicle applications. Before large scale implementation occurs, it is crucial that these agencies work with lawmakers and officials to determine adequate amounts of responsibility for the equipment and data generated by the system. In addition, agencies will need liability clauses, which state explicitly the conditions under which the agency will be held liable. Agencies benefit significantly by addressing these institutional issues upfront and before initial implementation (USDOT ITS JPO, 2004).

2.2.2 History of Connected Vehicles

Films have depicted driverless vehicles for decades, while researchers, automotive manufacturers, and transportation agencies have strived to meet the expectations of a safer and more efficient transportation network. Connected vehicle technology is one step toward driverless vehicles. Early connected vehicle technology projects were initiated in 2002, when the USDOT joined automotive manufacturers in researching vehicle to vehicle (V2V) crash avoidance techniques using high speed wireless communication. This partnership became official in 2006 with the Crash Avoidance Metrics Partnership (CAMP) between automotive manufacturers and the USDOT (USDOT ITS JPO, 2015). The partnership was to determine the feasibility of such technology and whether that technology could introduce benefits to the existing transportation network.

A critical step for connected vehicle applications came with the Federal Communications Commission (FCC) decision to allocate 75 megahertz of spectrum in the 5.9 GHz frequency range to improve transportation safety (USDOT ITS JPO, 2015). This decision allowed V2V and vehicle to infrastructure (V2I) testing using DSRC or Designated Short Range Communication. While DSRC provides great promise in a future of connected vehicles, researchers also are evaluating other forms of communication such as Wi-Fi, cellular data, and Bluetooth.

Connected vehicle technology is in its infancy, but significant progress has occurred over the past few years. For instance, in 2014 the National Highway Traffic Safety Administration (NHTSA) decided to pursue connected vehicle technology for light vehicles due to the impact that technology could have on safety (USDOT ITS JPO, 2015). In response to the NHTSA decision, safety pilot models were deployed in test beds to research connected vehicle technology further. The safety pilot tested the following technologies: (1) blind spot warning/ lane change warning, (2) forward collision warning, (3) electronic emergency brake lights, (4) intersection movement assist, (5) do not pass warning, and (6) control loss warning (USDOT ITS JPO, 2015).

In 2011, motor vehicle crashes accounted for 32,885 deaths in the United States (USDOT NHTSA, 2012) and were the leading cause of death for Americans between the ages of five and forty-four (Hoyert & Xu, 2012). Therefore, the USDOT placed emphasis on safety applications and exploring ways that the number and severity of motor vehicle crashes can be reduced. Connected vehicle technology paired with ITS applications encompass the primary strategy used by most agencies to address safety and other concerns of the transportation network.

2.2.3 Communication Technology

Communication is the core component of CV operations, and the requirements for communication operability are stringent. The ITS ePrimer Module 13 denotes that “communication technology for safety applications must be secure, low-latency, mature, stable, and able to work at highway speeds (Hill, 2013).”

Current research indicates that safety applications will be based on dedicated short-range communication (DSRC) technology, and non-safety applications may be based on alternative wireless technology, such as Bluetooth, WiFi, or cellular data. Challenges vary with each form of wireless communication, but ultimately amount to consistency, latency, and security requirements. High vehicle speeds and varied terrain may affect the efficiency of wireless communication. Challenges arise in standard wide scale implementation because a communication system may prove to be effective in one setting, such as an urban environment, but not effective in a rural setting with higher speeds, varying elevations, and more severe weather conditions.

2.2.4 Current Applications and Test Beds

Over time, CV research has evolved and proved feasible. Current research is focusing on uncovering specific and quantitative benefits of implementation while assessing and evaluating the public's acceptance of a CV environment. This research was essential for the 2014 NHTSA decision on continuing the development of CV applications for light vehicles.

Research conducted by USDOT and automotive manufacturers identified promising crash avoidance systems using V2V communications. These applications include Emergency Brake Light Warning, Forward Collision Warning, Intersection Movement Assist, Do Not Pass Warning, and Control Lost Warning. In addition, researchers are investigating methods for avoiding more complex collisions, such as head-on and motorcycle crashes (Hill, 2013).

V2V application research is ongoing, but in the next few decades it is likely that all new vehicles will be equipped with communication capabilities allowing exchange of information between vehicles. However, current emphasis is pointing researchers toward V2I applications. This is because deployment of V2I technologies does not require all vehicles to be equipped with communication capabilities to begin experiencing benefits.

V2I deployment at intersections is a promising application that will emerge in the next few decades. A specific CV application that addresses intersection collisions is Red Light Warning. This application uses Signal Phase and Timing (SPAT), geometric intersection descriptions, and positioning data to communicate between vehicles and roadside equipment. When an indication shows that a vehicle is going to run a red light, all nearby vehicles are given an advisory warning (Hill, 2013). There are approximately 311,000 intersections in North America, and research indicates that 80% of intersection crashes could be reduced with deployment of CV technologies at 50% of the intersections (155,500 sites) (AASHTO, 2014).

CV research is currently conducted across North America with many different ideas, objectives, technologies, and applications in mind. To bridge the gap between concepts and deployment, physical test beds have been built to allow researchers to test theories and create a reality. Current test beds are located in Arizona, California, Florida, Michigan, New York, and Virginia. AASHTO projects that CV deployment will originate at these locations, and in upcoming years, technology embedded corridors will link these test beds together (AASHTO, 2014).

2.2.5 Benefits of Connected Vehicle Technology

Connected vehicle applications can significantly reduce the frequency and severity of collisions by increasing drivers' situational awareness through wireless communication relaying information about hazards and events along the roadway. Research conducted by the Volpe Center indicates that Vehicle to Vehicle (V2V) technologies will reduce 79% of target annual collisions, Vehicle to Infrastructure (V2I) technologies will reduce 26% of target annual collisions, and combined V2V and V2I technologies are projected to reduce 81% of target annual collisions (Najm, Koopmann, Smith, & Brewer, 2010). Implementation of CV technologies will cause an exponential growth in the safety of transportation networks. Not only will communication between vehicles and roadside infrastructure help avoid collisions, but the technology will reduce risk for secondary crashes and emergency response time, effectively minimizing the impact of all remaining collisions.

2.2.6 Future of Connected Vehicles

The United States Department of Transportation is placing great emphasis on the creation of test beds to implement connected vehicle technology. To continue and encourage these efforts, the USDOT identified three primary research goals (USDOT ITS JPO, 2015):

1. operate, manage, and maintain the existing Connected Vehicle test beds for use by organizations and researchers in both the public and private sectors, and in doing so, continue to establish standards for new technology to enhance the safety, mobility, efficiency, and environmental impact of the existing transportation network
2. enhance and/ or modify existing test beds, and use the model as a prototype for future test beds
3. research, develop, and prototype generic management processes, equipment, and back-end services for wide scale implementation

While current efforts in connected vehicle technologies are highly focused on the creation and implementation of test beds, the USDOT also is working to implement stringent standards holding all manufacturers and agencies accountable, and to protect the privacy and security of all road users. In addition, liability concerns are being addressed with certification methods, requirements, and detailed descriptions of the core systems encompassing CV technology. Finally, efforts also are focused on human factors research, to determine how the public will react to wide-scale implementation of CV technology, and to consider technologies that can aid drivers in making better decisions and obtain greater attentiveness while operating their vehicle (USDOT ITS JPO, 2015).

The USDOT identified these three primary metrics for quantifying success and effectiveness of connected vehicle technology: (1) reduction in highway fatalities, (2) reduction in traffic incident-related travel delay, and (3) reduction in vehicle emissions (USDOT ITS JPO, 2015). From these performance measures it is evident that the concerns being evaluated are safety, mobility, and environmental impacts. In cooperation with the USDOT, AASHTO presented an update of the National Connected Vehicle Field Infrastructure Footprint Analysis on May 22, 2014. The purpose of this analysis, begun in 2003, is to help states and agencies understand their role in future and current CV implementation. The implementation analysis research considered many different variables: rural vs. urban settings, light vs. heavy vehicles, transit, and freight or commercial vehicles (AASHTO, 2014).

The Footprint Analysis incorporated development concepts, scenarios, standards, and costs for the following application packages (AASHTO, 2014):

- V2I Safety
- Mobility/Environment
- Road Weather
- Smart Roadside
- Border Crossings
- Fee Payment
- Agency Operations

USDOT requirements for security, privacy, and technology were formed into conceptual plan sheets, descriptions, and alternatives. These preliminary standards list all required communication technologies, features, and provide representative application scenarios. Examples of the applications in which detailed descriptions were created include travel times on urban freeways, curve speed warnings and weather events on rural highways, and increased security and efficiency at international border crossings (AASHTO, 2014).

AASHTO’s National Footprint Analysis provided the timeline in Table 2.1 for the implementation of connected vehicles in North America (AASHTO, 2014).

Table 2.1 AASHTO Connected Vehicle Implementation Timeline

Date	State of Implementation
2014-2015	Plan
2015-2017	Research and Pilot Applications (focusing on safety applications)
2017-2018	Evaluation of Applications
2018-2020	Deployment
2020-2040	Expansion

By 2040, AASHTO projects that 80% of signalized intersections will be equipped with V2I technology, 25,000 other roadside equipped applications (CCTV cameras, toll tag readers, etc.) will be in use, and 90% of all road miles will have real-time localized information (AASHTO, 2014).

2.3 Road Weather Management Programs

More than three-fourths of the nation’s roads, roughly three million miles of roadway, are located in rural areas (Albert, 2013). Twenty-three percent of all crashes occur during adverse weather conditions (FHWA, 2014) and result in over 7,400 fatalities and 673,000 injuries (Pisano, Lynette, & Michael). In addition, weather is a factor in 23% of all non-reoccurring delay, which is approximately 544 million vehicle hours of delay annually (FHWA, 2014). Light or heavy rain can reduce the average speed on a freeway by 3 to 16%; heavy snow can decrease average freeway speeds by 5 to 40% (FHWA, 2014). Transportation agencies spend nearly 2.3 billion dollars each year for winter maintenance, nearly 20% of most DOT’s yearly budget (FHWA, 2014).

Road Weather Management Programs (RWMP) are crucial to locations that experience severe adverse weather conditions, which prevent drivers from traveling as desired and decrease roadway safety. Before the introduction of ITS, RWMPs relied on maintenance worker and traveler reports to determine weather conditions and evaluate when a roadway should be closed. While these methods are still used in some jurisdictions, many areas with frequent inclement weather events have transitioned to using ITS applications to supplement existing RWMPs because of its reliability.

Road weather management strategies have been adopted by transportation authorities to mitigate effects of adverse weather conditions on freeways, especially in rural areas. Rural and urban transportation networks differ significantly; therefore, different ITS applications are required to address the specific problems of the location. For example, rural freeways typically facilitate longer trips to a variety of drivers, including daily commuters, commercial deliveries, and travelers who are unfamiliar with the roadway (Albert, 2013). In addition, travel between rural areas can be challenging because minimal route alternatives are available when collisions or adverse weather conditions cause a roadway closure or significant delay. Finally, rural road conditions are more challenging and adverse weather has a bigger impact on roadways and travelers (Albert, 2013).

This section discusses several ITS applications and technologies used to better determine road weather conditions, improve safety, and lead to more effective decisions regarding road closures and maintenance.

2.3.1 Road Weather Information Systems

To combat the negative effects of weather conditions on rural highways, transportation agencies began implementing Road Weather Information Stations (RWIS). The RWIS utilized roadside sensors capable of detecting and communicating real-time pavement and ambient temperatures, wind speed, and visibility. The sensors allow management agencies to provide advanced warnings to drivers traveling along a specific roadway segment, better distribute snowplows and anti-icing supplies to the most severe locations, and in some settings, assign variable speed limits to assist drivers' decision making based on existing conditions. The Wyoming DOT currently utilizes an RWIS and variable speed limit system to increase awareness of drivers traveling on I-80 during adverse conditions.

Another example of road weather management through the use of RWIS type sensors is illustrated in Oregon, where extreme wind speeds have caused drivers to lose control of their vehicles traveling through specific corridors and over bridges. In 2006, Oregon DOT implemented a high-wind detection and advisory system that detected high winds and warned drivers to pull over until conditions improved or to select an alternate route (Albert, 2013).

2.3.2 Other Detection Mechanisms

Aside from RWIS systems and sensors detecting road conditions, many transportation agencies implement static cameras and video cameras with high resolution to monitor roadway conditions. These images provide TMC operators and authorities the ability to evaluate conditions instantaneously and make decisions. Images and warnings of potential and current hazards can be translated to the traveling public. Many agencies equip snowplows with technology that can provide additional information to snowplow operators regarding the amount of deicing material to use. This can also give TMC operators a better idea of the potential for wet, slick, icy, or snow covered road surfaces.

2.3.3 Weather Responsive Traffic Management Strategies

The increased levels of road weather condition detection allows for more widespread implementation of Weather Responsive Traffic Management (WRTM) strategies. "WRTM is a combination of techniques, tools, and systems that transportation authorities can use for mitigating the impacts of weather on their operations (Gopalakrishna, 2011)."

Weather Responsive Traffic Management (WRTM) strategies must be formulated and used to decrease the negative effects adverse weather holds on rural transportation networks. WRTM includes two primary components: implementation of traffic advisory, control, and treatment strategies in response to or in preparation for developing roadway condition and visibility issues; and provision of proactive advisories to travelers to impact their decision making (Gopalakrishna, 2011).

Seven primary types of WRTM strategies exist:

1. *Passive Warning Systems*: Static information and /or warning signs to alert travelers that potentially hazardous road conditions may exist
2. *Active Warning Systems*: Add dynamic element (such as flashing beacons) to static warning signs to alert drivers that the specified conditions currently exist
3. *Pre-Trip Road Condition Information and Forecast Systems*: Provide current and forecasted weather and road condition data to travelers in order to influence their trip decisions
4. *En route Weather Alerts and Pavement Condition Information*: Provide travelers with real-time weather and road condition data existing or developing ahead on their route
5. *Speed Advisories*: Communicating non-enforceable speed advisories to achieve voluntary compliance with a recommended safe driving speed in response to negative weather or road conditions
6. *Variable Speed Limits*: Enforcing speed restrictions in direct response to weather conditions
7. *Personnel/ Asset Management*: Tools and strategies to better manage agency assets and personnel during inclement weather events (Gopalakrishna, 2011)

Some WRTM strategies include warning systems that alert drivers before and during their trip about existing and potential weather conditions, and vehicle restrictions that set requirements for vehicles entering a potentially dangerous roadway. In addition, traffic incident management sets procedures for expediting travel time and travel ability of emergency services during inclement weather, while implementing a procedure to clear the roadway quickly to avoid secondary collisions (Gopalakrishna, 2011). Another strategy involves the use of variable speed limits to slow drivers to a consistent speed when traveling in adverse weather conditions. Interstate 80 in Wyoming utilizes variable speed limits primarily to address the dangerous travel conditions during winter seasons. All transportation agencies are moving toward a proactive regional weather management approach where agencies prepare for anticipated weather threats systematically, rather than respond to existing conditions (Gopalakrishna, 2011).

2.4 Connected Vehicle Road Weather Condition Applications

Existing WRTM strategies are making a difference in rural areas, but there is room for improvement. The first challenge with implementing effective WRTM strategies is the effect of isolated weather events in the distances between stationary weather stations, such as RWIS. To improve WRTM strategies, improved linkage between remote sensor locations must be achieved. “The use of vehicle sensor data to improve weather and road condition products could revolutionize the provision of road weather information to transportation system decision-makers, including travelers (Drobot, et al., 2009).”

Weather conditions can be localized or variant within short distances along a roadway; therefore, mobile weather stations are needed to collect real-time information at continuous locations between stationary weather stations (Pisano P. , 2011). Mobile weather stations have the potential to (1) reduce the number of crashes and delays caused by adverse weather, (2) provide transportation agencies quality information to effectively treat snow and ice on their roadways, (3) allow better maintenance decision supporting systems, (4) provide more information to assist traveler decision making, and (5) allow better weather and road condition forecasts (Pisano P., 2011).

Sections 2.4.1–2.4.4 describe the methods for using vehicles as mobile weather stations through connected vehicle applications and current projects and research in this area.

2.4.1 Collection of Vehicle Data

All modern vehicles collect, communicate, and store real-time performance data throughout a trip; this vehicle data include (but is not limited to) ABS brake status, ambient temperature, engine speed, tire rotation, and windshield wiper status. All of these data are aggregated within the vehicle's computer, which is called the CAN-Bus. "CAN (Controller area network) is a message-oriented multi-master protocol for quick serial data exchange between electronic control units in automotive engineering and factory automation (Solutions for CAN/CAN FD: The Vector Solution for CAN Networks)." Advanced vehicle control systems require seamless intercommunication between electronic control units (ECUs). These ECUs are interconnected through the CAN-Bus, which acts as a networking technology between all individual control systems (McLaughlin).

The OBD-II or On-Board Diagnostics II is a second generation emissions diagnostic system that monitors vehicle emission parameters and stores diagnostic trouble codes (Stern & Biesecker, 2006). In 1996, the OBD-II system was standardized for passenger vehicles sold in the United States. This standardization required all vehicle manufacturers to use the same codes to communicate with the OBD-II system, and allowed for collection of basic vehicle performance data from most vehicles (Palmer Performance Engineering, 2013).

CAN-Bus readers, or vehicle interfaces (VIs) connect to a vehicle's OBD-II port and are sold by many private companies, giving vehicle owners and mechanics the ability to evaluate a vehicle's performance and identify potential problems (within the OBD-II portion of the CAN-Bus network). Traditionally, CAN-Bus readers were made to connect to various visualization devices, such as LCD screens, and with GPS modules to determine vehicle location (Arduino CAN-Bus Shield with uSD Card Holder, 2015). As technology advanced, companies transferred their focus to vehicle interfaces compatible with Bluetooth, Wi-Fi, or USB communication that could be connected to smartphones or tablet computers (CAN Bus Controllers, 2015), (GoPoint Technology BT1, 2015), (Komodo CAN Duo Interface, 2015), (OBDLink MK Bluetooth, 2015). These VIs allow for greater information dissemination and communication, and collection of a richer data set due to the computation power and additional smart-device data (such as location and accelerometer data).

In the report "Enabling Accelerated Installation of Aftermarket On-Board Equipment (OBE) for Connected Vehicles," Visteon Corporation and partners discussed that a primary concern in the large-scale deployment of connected vehicle technology is the degree of market penetration required for effectiveness. The report concluded that successful deployment of CV applications will depend on widespread installation of vehicle interfaces or on-board equipment units, specifically aftermarket units used to communicate between vehicles (Visteon Corporation, et al.). The problem with most aftermarket vehicle interface devices is that the information collected from the CAN-Bus is not sufficient for road condition-connected vehicle applications. High security is placed by each automotive manufacturer to ensure vehicles cannot be altered after production. Each manufacturer's vehicle make and model sends different CAN-Bus messages, making it impossible to use the same aftermarket software and device to read relevant CAN-Bus data. While the safety of this method is valuable, production of hundreds of aftermarket devices for each vehicle make and model is impractical.

Palmer Performance Engineering offers a solution for collecting vehicle performance data from various vehicle makes and models. With the use of the OBDLink vehicle interface, vehicle data can be collected through a smartphone application, Dash Command, or a computer program, ScanXL (Palmer Performance Engineering, 2013). Palmer Engineering's solutions provide enhanced diagnostic add-ons for specific vehicle manufacturers, allowing more data to be collected. However, because not all vehicle measures or parameters are available with each vehicle year and model, the diagnostic requires a guessand-check method to determine vehicle parameters for each individual vehicle (Palmer Performance Engineering, 2013).

Researchers and developers created the OpenXC Platform in response to the need for flexible vehicle interface software and hardware, which is a combination of open source hardware and software that uses standard and well-known tools to make vehicle data accessible (The Open XC Platform, n.d.). The OpenXC platform operates similarly to private VIs; a small hardware module (VI) is installed in the OBD-II port. The VI reads and translates data from the vehicle’s CAN-Bus and connects to Android and Python applications. This platform allows application developers to use the open source data translated from the VI to create new applications that address different problems, including distracted driving. In addition, developers created a basic Android application, OpenXC Enabler, which allows researchers to view and analyze vehicle data collected from the VI without creating a personalized application (The Open XC Platform, n.d.).

Similar to private company applications, the OpenXC hardware/software package can read generic information from most vehicle makes and models, but the information available is not sufficient for connected vehicle applications. In response to this shortfall, Ford Motor Company researchers partnered with OpenXC to create firmware for OpenXC hardware to collect and translate CAN-Bus messages from some Ford vehicles. The firmware package provided by Ford researchers allows Ford Motor Company to keep proprietary data secure and allows researchers and developers the ability to analyze more vehicle data to advance connected vehicle applications (The Open XC Platform, n.d.).

OpenXC compatible firmware, developed by Ford Researchers, for Ford vehicles is still dependent on a vehicles’ make and model. Firmware is provided for a variety of Ford vehicles, but not each separate vehicle. The limitation on available firmware requires researchers to locate specific vehicles in which the available firmware can provide the desired vehicle performance data. The Ford Developer Program provides a spreadsheet, “OpenXC Ford Vehicle Compatibility,” which provides firmware information for a selection of Ford vehicles, the vehicle performance measures collected from each vehicle, and the required vehicle interface for data collection (Ford Motor Company, 2014). Not only do the data collected depend on the firmware available for the particular vehicle, but some vehicle parameters only are available if the VI can connect to two CAN-Buses simultaneously. The three CAN-Buses are: CAN1, CAN2-1, and CAN2-2 (Ford Motor Company, 2014).

The Open XC Android platform currently allows for collection of the following CAN-Bus messages or signals from a selection of Ford Vehicles (The Open XC Platform, n.d.):

- Steering wheel angle
- Torque at transmission
- Engine speed
- Vehicle speed
- Accelerator pedal position
- Parking brake status
- Brake pedal status
- Transmission gear position
- Odometer
- Ignition status
- Fuel level
- Fuel consumption since restart
- Door status
- Headlamp status
- Windshield wiper status
- Latitude
- Longitude
- Button Event (specific to vehicle)

To access the CAN-Bus parameters available with select Ford vehicles, researchers have three options for VI hardware. First, the Ford developer program released a variety of Ford Reference Vehicle Interfaces for researchers to test OpenXC software. The Ford Reference VI connects to both CAN1 and CAN2-1 pins, and can be altered to connect to CAN2-2 pins. The VI is the most user-friendly and advanced, however, the Ford Developer Program only provides the devices at select time periods (Ford Motor Company, 2014). Figure 2.2 shows the Ford Developer Program VI (The Open XC Platform, n.d.).

Figure 2.2 Ford Developer Program Reference Vehicle Interface

The second OpenXC VI alternative is the CrossChasm C5. The CrossChasm C5 VI only connects to the CAN1 pins and cannot be altered. Nonetheless, the CrossChasm C5 is an ideal alternative for accessing most CAN-Bus data from the selected Ford Vehicles (The Open XC Platform, n.d.). Figure 2.3 shows the CrossChasm C5 VI (The Open XC Platform, n.d.).

Figure 2.3 CrossChasm C5 Vehicle Interface

The third OpenXC VI alternative requires the construction of a chipKIT based VI. The design uses entirely off-the-shelf components and can be assembled for a range of functionality, including the reading of CAN1, CAN2-1, and CAN2-2 bus pins. While this alternative allows significant flexibility, it requires a knowledge base to construct the VI (The Open XC Platform, n.d.). Figure 2.4 shows the chipKIT based VI (The Open XC Platform, n.d.).

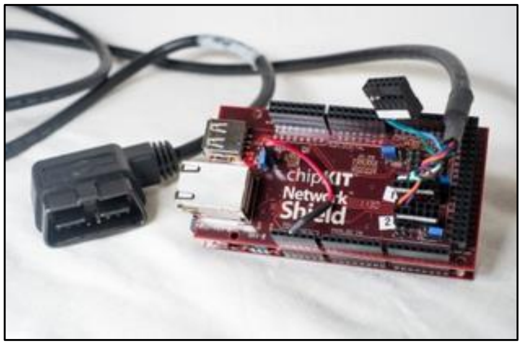
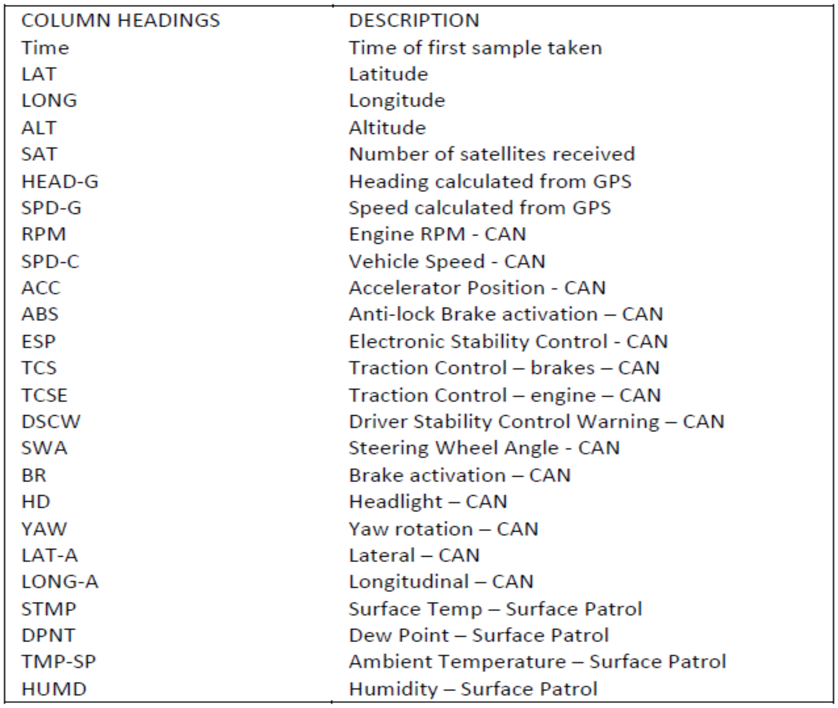


Figure 2.4 ChipKIT Based Vehicle Interface

Michigan's Department of Transportation (MDOT) and the University of Michigan Transportation Research Institute (UMTRI) signed a Non-Disclosure Agreement (NDA) with Ford Motor Company to allow complete collection of CAN-Bus data from Ford vehicles. The NDA allows MDOT and UMTRI to collect CAN-Bus communication outside the OBD-II diagnostics (Robinson & Cook, 2012). Figure 2.5 provides the data MDOT and UMTRI are able to collect from Ford vehicles (Robinson & Cook, 2012).



COLUMN HEADINGS	DESCRIPTION
Time	Time of first sample taken
LAT	Latitude
LONG	Longitude
ALT	Altitude
SAT	Number of satellites received
HEAD-G	Heading calculated from GPS
SPD-G	Speed calculated from GPS
RPM	Engine RPM - CAN
SPD-C	Vehicle Speed - CAN
ACC	Accelerator Position - CAN
ABS	Anti-lock Brake activation – CAN
ESP	Electronic Stability Control - CAN
TCS	Traction Control – brakes – CAN
TCSE	Traction Control – engine – CAN
DSCW	Driver Stability Control Warning – CAN
SWA	Steering Wheel Angle - CAN
BR	Brake activation – CAN
HD	Headlight – CAN
YAW	Yaw rotation – CAN
LAT-A	Lateral – CAN
LONG-A	Longitudinal – CAN
STMP	Surface Temp – Surface Patrol
DPNT	Dew Point – Surface Patrol
TMP-SP	Ambient Temperature – Surface Patrol
HUMD	Humidity – Surface Patrol

Figure 2.5 MDOT and UMTRI Vehicle Performance Parameters

As Figure 2.5 indicates, MDOT and UMTRI are able to collect Anti-lock Brake activation, Electronic Stability Control, Traction Control, and Driver Stability Control Warnings, four vehicle parameters that are highly protected and cannot be collected by any private or open-source software. These four parameters are relevant and important to determining road condition information as they provide possible indication of slick, wet, or icy roads.

Mobile data also includes data collected from external sensors attached to the vehicle. Early implementation of connected vehicle road condition evaluation projects shows that one of the greatest challenges with collecting CAN-Bus data was the non-standard, proprietary CAN-Bus message protocol between vehicle manufactures and vehicle makes and models (Robinson & Cook, 2012). To gather more comprehensive mobile data, external sensors were installed on vehicles. Information from the external sensors was aggregated with the vehicle data from CAN-Bus messages to provide a more realistic understanding of road conditions (Robinson & Cook, 2012).

MDOT and UMTRI used Vaisala Surface Patrol System external sensors to equip their connected vehicle fleet (Robinson & Cook, 2012). Surface temperature was collected through an infrared road surface temperature sensor mounted on the floor of a vehicle's trunk, and the humidity sensor provided real-time dew point temperatures (Robinson & Cook, 2012). Figure 2.6 shows the Vaisala Temperature and Humidity External Sensors (Vaisala, 2015). In 2012, this Vaisala package cost MDOT and UMTRI approximately $6,000 per vehicle, and therefore, was not deemed practical for implementation of a large fleet of vehicles (Robinson & Cook, 2012).

Figure 2.6 Vaisala Temperature and Humidity External Sensors

Another connected vehicle road condition solution, Weather Cloud, comes from a company in Boulder, Colorado. Weather Cloud considers a vehicle to be a valuable sensor for collecting weather data, but instead of attempting to read the vehicles' CAN-Bus data, the company has focused on using external weather sensors to collect mobile data (Weather Cloud, 2014). Weather Cloud currently uses three external sensors mounted on the vehicle to collect road condition data: windshield, back bumper, and tire. These sensors collect ambient temperature, wind direction and velocity, precipitation rate and type, tire slip and grip, pavement temperature, relative humidity, and visibility (Weather Cloud, 2014). From these data, Weather Cloud can infer the most likely road surface conditions from any vehicle, no matter the vehicle make, model, or manufacturer. Figure 2.7 shows the Weather Cloud external sensors and the company's methodology for determining road conditions. Unlike many companies producing vehicle external sensors, Weather Cloud is working to produce the full package: providing sensors and road condition data to the customer. Weather Cloud currently is marketing their products to Departments of Transportation for approximately $300 per vehicle for the set of three sensors. This cost allows DOTs to equip a large fleet of vehicles and quickly realize the benefits from the connected vehicle solution (Reeves, 2015). External sensors are invaluable to collecting mobile vehicle data because they are not reliant on the vehicle's manufacturer, make, or model. However, the challenge with external sensors lies in the required calibration and maintenance. Sensors must be calibrated prior to use and maintained throughout the devices' life to ensure that authentic data are being collected. In addition, the mechanism for analyzing the sensor data must have sufficient quality checking parameters to identify sensors that are not operating properly.

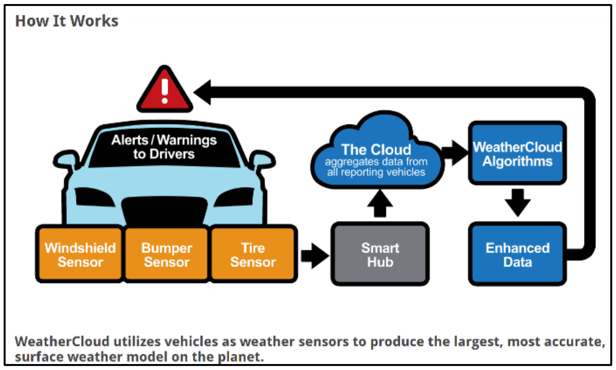


Figure 2.7 Weather Cloud External Sensors and Methodology

Early adopters of connected vehicle applications for determining road conditions considered communicating or transferring data from roadside sensors. As smart-device (smartphone and tablet computer) technology became available, it became evident that using smart-devices would be the most cost efficient mechanism for data communication and would offer the greatest ease of deployment (Robinson & Cook, 2012). Not only did smart-devices provide a cost effective alternative to roadside equipment, their use allowed for collection of a greater and less-restricted mobile data set.

Smart-devices can collect vehicle data from the vehicle interface and external sensors, while also gathering data from the smart-devices' internal sensors. These internal sensors include a GPS receiver, 3-axis accelerometer, compass, and camera. When the device is firmly mounted to the vehicle's dashboard, the 3-axis accelerometer collects motion and vibration data, which can then be used to determine roadway roughness. MDOT and UMTRI further analyzed motion and vibration data to indicate the probability of snow or ice on the roadway, and they used the roughness data in asset management applications (Robinson & Cook, 2012). Weather Cloud also uses smart-devices to collect data and disseminate road condition messages and warnings to drivers (Weather Cloud, 2014).

The greatest benefits to using smart-devices as additional mobile sensors and data aggregators are low cost, high computing power, dual use (many agencies already purchase smartphones for their employees), and built in cameras with geo-tags (pictures with embedded GPS coordinates) (Robinson & Cook, 2012). However, smart-devices are not without disadvantages. USB connectors used for mobile charging are fragile, accelerometer calibration is highly sensitive to device mounting, devices have poor tolerance to extreme temperatures, and battery life is limited (Robinson & Cook, 2012).

2.4.2 Communication or Transfer of Vehicle Data

Initially, connected vehicle research focused on vehicle-to-vehicle and vehicle-to-infrastructure communications. During this time, connected vehicle road condition reporting was assumed to be completed through communication between the vehicle interface and roadside equipment, located at set increments along a specific route. Figure 2.8 shows the communication diagram when roadside equipment is used.

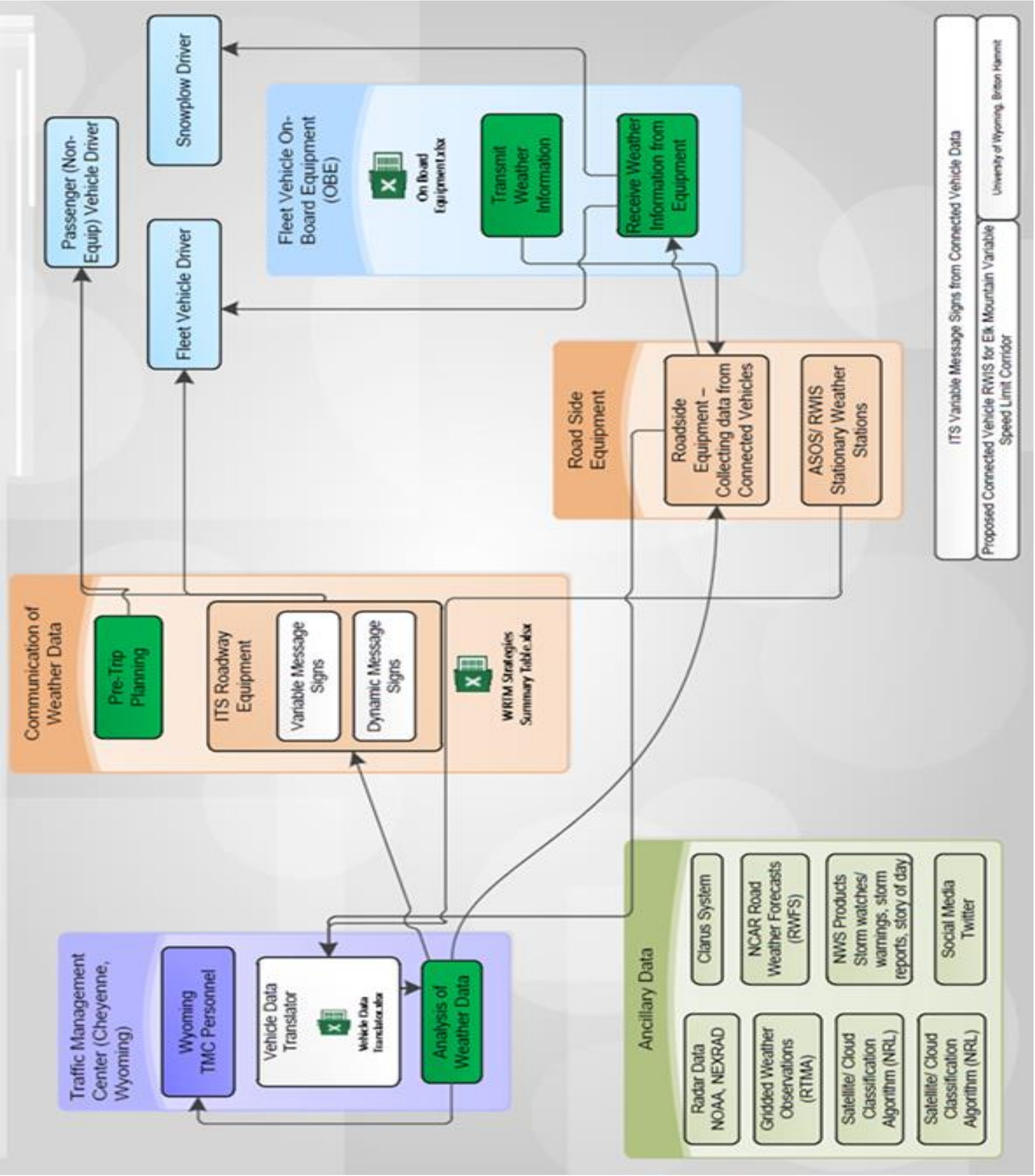


Figure 2.8 Communication Diagram of Road Weather Condition Reporting System Considering the Use of Roadside Equipment (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011)

The roadside equipment would communicate mobile data to the backhaul server using radio communications, Wi-Fi, or fiber optic cable, depending on availability and distance. Using roadside equipment to communicate vehicle data created many issues that limited its exposure: capital costs, limited data storage, communication between the vehicle and the roadside device, and low route flexibility. Similar to RWIS systems, the use of roadside equipment limited feasibility of widespread deployment due to high capital and maintenance costs.

When smart-devices became affordable and increasingly common, focus shifted from transferring data from roadside equipment to using the cellular network, Wi-Fi, or radio transmission from a smart-device. Smart-devices offer a more flexible and affordable alternative to roadside equipment. Figure 2.9 illustrates the communication and operation of a road weather condition program using smart devices for long range communication.

Not only is implementation significantly simpler, entailing lower capital costs, and requiring less maintenance, but smart-devices are not limited to areas or routes equipped with roadside equipment. Rather, an application is downloaded on the smart-device to aggregate different sources of mobile data and transfer or store the data at any roadway location. As expected, this system does entail higher monthly costs, considering cellular data costs required to continually transmit data.

The MDOT and UMTRI use an application called *DataProbe* to collect data and then transfer real-time mobile data to the backhaul server at specific time increments (Robinson & Cook, 2012). Weather Cloud uses a smart-device called the *Smart Hub* to aggregate sensor data and add vehicle dynamics data (accelerometer data) from the device itself. The Smart Hub condenses the data and pushes it to the cloud to be analyzed (Weather Cloud, 2014). Developers on the OpenXC platform created an Android application that reads the vehicle data from OpenXC supported VIs. The application is called *OpenXC Enabler,* and it operates through a Bluetooth, Wi-Fi, or USB connection to the VI. The *OpenXC Enabler* can store the vehicle data on the smart-device's internal memory, external memory, or automatically transfer the data to a backhaul server for real-time data collection. Unlike the MDOT/ UMTRI and Weather Cloud solutions, the OpenXC Enabler only collects mobile data from the CAN-Bus and GPS coordinates from the smart-device (The Open XC Platform, n.d.).

Smart-devices allow for cost-effective mobile data aggregation and communication in real-time or non-real time applications. The next section discusses processing and analysis of the mobile data after it has been aggregated and transferred.

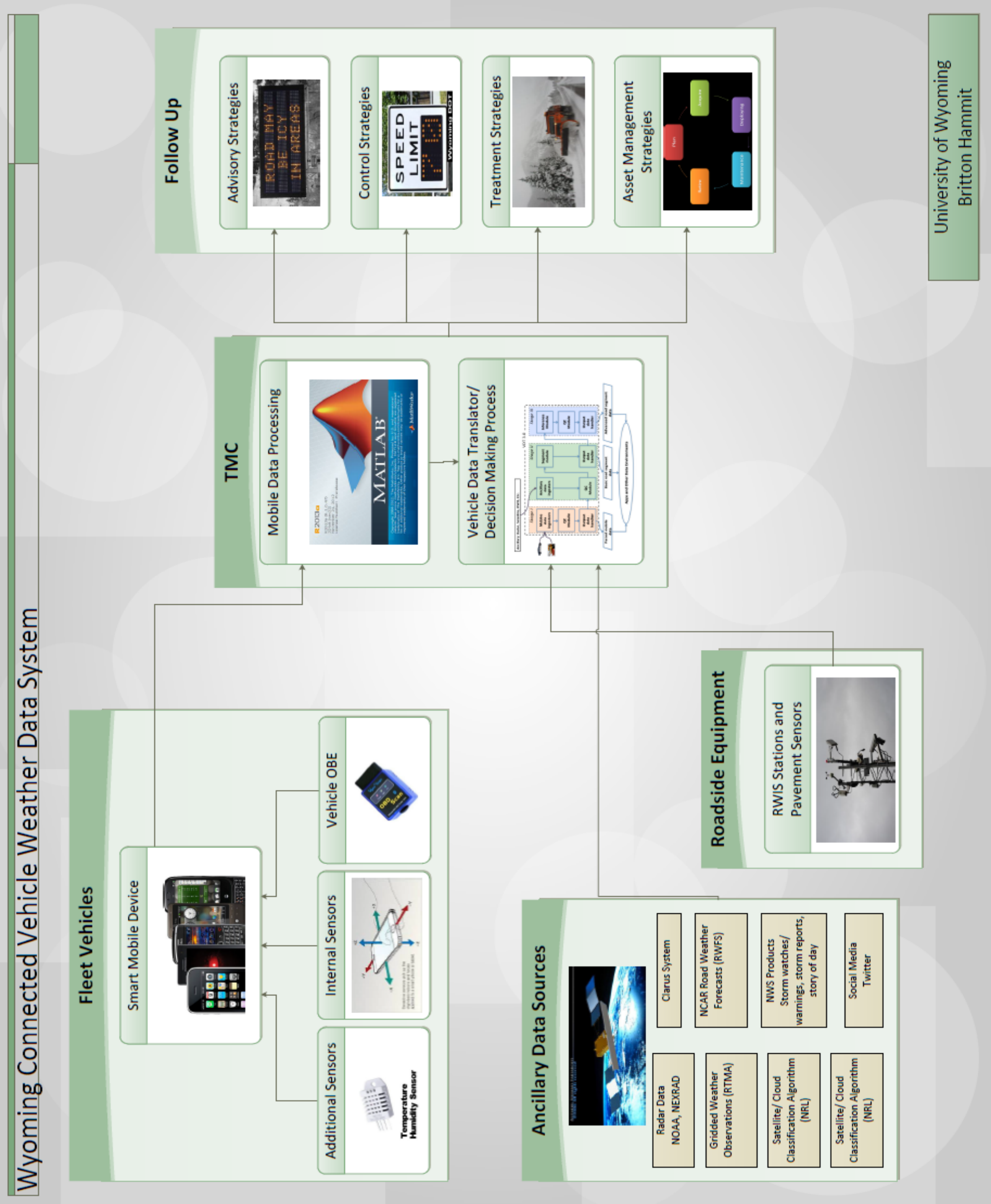


Figure 2.9 Communication Diagram of Road Weather Condition Reporting System Considering the Use of Smart Devices and Cellular Data (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011) (Robinson & Cook, 2012)

2.4.3 Processing and Analysis of Data

As discussed in 2.2.1 Institutional Issues, mobile data take many forms and must be collected at short time increments to allow for continuous road condition assessment. For this reason, robust data analysis programs must be used to accurately and efficiently evaluate mobile data and determine probable road conditions.

The National Center for Atmospheric Research (NCAR) created an open source software called: Pikalert or the Vehicle Data Translator (VDT). The VDT is a software program that ingests mobile data and outputs segmented road weather condition reports. The VDT has four primary functions:

- “Extract the necessary data to derive weather and road condition information.
- Filter the data or remove unnecessary or unwanted information.
- Quality-check the information using other local surface observations and ancillary datasets.
- Organize and process the data for user-defined road segments (Pisano P., 2011).”

To accomplish these primary functions, a third version of the VDT was created to follow a three-stage process, as shown in Figure 2.10 (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011).

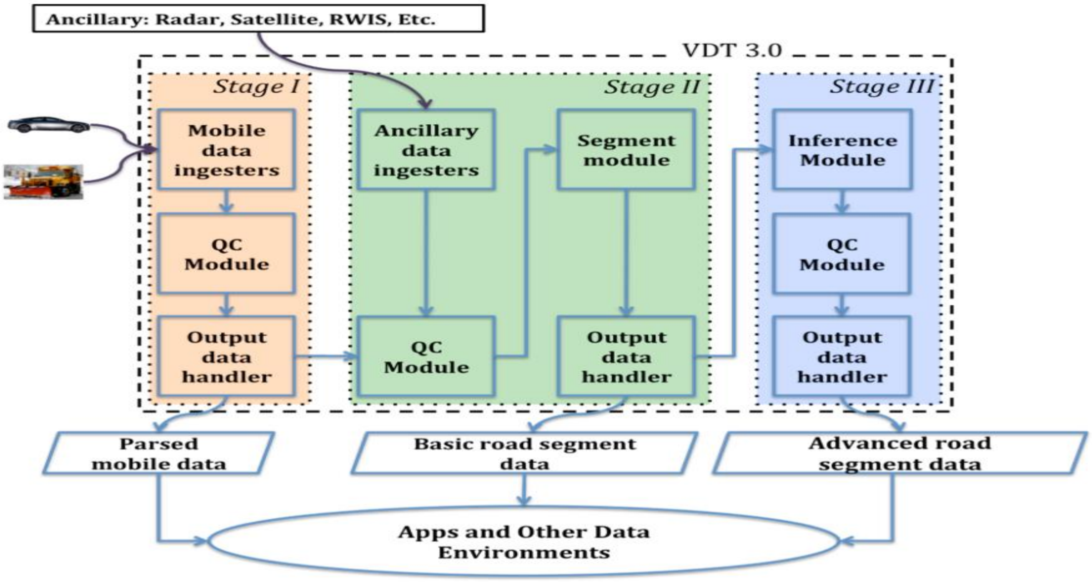


Figure 2.10 VDT 3.0 Three-Stage Process Diagram

The first stage ingests mobile data from the vehicle’s CAN-Bus, external sensors, and smart-device, and extracts relevant information such as time, location, temperature, and traction control (Pisano P. , 2011). Before entering the second stage, data are sent through the quality checking (QC) module to ensure that all data have realistic times and locations; all data with unrealistic time and location tags are removed from the data set (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011).

The second stage combines the quality checked mobile data from the first stage with appropriate ancillary data from sources including satellites, radar, and RWIS. Ancillary data is defined as any data used to determine segmented-weather data that do not originate from a vehicle. The mobile data are sent through an additional QC module to eliminate any mobile data that are improbable when compared with the ancillary data. The ancillary data do not go through a QC module because the ingested ancillary data are assumed to have passed QC modules prior to inclusion into the VDT (Drobot, Chapman, Lambi, Wiener,

& Anderson, 2011). The quality checked mobile data and ancillary data are combined within the segment module to compute road segment statistics, such as the mean air temperature over a specific road segment (Pisano P. , 2011).

The third and final stage of the VDT intakes road segment statistics to the inference module. The inference module uses algorithms, such as decision trees and fuzzy logic, to produce advanced road segment data. These data are then sent through a third QC module and assigned a confidence value before leaving the VDT as advanced road segment data (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011). The third version of the VDT produces three primary output variables: precipitation, pavement condition, and visibility. Precipitation output provides an assessment of the type and intensity of precipitation, such as snow, rain, ice, or hail. Pavement condition output provides an assessment of the pavement condition on a segment of road, such as dry, wet, road splash, snow, icy/slick, and risk of hydroplaning. Visibility output provides an indication of decreased visibility hazards such as dense fog, heavy rain, blowing snow, and smoke. Each output variable contains an option for “no present conditions” (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011).

Ancillary data are used to bolster confidence of the reported weather data in the VDT. More sources of ancillary data will be made available to be integrated into the VDT as meteorological technology continues to advance. Table 2.2 lists the current ancillary data sources used in the third version of the VDT (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011).

Table 2.2 Ancillary Data Sources Used in the VDT 3.0

Radar	NWS Products
Gridded Weather Observations	Social Media
Satellite	Clarus System
Surface Stations	Road Weather Forecasts

A variety of ancillary data sources are used to provide the most accurate segmented road weather data. Among the ancillary data listed in Table 2.2 is social media, such as Twitter. The Twitter social media platform allows travelers to report road traffic and conditions delivered as plain text reports. The Twitter Search Application Program Interface collects relevant roadway data every five minutes and processes it into a form that can be integrated into the VDT. The third version of the VDT does not use the Twitter information in any of the algorithm processes, but provides information to the end user.

Each of the three outputs are created by a series of sophisticated algorithms used to analyze mobile and ancillary data. Table A.1, Table A.2, and Table A.3 (Appendix A) provide an overview of the various algorithms in the inference module used to produce the precipitation, pavement condition, and visibility outputs, respectively.

It is evident that quality checking is an important component of the Vehicle Data Translator. The purpose of the QC modules are to identify and eliminate observations, which are highly improbable due to known historical values, sensor ranges, and vehicle locations. In addition, the QC modules are meant to identify potential malfunctions or calibration errors in the mobile data sources by comparing mobile data to ancillary data and mobile data from neighboring vehicles (Pisano P., 2011). Table 2.3 shows the 10 primary Quality Checking routines in the VDT. In addition, Table 2.3 provides a brief description, outlines the challenges, and gives the scoring system for each routine (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011).

Table 2.3 Quality Checking Routines for the VDT 3.0

Quality Check Routines				
Quality Check		**Definition**	**Challenges**	**Pass/Fail**
Clarus Based	**Anticipated Range Test (ART)**	Detects readings that fall outside the anticipated realistic range of sensor **hardware specifications** or theoretical limits (minimum and maximum values). This test is useful in identifying observations that are not likely possible with the given sensor.	It is not possible to identify the ART bounds with precision for some vehicle instruments because the OEMs do not release this information, and sensor identification is anonymous due to privacy laws and regulations.	
	Persistence Test (PET)	The persistence test detects whether sensor readings remain constant for a predefined variable-specific period of time. EX: if the sensor is displaying the same reading for an amount of time, then the sensor would not pass the test.	This is only an acceptable test for fleet vehicles where the identity of the vehicle/ sensor can be made known.	1 = Pass, 0 = Fail
	Time Step Test (TST)	The TST detects sensor readings whose values change by more than a predefined variable-specific or station-specific rate over: 30 minute (past) & 5 minute (future) configurable period. The test requires at least two readings (current and past). EX: An air temperature reading from 2PM would be compared to corresponding air temperature readings *from the same sensor* that was recorded in the time range of 1:30PM-2:05PM.	This is only an acceptable test for fleet vehicles where the identity of the vehicle/ sensor can be made known.	1 = Pass, 0 = Fail Considering Binary Scale
	Spatial Test - Temperature: Air and Pavement (STTa, STTp)	In areas that there are more than 5 observations within a 69-mile radius and five minute observation time, the interquartile range (IQR) is used as a more robust method for spatial QC. In areas where there are not enough observations, the Barnes Spatial QC method will be used.		1 = Pass, 0 = Fail Considering Binary Scale
	Spatial Test - Air Pressure (STP)	The Pressure Spatial Test (PST) will compare the observations with the closest surface stations in space and time. The nearest stations should be within a 69mi radius and five minute observation time from the data point.		1 = Pass, 0 = Fail Considering Binary Scale
	Climate Range Test (CRT)	The CRT detects sensor readings that fall outside the predetermined climate range values. Bounds for the CRT test were determined by computing monthly minimum and maximum values over a 2.5 degree x 2.5 degree fixed latitude-longitude grid.		1 = Pass, 0 = Fail
Non-Clarus Based	**Data Filtering Test (DFT)**	The DFT eliminates data that is obviously incorrect: latitude values greater than 90N, or a time greater than 23:59:59. This test also identifies situations (such as traveling through a tunnel), that may be misleading (headlights and wiper status will vary in a tunnel).	There is some research that indicates that low speed, air temperature data may not be reliable; however, other findings do not show the same results.	1 = Pass, 0 = Fail
	Model Analysis Test (MAT)	The MAT compares the air temperature and pressure observations from the vehicles to those of a numerical weather model analysis field for the closest grid point (RTMA data ingested once per hour).	Considering the binary scale with confidence values decreasing over the hour long time period from the data being collected (because it becomes more and more inaccurate).	1 = Pass, 0 = Fail Considering Binary Scale
	Neighboring Vehicle Test (NVT)	The NVT compares the given vehicle observation to neighboring vehicles in the road segment. Specifically: standard deviation and the mean of observations along a one mile road segment during a five-minute time period that will be adjusted with a set or minimum number of vehicles required.	This test may be challenging to achieve accurate and meaningful results with a limited number of vehicles.	
	Combined Algorithm Test (CAT)	The CAT is designed to take the results of all the previous QC tests and combine them in order to assign a confidence to the observation that is being QC'd.	How to represent the data: number of tests passed (but are some tests more representative than others) or a scale ranging from 0.00 (no confidence) to 1.00 (full confidence)?	0-1 or # of tests passed

The first six quality-checking algorithms shown in Table 2.3 were developed from the Clarus project, an initiative that combined atmospheric and pavement observation from RWIS across Northern America (Ray, 2011). In previous versions of the VDT, the Clarus system was used as an ancillary data source to supplement vehicle data. The Clarus initiative was shut down in 2015, and therefore, it is not used in the fourth version of the VDT. In addition to using Clarus QC algorithms to establish the QC modules in the VDT, connected vehicle temperature and pressure data from the 2008 Detroit Proof-of-Concept experiment and the 2009 Development Test Bed Environment were used to determine QC algorithms (Drobot, et al., 2009).

The fourth version of the VDT does not follow the same step-by-step mechanism as the third version, as shown in Figure 2.11 (Chapman, The Pikalert Road Weather Hazard Forecast System Presentation, 2014).

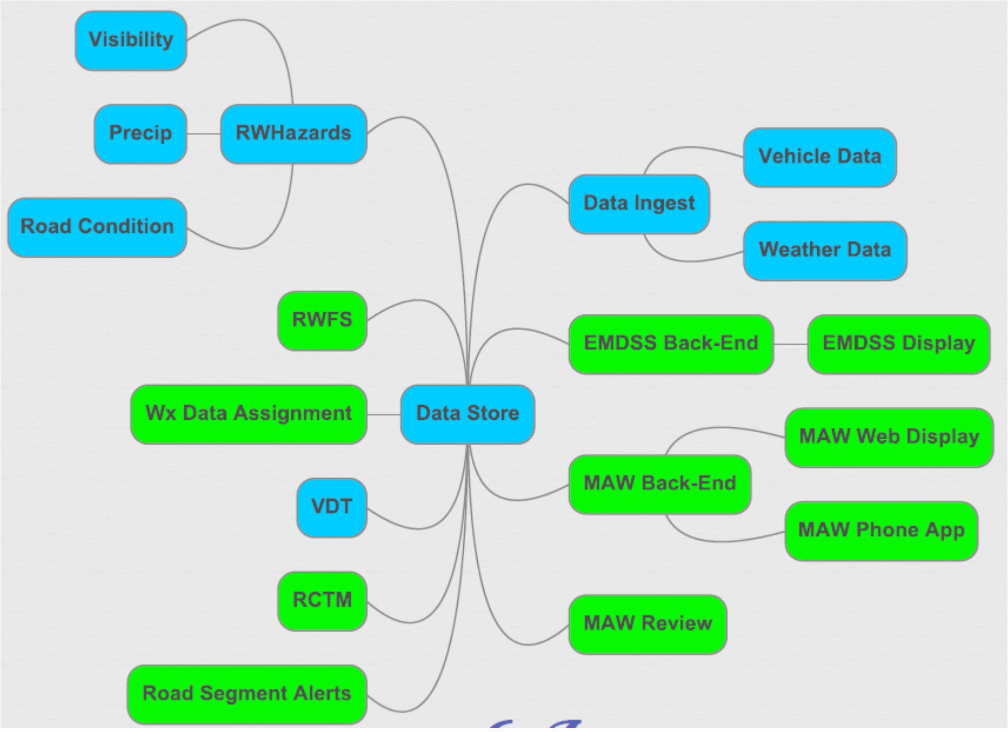


Figure 2.11 VDT 4.0 Process Diagram

While the VDT process diagram changed significantly from the third version, the fourth version of the VDT operates similarly, but provides a significant increase in data applications including road segment alerts, EMDSS (enhanced maintenance decision support systems), and MAW review (motorist advisory warnings). As shown, the process diagram for the VDT 4.0 does not include detailed review of the VDT modules; rather, it provides an overview of how the data from the VDT is used.

NCAR's Pikalert/ VDT software is the most advanced data software available to determine road conditions from mobile data. However, vehicle performance and basic road conditions can be analyzed through other computing programs, such as Matlab. The MDOT/UMTRI Slippery Road Detection and Evaluation Project sent all of its mobile data to NCAR to gain advanced road segment data. Researchers also used Matlab Visualization tools to quickly analyze each data set (Robinson & Cook, 2012). The MDOT/UMTRI Matlab program examines the quality of each data set and identifies any anomalies present in the data. If anomalies are found, data are set aside for further review. If no anomalies are found, data are summarized and moved to a separate folder (Robinson & Cook, 2012).

The summary file provides the main characteristics of each data file and indicates the number of potential *events* that occurred so files of interest can be found quickly. *Events* are defined as any activation of anti-lock brakes, electronic stability control, or the traction control system (Robinson & Cook, 2012). These events can be compared with road surface temperature, additional vehicles experiencing the same event, road surface type, and vehicle performance history to determine the most probable road surface condition. In addition to providing the summary file, the MDOT/UMTRI Matlab program provides visual representation of many mobile data variables including brake status, smart-device accelerometer data, and steering wheel angle. The visual analysis, combined with specific algorithms, allowed MDOT/UMTRI to begin to identify locations with slippery conditions (Robinson & Cook, 2012).

The following section discusses current research and implementation efforts for connected vehicle road condition evaluations.

2.4.4 Current Research and Implementation Efforts

Transportation agencies in areas with severe weather conditions understand the dire need to provide real-time, accurate information to travelers on roadways. These agencies also understand the need for continuous, segmented road condition data to best assign winter maintenance equipment and materials. Regardless, only a few transportation agencies have looked into advanced methods of road condition assessment through the collection of mobile data.

As discussed in previous sections, the Michigan DOT and the University of Michigan's TRI partnership with FHWA represents one of the forerunners of using mobile data technology to evaluate road condition data. The MDOT currently uses Weather Responsive Decision Making, which combines a variety of datasets including local weather and radar, traffic cameras, RWIS, and mobile vehicle data (CAN-Bus, external sensor, and smart-device data). The conglomeration of these data allow the state of Michigan to take full advantage of mobile weather data to provide valuable information to travelers and decision makers (Cook, Using Connected Vehicle Data for WRTM in Michigan Presentation, 2014).

The largest effort to increase the use of mobile data in road condition assessment was initiated by the Federal Highway Administration project, Integrated Mobile Observations (IMO). FHWA, Michigan DOT, Minnesota DOT, and Nevada DOT joined to work under the IMO project and develop an architecture that provides efficient WRTM (Weather Responsive Traffic Management) strategies and advanced data collection and analysis (Cook, Using Connected Vehicle Data for WRTM in Michigan Presentation, 2014). This program utilizes an ELM 327 VI connected to the vehicle's CAN-Bus network, external sensors, and a smartphone to translate vehicle data over the cellular network to NCAR. NCAR processes data through the Pikalert/ VDT software from the three participating DOTs. After processing, the mobile data is sent back to the states and used for Motorist Advisory Warnings (MAW) and Maintenance Decision Support Systems (MDSS) (Cook, Using Connected Vehicle Data for WRTM in Michigan Presentation, 2014).

The IMO project includes various DOT fleet vehicles from each state, as well as snowplows, to allow greater data collection during storm events. The IMO data collection could be used for many applications including, real-time road quality monitoring, fleet monitoring and management, travel times and incident updates, visibility monitoring, and vehicle diagnostics (Cook, Robinson, Belozowski, Croze, & Pratt). Outcomes of the IMO project varied with each state. The Nevada DOT experienced low quality CAN-Bus data. When NCAR's Pikalert/ VDT outputs for Michigan and Minnesota were compared with the observed RWIS data in the area, a strong correspondence between mobile and stationary road conditions reports was recognized, indicating potential value in mobile data collection (Chapman, Drobot, Anderson, & Burghardt, 2013).

2.5 Summary of Literature Review

The purpose of completing a comprehensive state of practice literature review was to guide research efforts and strategies. Currently, limited research exists in detecting road weather conditions through a vehicle’s CAN-Bus and communicating data to be used in safety, mobility, and efficiency applications. Significantly more research has been completed regarding intelligent transportation systems, connected vehicles, and road weather management. This broad information is valuable for identifying research opportunities, challenges, constraints, and avenues with respect to connected vehicle applications for road weather management.

The literature review started with an overview of ITS, discussing processes behind ITS implementation, the history of ITS, efforts made in establishing ITS architecture and standards, existing ITS applications and their benefits, and the future of ITS. Next, a large component of ITS--connected vehicles, was discussed in detail. Institutional issues for CV technology were introduced, the history of CV applications reviewed, and communication technology for CV implementation explained. In addition, current CV applications and test beds were presented with a summary of the benefits and perceived future of CV technology. Then, a brief overview of existing Road Weather Management Strategies was discussed. Specifically, RWIS systems and other detection mechanisms were explained and specific Weather Responsive Traffic Management strategies were outlined. Finally, current research on connected vehicle road weather condition applications was discussed. Before current research and implementation efforts were described, the three primary components of most existing systems were split and details were provided for collection of data, communication or transfer of data, and processing and analysis of data.

3. RESEARCH METHODOLOGY

As stated in Section 1. Introduction, the purpose of this research is to evaluate how rural corridor management, specifically variable speed limit assignment during winter weather events, would be affected by mobile data from a vehicle's CAN-Bus. This section identifies research methodology used to evaluate research objectives.

3.1 Objective One – Connected vehicle technology

The first research objective is: *determine the most effective technology for collecting connected vehicle data from vehicles' CAN-Bus*. This objective was met through a detailed literature review and evaluation of agencies, universities, and other entities currently collecting CAN-Bus data from vehicles. Published reports and documents were analyzed to determine outcomes and lessons learned from projects collecting CAN-Bus data. Researchers working on projects with similar goals and boundary conditions were contacted and informal interviews were conducted. A "trial-and-error" approach was used to test a variety of different vehicle interfaces on test vehicles. Relationships were formed with the University of Wyoming Fleet Services to allow researchers to conduct vehicle tests on fleet vehicles on a consistent basis.

Section 2. State of Practice Literature Review, outlines information collected from the detailed literature review used to evaluate connected vehicle technology. Section 4.1 Vehicle Interface Selection, provides the information and data collected from the trial-and-error procedure used to determine the most effective and complete method for receiving messages from a vehicle's CAN-Bus network.

3.2 Objective Two – Conversion of connected vehicle data to weather data

The second research objective is to *investigate the reliability and practicality of ascertaining segmented road condition data from NCAR's Pikalert System*. To accomplish this objective, researchers hired a University of Wyoming Computer Science Master's student, Nels Frazier, to assist in programming and setting up the Pikalert system. However, due to difficulty in applying the Pikalert system to the collected data, the majority of the data analysis was conducted qualitatively using MatLab and ArcGIS to create graphical representations of the vehicle data.

Section 5.1 NCAR Pikalert/VDT, provides the procedures followed to set up a UWYO computer environment for NCAR's Pikalert system, the challenges associated with setting up the system, and the results of such efforts.

3.3 Objective Three – Integration of connected vehicle data to VSL operations

The third research objective is to *determine whether connected vehicle CAN-Bus data is suitable for supporting data requirements of VSL decision-making algorithms*. This objective was partially accomplished through the data gathered; however, due to the lack of crucial vehicle data and difficulty using NCAR's Pikalert system for analysis, it was determined that connected vehicle data would not be suitable to integrate with VSL operations at this time. It is likely that improvements to the standard data sets that connected vehicle-compliant vehicles will address many of the data issues encountered during this research effort.

Section 6. Conclusions and Recommendations, provide the final conclusions evaluating the practical use of CAN-Bus data in assigning variable speed limits, and the data's compatibility in existing VSL decision-making algorithms.

3.4 Objective Four – Identify future research needs

The fourth research objective is to *recommend and identify future research needs regarding the prospective use of connected vehicle data in rural roadway corridors subject to significant weather events*. Recommendations and future research were determined through an evaluation of the research results: collection of necessary CAN-Bus data, analysis of CAN-Bus data in Pikalert and other data analysis programs, and practicality in using CAN-Bus data to assign variable speed limits during adverse weather conditions. In addition, the literature review also was revisited and used to supplement the recommendations and future research needs.

Section 6. Conclusions and Recommendations and Section 7. Future Research Needs, provide the final recommendations and future research needs regarding the use of connected vehicle data to replace or supplement current road weather management strategies.

4. DATA COLLECTION

Connected vehicle applications depend on reliable data collection of relevant data parameters. As mentioned in Section 2. State of Practice Literature Review, one of the most challenging components to a connected vehicle road condition reporting system is collecting CAN-Bus data from vehicles. This is due to the data security protocols and complex nature of CAN-Bus messages from each individual vehicle make, model, and manufacturer. Therefore, the selection of a vehicle interface (VI) capable of reliably collecting all necessary data from a vehicle's CAN-Bus is difficult to obtain without vehicle manufacturers and information directly from the source.

The following sections illustrate the procedures used to select an adequate vehicle interface and the collection of CAN-Bus data. RWIS data also were collected to provide a basis for comparing vehicle data with actual weather conditions.

4.1 Vehicle Interface Selection

The UWYO research team tested a variety of vehicle interfaces and associated data collection mechanisms (devices used to read and store the VI data, referred to in the literature review as smart-devices) before selecting the Open XC CrossChasm C5 (CrossChasm, 2014) VI with a Samsung Galaxy Tablet (Samsung, 2015). The criteria in which each VI was tested included:

- availability of necessary input data
- ability to attain appropriate vehicle to collect data
- reliability of data collection

The first criteria, *availability of necessary input data*, was assessed based on the NCAR Pikalert/VDT vehicle data input parameters listed in the VDT 3.0 System Description (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011). Table 4.1 provides the vehicle CAN-Bus data requirements for the third version of NCAR's VDT (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011).

Table 4.1 Vehicle CAN-Bus Data Requirements for NCAR Pikalert System

External Air Temperature	Vehicle Velocity	Wiper Status
Atmospheric Pressure	Brake Status	Headlight Status
Antilock Braking Status	Vehicle Heading	Accelerometer
Traction and Stability Control	Tire RPM	Location
Steering Rate of Change	Engine Torque and Diagnostics	Time

The second criteria, *ability to attain appropriate vehicle to collect data*, was assessed based on the UWYO available vehicles through the fleet service (UWYO Fleet Services, n.d.). The UWYO fleet services allowed researchers to test data collection methods on various fleet vehicle prior to full-scale data collection trips where vehicles were rented for single or multiple days.

The third criteria, *reliability of data collection*, was evaluated through full-scale data collection trips where the VI and collection method were used to traverse a specified route along Interstate-80 between Laramie and Rawlins, Wyoming. Reliability of the collection methods were confirmed when the VI and collection method continuously functioned throughout the 200-mile roundtrip.

Sections 4.1.1–4.1.5 outline tests performed with each VI and corresponding data collection mechanism.

4.1.1 OBDLink & Verizon Ellipse Tablet with Dash Command

The first VI examined was the OBDLink MX Bluetooth (OBDLink MK Bluetooth, 2015), shown in Figure 4.1 (Scantool-Direct, 2015).

Figure 4.1 OBDLink MX Bluetooth Vehicle Interface

This VI was selected because the device supports all legislated OBD-II protocols in vehicles manufactured after 1995; in addition, the MX version contained the option for advanced Ford, GM, and Mazda vehicle package, allowing greater data collection from Ford, GM, and Mazda vehicles (OBDLink MK Bluetooth, 2015). The OBDLink MX device supported Bluetooth communication functions allowing connection to a Verizon Ellipse 7 Tablet (Verizon , 2015), shown in Figure 4.2.

Figure 4.2 Verizon Ellipse 7 Tablet

The OBDLink MX device provided a variety of android and windows software interfaces to collect vehicle CAN-Bus data, among these applications were: OBDLink, OBDwiz, Torque, ScanXL and DashCommand (OBDLink MK Bluetooth, 2015). The OBDLink and DashCommand android applications were downloaded onto the Verizon Ellipse 7 tablet to begin testing. The DashCommand application proved to be more valuable to research goals because it allowed multiple data collection views (shown in Figure 4.3), and the ability to buy additional vehicle parameter packages (allowing the collection of more CAN-Bus data) for the specific test vehicle.

Figure 4.3 Dash Command Android Application Views

Two vehicles were tested using the OBDLink MX VI and the DashCommand Application: a 2010 Ford Escape and a 2007 Ford Taurus (vehicle models shown in Figure 4.4).

Figure 4.4 2010 Ford Escape and 2007 Ford Taurus Used for Data Collection

Additional Dash Command vehicle parameter packages were purchased and CAN-Bus data were collected and recorded for each vehicle. The vehicle parameter packages allowed more data, specifically engine and transmission data, to be collected for the specified vehicle model and vehicle year. Figure 4.5, Figure 4.6, Figure 4.7, and Figure 4.8 illustrate selected data collected from the OBDLink VI and Dash Command android application during a test trip.

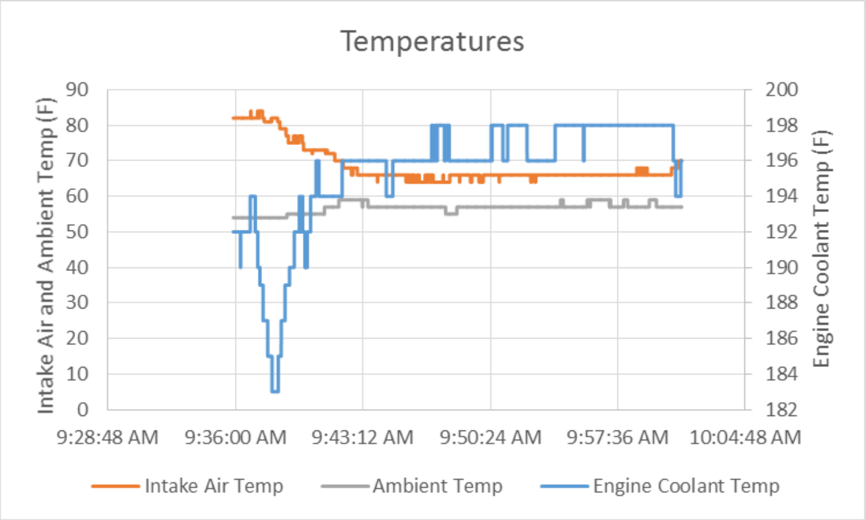


Figure 4.5 Temperature Data Collected from OBDLink and Dash Command on July 31, 2014 using 2010 Ford Escape

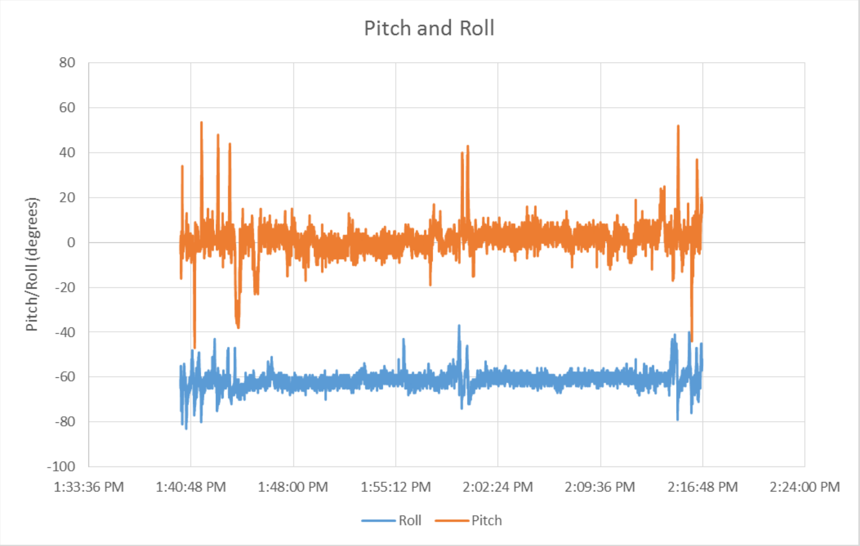


Figure 4.6 Pitch and Roll Steering Data Collected from OBDLink and Dash Command on September 2, 2014 using 2010 Ford Escape

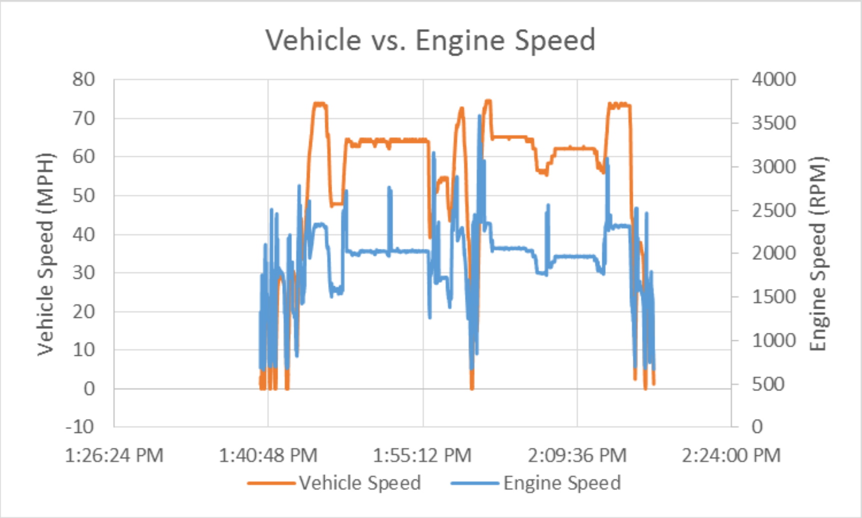


Figure 4.7 Vehicle Speed vs. Engine Speed Collected from OBDLink and Dash Command on September 2, 2014 using 2010 Ford Escape

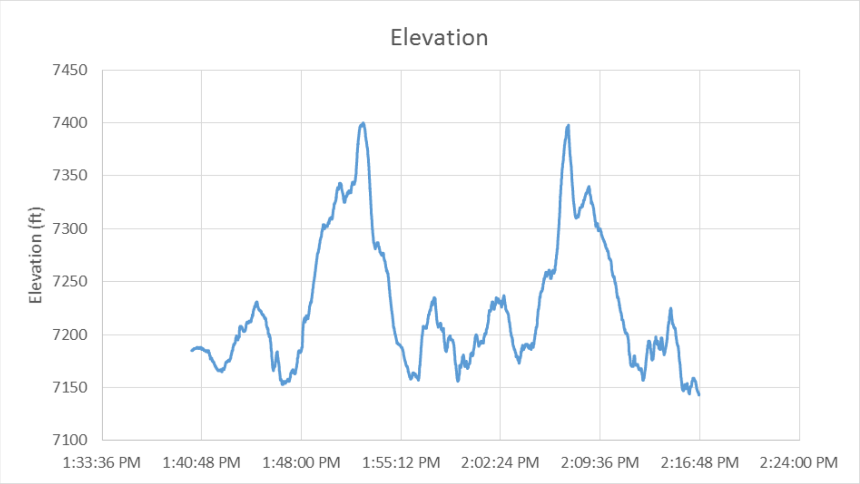


Figure 4.8 Elevation Data Collected from OBDLink and Dash Command on September 2, 2014 using 2010 Ford Escape

Higher quality CAN-Bus data were collected from the 2010 Ford Escape, however, the CAN-Bus data available did not include crucial parameters such as traction and stability control, windshield wiper status, and headlight status, among others listed in Table 4.1. Therefore, focus was redirected from the DashCommand Android application to the corresponding Windows software, ScanXL (Palmer Performance Engineering, 2013).

4.1.2 OBDLink & Windows Computer with ScanXL

Palmer's ScanXL Professional (Palmer Performance Engineering, 2013) software provides a range of general vehicle diagnostics. According to specifications, use of the ScanXL Professional software with manufacturer-enabled diagnostics should enable the collection of proprietary vehicle parameters such as ABS brakes. When purchased, the Manufacturer Enhanced Diagnostics were available for

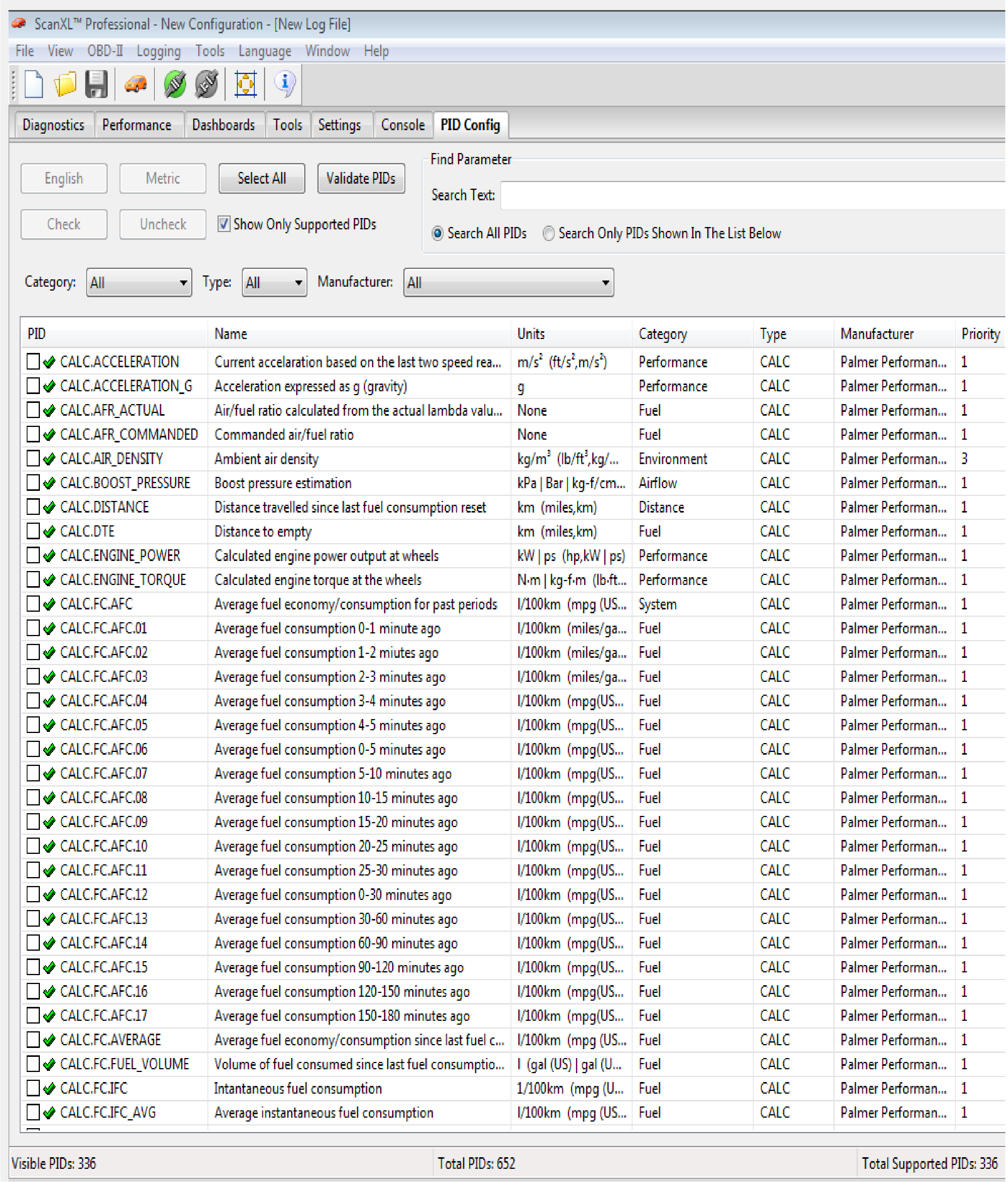
Ford/Lincoln/Mercury, GM, and Mazda vehicles manufactured between 1996 and 2009 (Palmer Performance Engineering, 2013).

The ScanXL Professional software program and the Ford/Lincoln/Mercury enhanced diagnostics package were purchased and tested on three test vehicles: 2007 Ford Taurus, 2010 Ford Escape, and 2014 Ford Fusion (illustrated in Figure 4.9).

Figure 4.9 2014 Ford Fusion Used for Data Collection

After discussions with Palmer Engineering sales representatives, it became evident that the only method for determining which vehicles supported which CAN-Bus messages or vehicle parameters was a trial-and-error testing method. Therefore, each of the three test vehicles were connected to the ScanXL software using the OBDLink VI, and the available parameters for each vehicle were analyzed. While the enhanced diagnostic package for Ford vehicles was intended to support vehicles manufactured between 1996 and 2009, more vehicle parameters were available for the 2010 Ford Escape and the 2014 Ford Fusion than the 2007 Ford Taurus.

Figure 4.10 illustrates a portion of the vehicle parameters supported through the ScanXL software for the 2010 Ford Escape. Figure 4.11 shows the data collection screen for selected parameters in the 2010 Ford Escape. The data collection screen indicated real-time data and aggregated all data into a log file to be analyzed further.



☑ Show Only Supported PIDs

Find Parameter

Search Text:

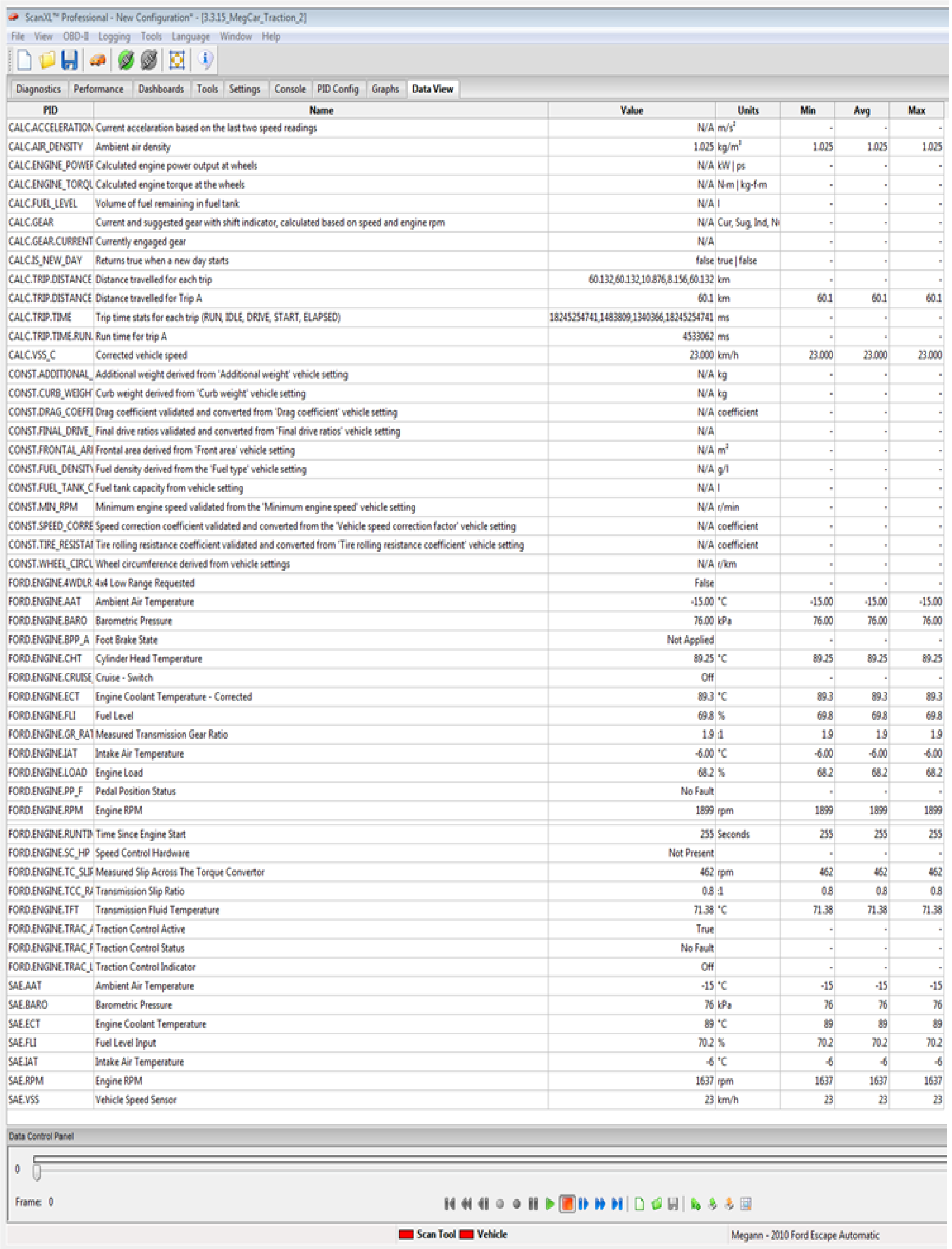
● Search All PIDs ○ Search Only PIDs Shown In The List Below

Category: All Type: All Manufacturer: All

PID	Name	Units	Category	Type	Manufacturer	Priority
☐ ✓ CALC.ACCELERATION	Current accelaration based on the last two speed rea...	m/s^2 (ft/s^2,m/s^2)	Performance	CALC	Palmer Performan...	1
☐ ✓ CALC.ACCELERATION_G	Acceleration expressed as g (gravity)	g	Performance	CALC	Palmer Performan...	1
☐ ✓ CALC.AFR_ACTUAL	Air/fuel ratio calculated from the actual lambda valu...	None	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.AFR_COMMANDED	Commanded air/fuel ratio	None	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.AIR_DENSITY	Ambient air density	kg/m^3 (lb/ft^3,kg/...	Environment	CALC	Palmer Performan...	3
☐ ✓ CALC.BOOST_PRESSURE	Boost pressure estimation	kPa | Bar | kg-f/cm...	Airflow	CALC	Palmer Performan...	1
☐ ✓ CALC.DISTANCE	Distance travelled since last fuel consumption reset	km (miles,km)	Distance	CALC	Palmer Performan...	1
☐ ✓ CALC.DTE	Distance to empty	km (miles,km)	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.ENGINE_POWER	Calculated engine power output at wheels	kW | ps (hp,kW | ps)	Performance	CALC	Palmer Performan...	1
☐ ✓ CALC.ENGINE_TORQUE	Calculated engine torque at the wheels	N·m | kg-f·m (lb·ft...	Performance	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC	Average fuel economy/consumption for past periods	l/100km (mpg (US...	System	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.01	Average fuel consumption 0-1 minute ago	l/100km (miles/ga...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.02	Average fuel consumption 1-2 miutes ago	l/100km (miles/ga...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.03	Average fuel consumption 2-3 minutes ago	l/100km (miles/ga...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.04	Average fuel consumption 3-4 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.05	Average fuel consumption 4-5 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.06	Average fuel consumption 0-5 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.07	Average fuel consumption 5-10 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.08	Average fuel consumption 10-15 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.09	Average fuel consumption 15-20 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.10	Average fuel consumption 20-25 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.11	Average fuel consumption 25-30 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.12	Average fuel consumption 0-30 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.13	Average fuel consumption 30-60 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.14	Average fuel consumption 60-90 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.15	Average fuel consumption 90-120 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.16	Average fuel consumption 120-150 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AFC.17	Average fuel consumption 150-180 minutes ago	l/100km (mpg(US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.AVERAGE	Average fuel economy/consumption since last fuel c...	l/100km (mpg (US...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.FUEL_VOLUME	Volume of fuel consumed since last fuel consumptio...	l (gal (US) | gal (U...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.IFC	Intantaneous fuel consumption	1/100km (mpg (U...	Fuel	CALC	Palmer Performan...	1
☐ ✓ CALC.FC.IFC_AVG	Average instantaneous fuel consumption	l/100km (mpg (US...	Fuel	CALC	Palmer Performan...	1

Visible PIDs: 336 Total PIDs: 652 Total Supported PIDs: 336

Figure 4.10 Screenshot of Select PIDs (Parameter Identification) for 2010 Ford Fusion



PID	Name	Value	Units	Min	Avg	Max
CALC.ACCELERATION	Current accelaration based on the last two speed readings	N/A	m/s^2	-	-	-
CALC.AIR_DENSITY	Ambient air density	1.025	kg/m^3	1.025	1.025	1.025
CALC.ENGINE_POWEF	Calculated engine power output at wheels	N/A	kW | ps	-	-	-
CALC.ENGINE_TORQL	Calculated engine torque at the wheels	N/A	N-m | kg-f-m	-	-	-
CALC.FUEL_LEVEL	Volume of fuel remaining in fuel tank	N/A	l	-	-	-
CALC.GEAR	Current and suggested gear with shift indicator, calculated based on speed and engine rpm	N/A	Cur, Sug, Ind, N	-	-	-
CALC.GEAR.CURRENT	Currently engaged gear	N/A		-	-	-
CALC.IS_NEW_DAY	Returns true when a new day starts	false	true | false	-	-	-
CALC.TRIP.DISTANCE	Distance travelled for each trip	60.132,60.132,10.876,8.156,60.132	km	-	-	-
CALC.TRIP.DISTANCE	Distance travelled for Trip A	60.1	km	60.1	60.1	60.1
CALC.TRIP.TIME	Trip time stats for each trip (RUN, IDLE, DRIVE, START, ELAPSED)	18245254741,1483809,1340366,18245254741	ms	-	-	-
CALC.TRIP.TIME.RUN.	Run time for trip A	4533062	ms	-	-	-
CALC.VSS_C	Corrected vehicle speed	23.000	km/h	23.000	23.000	23.000
CONST.ADDITIONAL_	Additional weight derived from 'Additional weight' vehicle setting	N/A	kg	-	-	-
CONST.CURB_WEIGH	Curb weight derived from 'Curb weight' vehicle setting	N/A	kg	-	-	-
CONST.DRAG_COEFFI	Drag coefficient validated and converted from 'Drag coefficient' vehicle setting	N/A	coefficient	-	-	-
CONST.FINAL_DRIVE_	Final drive ratios validated and converted from 'Final drive ratios' vehicle setting	N/A		-	-	-
CONST.FRONTAL_ARI	Frontal area derived from 'Front area' vehicle setting	N/A	m^2	-	-	-
CONST.FUEL_DENSIT	Fuel density derived from the 'Fuel type' vehicle setting	N/A	g/l	-	-	-
CONST.FUEL_TANK_C	Fuel tank capacity from vehicle setting	N/A	l	-	-	-
CONST.MIN_RPM	Minimum engine speed validated from the 'Minimum engine speed' vehicle setting	N/A	r/min	-	-	-
CONST.SPEED_CORRE	Speed correction coefficient validated and converted from the 'Vehicle speed correction factor' vehicle setting	N/A	coefficient	-	-	-
CONST.TIRE_RESISTAI	Tire rolling resistance coefficient validated and converted from 'Tire rolling resistance coefficient' vehicle setting	N/A	coefficient	-	-	-
CONST.WHEEL_CIRCL	Wheel circumference derived from vehicle settings	N/A	r/km	-	-	-
FORD.ENGINE.4WDLR	4x4 Low Range Requested	False		-	-	-
FORD.ENGINE.AAT	Ambient Air Temperature	-15.00	°C	-15.00	-15.00	-15.00
FORD.ENGINE.BARO	Barometric Pressure	76.00	kPa	76.00	76.00	76.00
FORD.ENGINE.BPP_A	Foot Brake State	Not Applied		-	-	-
FORD.ENGINE.CHT	Cylinder Head Temperature	89.25	°C	89.25	89.25	89.25
FORD.ENGINE.CRUISE	Cruise - Switch	Off		-	-	-
FORD.ENGINE.ECT	Engine Coolant Temperature - Corrected	89.3	°C	89.3	89.3	89.3
FORD.ENGINE.FLI	Fuel Level	69.8	%	69.8	69.8	69.8
FORD.ENGINE.GR_RAT	Measured Transmission Gear Ratio	1.9	:1	1.9	1.9	1.9
FORD.ENGINE.IAT	Intake Air Temperature	-6.00	°C	-6.00	-6.00	-6.00
FORD.ENGINE.LOAD	Engine Load	68.2	%	68.2	68.2	68.2
FORD.ENGINE.PP_F	Pedal Position Status	No Fault		-	-	-
FORD.ENGINE.RPM	Engine RPM	1899	rpm	1899	1899	1899
FORD.ENGINE.RUNTII	Time Since Engine Start	255	Seconds	255	255	255
FORD.ENGINE.SC_HP	Speed Control Hardware	Not Present		-	-	-
FORD.ENGINE.TC_SLIF	Measured Slip Across The Torque Convertor	462	rpm	462	462	462
FORD.ENGINE.TCC_RA	Transmission Slip Ratio	0.8	:1	0.8	0.8	0.8
FORD.ENGINE.TFT	Transmission Fluid Temperature	71.38	°C	71.38	71.38	71.38
FORD.ENGINE.TRAC_A	Traction Control Active	True		-	-	-
FORD.ENGINE.TRAC_F	Traction Control Status	No Fault		-	-	-
FORD.ENGINE.TRAC_L	Traction Control Indicator	Off		-	-	-
SAE.AAT	Ambient Air Temperature	-15	°C	-15	-15	-15
SAE.BARO	Barometric Pressure	76	kPa	76	76	76
SAE.ECT	Engine Coolant Temperature	89	°C	89	89	89
SAE.FLI	Fuel Level Input	70.2	%	70.2	70.2	70.2
SAE.IAT	Intake Air Temperature	-6	°C	-6	-6	-6
SAE.RPM	Engine RPM	1637	rpm	1637	1637	1637
SAE.VSS	Vehicle Speed Sensor	23	km/h	23	23	23

Figure 4.11 Screenshot of Data Collection Screen while Collecting Data from 2010 Ford Fusion using OBDLink and ScanXL

As Figure 4.11 indicates, crucial parameters, such as Tire Rolling Coefficient and Engine Torque at Wheels were not available. In addition, testing indicated that the traction and stability control parameters did not indicate activation of traction or stability events when the vehicle's traction and stability control system was activated (showing a warning inside the vehicle). The ScanXL software also did not allow ABS braking data and headlamp data to be collected through the OBDLink VI. Finally, due to the data collection aggregated on a Windows computer, rather than a smart device, location data were collected separately and all vehicle data were matched to location data through the timestamp.

Researchers contacted Palmer Engineering regarding issues in data collection with their software and vehicle interface. In response, Palmer Engineering representatives suggested contacting Ford Motor Company to query information regarding vehicle parameters available for different vehicles. After little success contacting Ford, research focus switched to OpenXC (The Open XC Platform, n.d.), an open source platform that enabled less restricted and more flexible CAN-Bus data collection.

4.1.3 CrossChasm C5 & Verizon Ellipse Tablet with OpenXC Enabler

The OpenXC Platform combines hardware and software that enables individuals to access data from a vehicle's CAN-Bus. Unlike other VI/Software packages, OpenXC allows developers and researchers the ability to use data and applications to create custom applications to fit specific needs (The Open XC Platform, n.d.). For the purpose of this research, the basic android application and interface provided were sufficient; therefore, a custom application was not built.

To use the OpenXC platform with a live vehicle, three hardware components were required:
(1) Supported vehicle interface, (2) Compatible host device, and (3) Compatible vehicle (OpenXC, n.d.). The ideal VI for this research was the Ford Reference VI, however, Ford Motor Company was not releasing this hardware during the fall of 2014, when data collection methods were being identified. Therefore, the second pre-assembled VI, CrossChasm C5, was selected and purchased. The downside with using the CrossChasm C5 VI is that only CAN1 bus pins can be connected, while the Ford Reference VI could connect to CAN1, CAN2-1, or CAN2-2 pins. The connection to multiple pins is relevant because it allows for greater data collection for some vehicles.

In cooperation with OpenXC, Ford Motor Company released data indicating vehicle parameters that could be collected from select Ford vehicle models and years, the CAN-Bus pins required for collection, and firmware files allowing data collection. The information provided indicated that firmware was not available for two of the three test vehicles: 2010 Ford Escape and 2007 Ford Taurus. However, firmware was available for the 2014 Ford Fusion, and Table 4.2 indicates the vehicle parameters available for collection using the CAN1 pin.

Table 4.2 Vehicle Parameters Available Using CrossChasm C5 and OpenXC Software

Vehicle Parameter	
Steering Wheel Angle	Vehicle Speed
Engine Speed	Fuel Consumed Since Restart
Transmission Gear Position	Door Status
Ignition Status	Windshield Wiper Status
Brake Pedal Status	Odometer
Headlamp Status	High Beam Status
Accelerator Pedal Position	Fuel Level
Torque At Transmission	Latitude & Longitude

After purchasing the CrossChasm C5, the VI was programmed with the specified Ford Reference firmware allowing for data collection from the 2014 Ford Fusion (Ford Motor Company, 2014). The firmware was flashed to the VI using procedures provided by the OpenXC and CrossChasm partnership (OpenXC & CrossChasm).

Once the CrossChasm C5 VI was programmed, the OpenXC enabler software was downloaded to the Verizon Ellipse tablet. However, due to limitations in the Verizon Ellipse tablet software, the OpenXC enabler software could not be downloaded successfully to allow communication between the VI and the application. Therefore, a new smart device, Samsung Galaxy Tablet was tested.

4.1.4 CrossChasm C5 & Samsung Galaxy Tablet with OpenXC Enabler

To test the programmed CrossChasm C5 with the OpenXC Enabler software and android application, a Samsung Galaxy Tablet was purchased and the application was downloaded to the tablet. In-vehicle testing indicated that the CrossChasm C5 VI and the Samsung Galaxy tablet combination successfully collected data shown in Table 4.2. Figure 4.12 illustrates the data collection screen from the OpenXC Enabler android application operating in conjunction with the CrossChasm C5 VI. Only real-time data are shown on the data collection screen, however, all data were logged within the Samsung Galaxy’s internal and external memory.

Accelerator Pedal	0.0 %
Brake Pedal	off
Engine Speed	774.0 RPM
Fuel Consumed	0.212475 L
Fuel Level	92.282906 %
Headlamp	off
High Beams	off
Ignition Status	RUN
Latitude	41.301464 °
Longitude	-105.583359 °
Odometer	43886.507812 km
Parking Brake	off
Steering Wheel	12.700073 °
Transmission Torque	5.0 Nm
Transmission Gear	NEUTRAL
Vehicle Speed	0.0 km / h
Windshield Wiper	off

Figure 4.12 Data Collection Screen from OpenXC Enabler Android Application with Data translated by CrossChasm VI for 2014 Ford Fusion

While testing of the CrossChasm C5 VI was a success in conjunction with the Samsung Galaxy tablet, test vehicle selection was significantly limited because the VI could only connect to the CAN1 pins. For that reason, a homemade VI was made following instructions provided by OpenXC. The homemade VI was intended to allow connection to CAN1, CAN2-1, and CAN2-2 pins, increasing the number of potential test vehicles.

4.1.5 Homemade OpenXC VI & Samsung Galaxy Tablet with OpenXC Enabler

A homemade OpenXC VI was created following detailed instructions provided by OpenXC developers (OpenXC, n.d.). UW researchers received assistance from a technician in the University of Wyoming Electrical Engineering department and assembled the device according to instructions. Figure 4.13 shows photographs taken by UW researchers as the device was being assembled and after assembly.

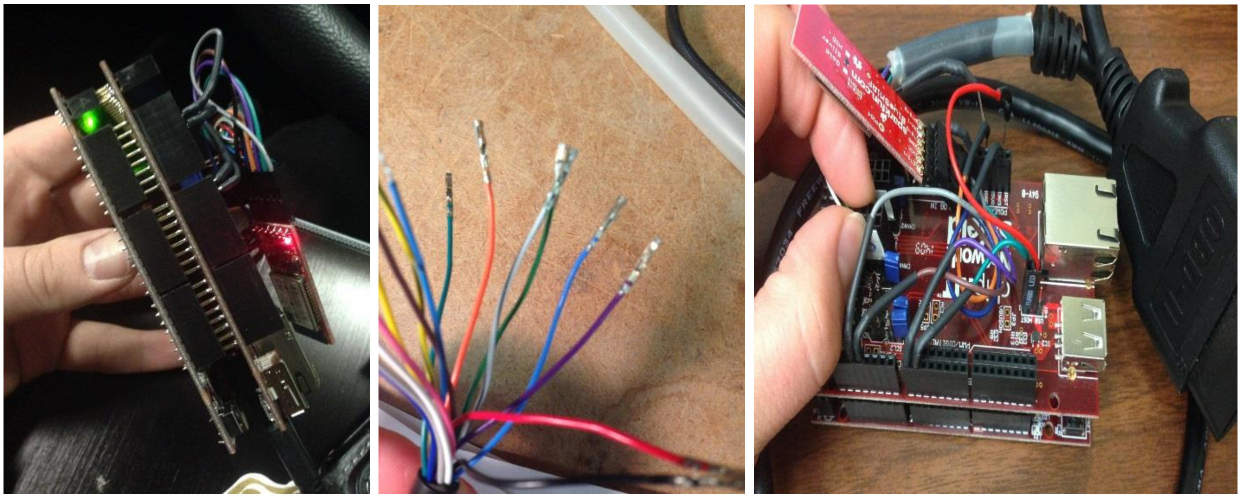


Figure 4.13 Photos of the Homemade OpenXC VI during Construction

Instructions provided by OpenXC were followed carefully, but when testing the VI in the 2014 Ford Fusion, the device caused the vehicle to turn-off and warning signs to turn-on. After multiple attempts at programming and reassembling the VI, successful data collection from the vehicle was not achieved; therefore, the CrossChasm C5 VI paired with the Samsung Galaxy Tablet equipped with OpenXC Enabler Software was selected as the final data collection mechanism.

4.2 CAN-Bus Data Collection

While the CrossChasm C5 VI and Samsung Galaxy Tablet with OpenXC Enabler proved to be the best method for collecting, communicating, and aggregating vehicle data, crucial data elements were not able to be collected. When comparing the data requirements from NCAR's VDT (Table 4.1 Vehicle CAN-Bus Data Requirements for NCAR Pikalert System) to the actual data collected from the CrossChasm C5 and OpenXC (Table 4.2 Vehicle Parameters Available Using CrossChasm C5 and Open XC Software) it is evident that Traction and Stability Control, ABS Braking, and Accelerometer data could not be collected. UW researchers could not find an open-source or off-the-shelf vehicle interface able to collect these vehicle data due to the proprietary nature of the data. Vehicle privacy and security concerns limit motor vehicle companies, such as Ford, from providing researchers and developers firmware coded to access the components of their vehicles' CAN-Buses with safety-critical vehicle parameters. As discussed in Section 2. Stat of Practice Literature Review, large-scale research projects, such as the joint efforts between UMTRI, MDOT, and FHWA are able to collect these proprietary data with a formalized agreement, Non-Disclosure Agreement (NDA), with Ford Motor Company. However, after multiple efforts to contact Ford Motor Company, UW researchers were unable to reach the appropriate contacts and establish a similar agreement with Ford.

Once the CrossChasm C5 VI and OpenXC Enabler on the Samsung tablet were selected, full data analysis trips were conducted. A full data analysis trip included a trip from Laramie to Walcott, Wyoming, (located west of Rawlins, Wyoming) or a trip from Walcott to Laramie, specifically focusing on the VSL corridor through the route. Figure 4.14 shows the data analysis route, and indicates that each individual trip covers approximately 80 miles of interstate roadway.

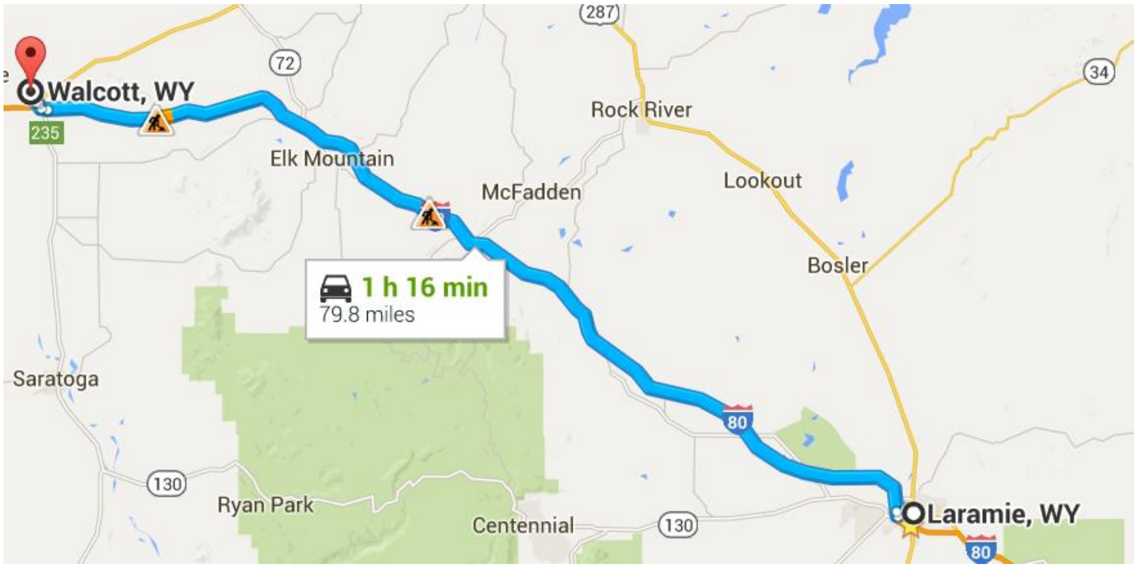


Figure 4.14 Primary Data Analysis Route between Laramie and Walcott, Wyoming, along I-80, Google Maps

Data collection trips were conducted in February and March of 2015, and 13 trips between Laramie and Walcott, Wyoming, were completed. Four trips were conducted in dry and sunny conditions, while the other trips were conducted in various winter conditions. In addition, three other trips were conducted; (1) from Laramie, Wyoming, to Boulder, Colorado; (2) from Laramie, Wyoming, to Herrick Lane; (3) from Herrick Lane to Laramie. Photos from various data collection trips can be found in Appendix B: Data Collection Photographs. Table 4.3 provides information for each of the 16 test trips, including the date and time, origin and destination, distance traveled, driver, passenger, and vehicle.

Table 4.3 CrossChasm C5 and OpenXC Enabler Data Collection Trip Summary

TripIDNumber	Date	Origin	Departure Time	Destination	Arrival Time	Distance Traveled	Driver	Passenger	Vehicle
CC1	2/6/2015	Laramie	9:00	Walcott	10:30	78miles	B.Hammit	H. Smith	2014 Ford Fusion
CC2	2/6/2015	Walcott	10:30	Laramie	12:00	78miles	B.Hammit	H. Smith	2014 Ford Fusion
CC3	2/6/2015	Laramie	13:00	Walcott	14:30	78miles	B.Hammit	H. Smith	2014 Ford Fusion
CC4	2/6/2015	Walcott	14:30	Laramie	16:00	78miles	B.Hammit	H. Smith	2014 Ford Fusion
CC5	2/15/2015	Laramie	12:00	Walcott	13:30	78miles	B.Hammit	L. Johnson	2014 Ford Fusion
CC6	2/15/2015	Walcott	13:30	Laramie	15:00	78miles	B.Hammit	L. Johnson	2014 Ford Fusion
CC7	2/16/2015	Laramie	8:15	Walcott	9:45	78miles	B.Hammit	S. Ganley	2014 Ford Fusion
CC8	2/24/2015	Laramie - I-80 & Grand	12:15	Boulder	14:35	145miles	R. Young	B. Hammit	2014 Ford Fusion
CC9	2/26/2015	Laramie	15:45	Walcott	17:00	78miles	B.Hammit	--	2014 Ford Fusion
CC10	2/26/2015	Walcott	17:30	Laramie	19:00	78miles	B.Hammit	--	2014 Ford Fusion
CC11	3/3/2015	Laramie	18:40	Herrick Lane	19:10	16miles	B.Hammit	H. Smith	2014 Ford Fusion
CC12	3/3/2015	Herrick Lane	19:10	Laramie	19:35	16miles	B.Hammit	H. Smith	2014 Ford Fusion
CC13	3/4/2015	Laramie	9:20	Walcott	10:40	78miles	B.Hammit	--	2014 Ford Fusion
CC14	3/4/2015	Walcott	10:40	Laramie	12:05	78miles	B.Hammit	--	2014 Ford Fusion
CC15	3/25/2015	Laramie	9:15	Walcott	10:30	78miles	B.Hammit	--	2014 Ford Fusion
CC16	3/25/2015	Walcott	10:30	Laramie	11:45	78miles	B.Hammit	--	2014 Ford Fusion

All test trips between Laramie and Walcott, Wyoming, were driven by Britton Hammit to normalize any variation that could occur between drivers. During each trip, the vehicle was operated normally, following all traffic laws and representing common driving behavior. Vehicle data were exported from the OpenXC Enabler in .JSON or JavaScript Object Notation. From this format, the data were converted to .CSV or Comma Separated Values data formats for analysis conducted in Microsoft Excel, Matlab, and GIS.
All trips originating or ending in “Laramie” indicate a geographical location at the interchange of I-80 and 3rd Street with Latitude and Longitude values of: 41.297628, -105.594675 and milepost I-80 313. All trips originating or ending in “Walcott” indicate a geographical location at the interchange of I-80 and Lincoln Highway with Latitude and Longitude values approximately 41.741557, -106.830530 and milepost I-80 235. These starting and stopping locations were selected for a majority of the trips because the route encompasses a variable speed limit passage between Laramie and Rawlins, Wyoming. The variable speed limit corridor infrastructure is shown in Figure 4.15.

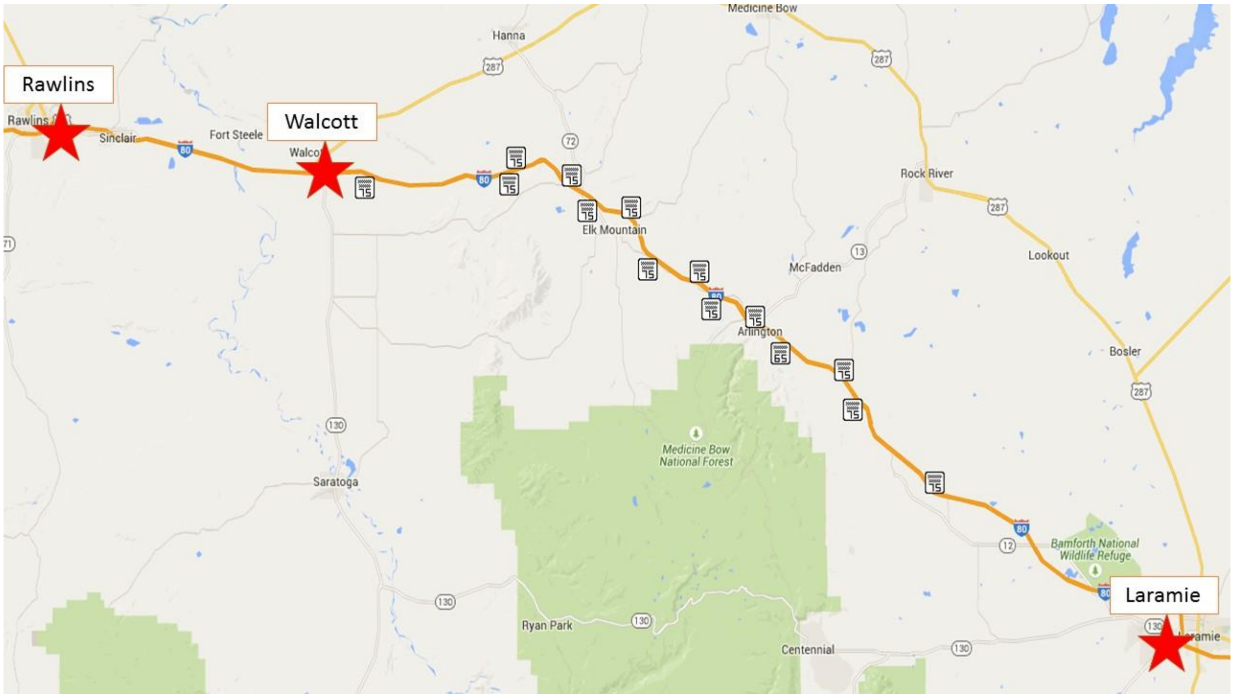


Figure 4.15 Variable Speed Limit Corridor between Laramie and Rawlins, Wyoming (WYDOT, n.d.)

4.3 RWIS Data Collection

In addition to collecting the CAN-Bus data from the vehicles, RWIS data from the 13 RWIS stations along the Laramie – Walcott, Wyoming, corridor were collected to provide vehicle data comparison. The RWIS data were collected after the data collection event for the time period during data collection trips. The RWIS sensor locations along the corridor are shown in Figure 4.16.

Figure 4.16 RWIS Locations between Laramie and Walcott, Wyoming (WYDOT, n.d.)

The RWIS data corresponding to each trip between Laramie and Walcott, Wyoming, are found in Appendix C: RWIS Weather Data. The data collected for each trip are shown in Table 4.4.

Table 4.4 RWIS Data Collected

RWIS Weather Data	
Air Temp	Precipitation Rate
Relative Humidity	Visibility
Dew Point	Surface Temperature
Average Wind Speed	Precipitation Type
Gust Wind Speed	Precipitation Intensity
Precipitation Accumulation	Surface Status

5. DATA VISUALIZATION

Data analysis and visualization for this report is split into three primary components: NCAR's Pikalert analysis, MatLab data visualization, and GIS data visualization. Due to difficulty using NCAR's Pikalert system, primary analysis was completed qualitatively using the MatLab and GIS data visual representations. A qualitative analysis combining the vehicle data and RWIS data also is provided.

5.1 NCAR's Pikalert/ VDT

Initial project intentions focused on using NCAR's Pikalert Vehicle Data Translator to determine quality of the collected vehicle data, while gathering segmented weather data for use in assigning variable speed limits. However, attempts to run and operate the Pikalert system on a University of Wyoming computer environment were unsuccessful. In response, researchers contacted NCAR and provided a sample of the vehicle data collected on the test trips. After looking over UW's trip data, NCAR responded by indicating crucial data, such as ambient temperature, were not collected through the vehicle files, and definitive weather data could not be aggregated without those components.

NCAR's Pikalert system is heavily dependent on ambient temperature data collection, which is typically gathered through external sensors. The scope of this research was to determine feasibility of collecting vehicle data, from a vehicle's CAN-Bus, capable of replacing or supplementing RWIS systems with open-source or off-the-shelf vehicle interfaces and software. For that reason, external sensors were not implemented or used for data collection.

5.2 Matlab Visualization

MatLab was used to censor vehicle and RWIS data to better understand conditions during each trip. Basic quality checking, or censoring, was performed to eliminate data with unreasonable vehicle parameter or location readings. Initially, an analysis of all RWIS data was conducted and summary tables and graphics were created. Table 5.1 and show the RWIS conditions collected for each trip. Detailed RWIS data from each trip are shown in Appendix C: RWIS Weather Data.

Table 5.1 Average RWIS Data for Laramie – Walcott, Wyoming, Trips

RWIS Weather Data	Statistical Calculations	Trips					
		CC1,2,3,4	CC5,6	CC7	CC9,10	CC13,14	CC15,16
Air Temp (F)	Average	50.37	24.81	17.11	6.45	6.60	27.04
	Standard Deviation	2.84	0.73	1.41	1.43	1.60	1.58
	Variance	8.15	0.76	2.40	2.32	3.01	2.60
	Maximum	66.00	26.43	19.32	7.75	12.85	29.42
	Minimum	46.47	23.54	13.32	5.13	3.68	24.97
Relative Humidity (%)	Average	26.23	94.81	94.50	88.23	78.04	85.02
	Standard Deviation	4.23	3.32	1.67	1.68	5.11	4.34
	Variance	18.11	57.12	5.15	3.58	38.27	21.14
	Maximum	35.13	98.46	98.16	90.83	91.59	93.87
	Minimum	18.75	88.78	90.11	82.95	51.94	74.71
Dew Point (F)	Average	16.29	23.67	15.80	3.74	0.74	23.06
	Standard Deviation	1.77	0.77	1.41	1.24	2.12	0.94
	Variance	3.56	0.86	2.43	1.67	4.92	0.96
	Maximum	37.64	25.19	17.53	4.80	5.65	26.42
	Minimum	9.33	22.41	12.42	2.38	-6.71	20.77
Average Wind Speed (mph)	Average	27.93	8.82	3.74	15.11	5.57	11.29
	Standard Deviation	4.51	1.45	0.92	1.68	2.26	1.58
	Variance	23.05	2.36	1.12	3.49	5.93	2.67
	Maximum	39.42	15.14	12.00	22.02	8.76	14.68
	Minimum	13.10	4.57	0.79	11.43	2.00	7.32
Gust Wind Speed (mph)	Average	37.83	12.14	5.96	20.72	7.61	15.24
	Standard Deviation	5.38	1.74	1.31	2.02	2.52	1.82
	Variance	31.75	3.34	2.16	4.87	7.22	3.41
	Maximum	48.99	13.05	16.74	27.77	11.41	18.29
	Minimum	19.24	6.84	2.00	16.23	3.44	10.84
Precipitation Accumulation (in)	Average	0.00	0.06	0.11	0.06	0.11	0.33
	Standard Deviation	0.00	0.01	0.00	0.01	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00
	Maximum	0.00	0.12	0.24	0.19	0.23	1.02
	Minimum	0.00	0.03	0.00	0.01	0.03	0.02
Precipitation Rate (in/hr)	Average	0.00	0.01	0.00	0.00	0.00	0.00
	Standard Deviation	0.00	0.02	0.00	0.00	0.00	0.01
	Variance	0.00	0.00	0.00	0.00	0.00	0.00
	Maximum	0.00	0.01	0.00	0.00	0.00	0.01
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00
Visibility (ft)	Average	6560.00	5398.43	6523.57	6446.43	6560.00	6530.63
	Standard Deviation	0.00	1266.26	110.51	281.71	0.00	92.61
	Variance	0.00	1726829.20	158748.00	151768.20	0.00	69423.56
	Maximum	6560.00	6270.19	6560.00	6560.00	6560.00	6560.00
	Minimum	6560.00	3686.60	6086.47	6227.75	6560.00	6232.71
Surface Temperature (F)	Average	63.64	37.52	26.82	21.74	33.39	42.80
	Standard Deviation	7.71	2.37	3.63	5.12	6.24	7.76
	Variance	62.39	5.66	13.98	26.80	39.31	60.53
	Maximum	103.98	40.76	29.51	24.39	35.94	45.82
	Minimum	54.82	34.94	24.67	19.97	31.09	40.85
Precipitation Type	Percent "None"	100.00	26.43	98.79	88.65	96.38	77.43
	Percent "Snow"	0.00	48.08	1.21	11.35	3.62	22.57
	Percent "Frozen"	0.00	16.84	0.00	0.00	0.00	0.00
	Percent "Rain"	0.00	0.00	0.00	0.00	0.00	0.00
	Percent "Yes"	0.00	1.04	0.00	0.00	0.00	0.00
Precipitation Intensity	Percent "None"	100.00	26.43	98.79	88.65	96.38	77.43
	Percent "Slight"	0.00	61.79	1.21	11.35	3.62	22.33
	Percent "Moderate"	0.00	4.16	0.00	0.00	0.00	0.25
	Percent "Heavy"	0.00	0.00	0.00	0.00	0.00	0.00
Surface Status	Percent "Dry"	74.87	0.00	23.03	30.63	25.00	10.08
	Percent "Trace Moisture"	12.63	25.37	57.24	58.13	52.94	54.44
	Percent "Wet"	3.09	49.75	0.66	0.00	8.82	17.74
	Percent "Ice Warning"	0.13	0.00	11.84	10.63	4.78	0.00
	Percent "Chemically Wet"	9.41	12.50	7.24	0.63	8.46	16.53
	Percent "Snow Watch"	0.00	0.00	0.00	0.00	0.00	1.08

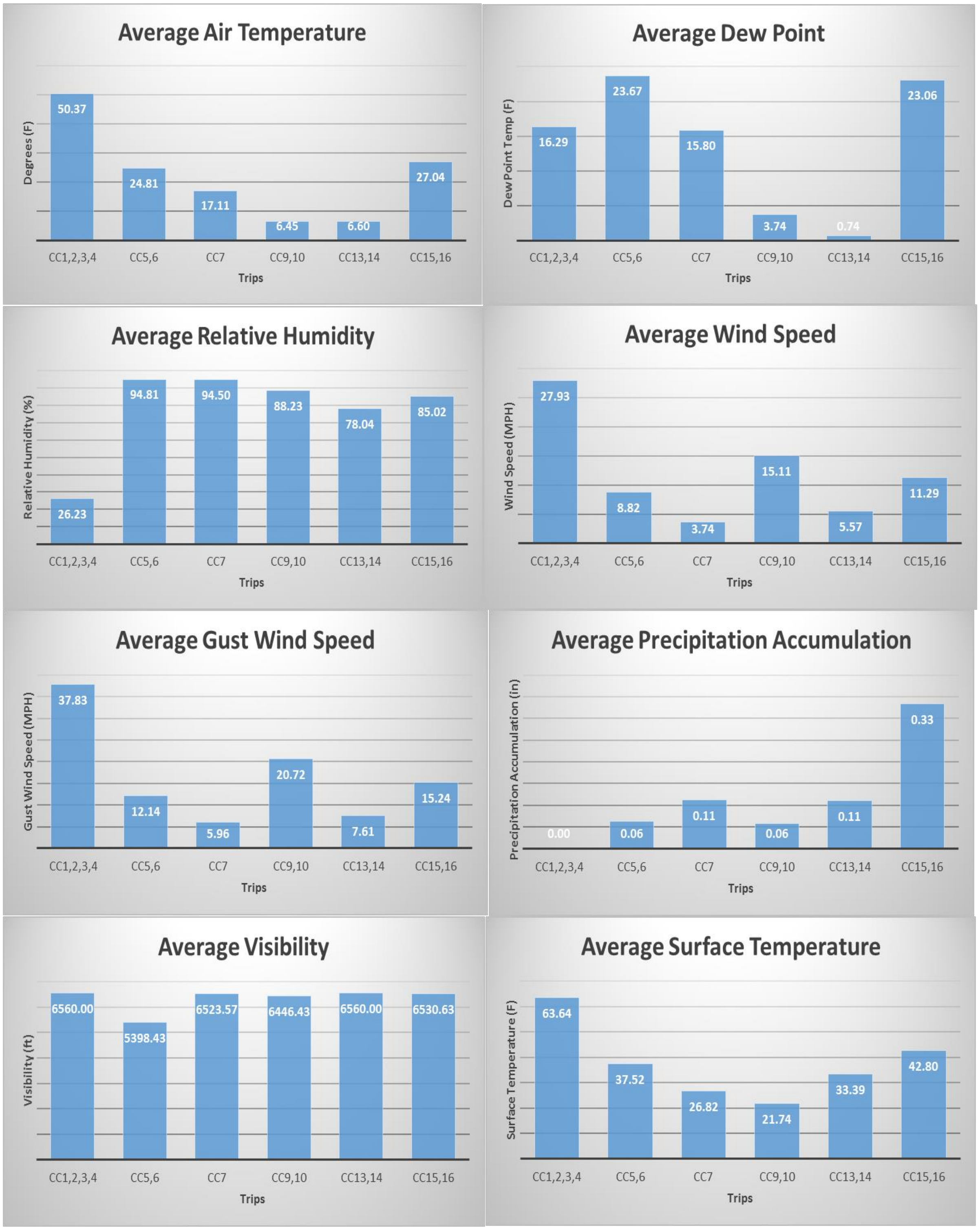


Figure 5.1 Average RWIS Data for Laramie – Walcott, Wyoming, Trips

As Table 5.1 and Figure 5.1 indicate, Trips CC 1, 2, 3, and 4 occurred on a single day in dry conditions. The trips were to provide a baseline condition for comparison to all trips taken in adverse roadway conditions. Trips CC 9, 10, 13, and 14 occurred in the coldest temperature with minimal precipitation accumulation, indicating the possibility of ice formation along the roadway, and Trips 15 and 16 had the highest average precipitation accumulation and an average ambient temperature near 32 degrees F indicating the possibility of rain or slush. Trips CC 5 and 6 showed the largest decrease in visibility and the highest dew point temperature, indicating formation of fog.

After evaluating the RWIS data for the trips, all vehicle data were implemented into MatLab to provide numeric and graphical representations of each trip considering six vehicle parameters: Vehicle Speed, Engine Speed, Accelerometer Pedal Status, Transmission Torque, Steering Wheel Angle, and Windshield Wiper Status. The OpenXC data collection software collects each parameter at different time intervals. For example, the latitude and longitude could be collected milli-seconds apart from the accelerator pedal position or vehicle speed; therefore, linear interpolation was used between latitude and longitude values to provide locations for each vehicle parameter recording. Linear interpolation was deemed acceptable in the situation due to the high frequency of data collection. Longitude and latitude data were collected approximately once per second, making a linear interpolation of location change occurring in one-second timeframes adequate.

Each vehicle parameter, such as accelerator pedal position, engine speed, steering wheel angle, transmission torque, and vehicle speed were collected approximately every 1/10th of a second. The windshield wiper data (“true” indicating activation of wiper and “false” indicating no wiper activation) were collected approximately every 9/10ths of a second. To provide a deeper analysis of vehicle data, the actual acceleration and deceleration rates were calculated from the interpolated timestamp and vehicle speed data. In addition, the frequency of windshield wiper activations for each mile-segment along the test route were calculated. The OpenXC application was created with these specific data collection intervals. Further research could involve determining the most appropriate aggregation level for each vehicle parameter.

A summary of the vehicle data collected are shown in Table 5.2, Figure 5.2, Figure 5.3, Figure 5.4, Figure 5.5, and Figure 5.6. The detailed vehicle data from each trip are shown in Appendix D: Vehicle Data Representation.

Table 5.2 Vehicle Data Summary for Laramie – Walcott, Wyoming, Trips

Trips		CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC10	CC13	CC14	CC15	CC16
Vehicle Speed	Mean	75.16	78.28	77.19	76.7	73.18	71.01	70.19	64.29	67.35	74.84	66.34	79.27
	Min	60.38	75	46.81	46.86	59.8	49	50.1	33.15	43.17	57.66	32.04	62.37
	Max	77.86	85.67	80	78.86	82.15	82.86	84.08	84.46	82.11	87.07	81.74	87.08
	Stdev	2.69	0.73	3.02	4.07	4.15	4.35	6.56	7.07	6	5.19	8.94	2.3
	Median	75.98	78.16	77.9	77.98	74.14	70.74	70.78	63.87	67.83	75.5	67.38	79.98
	Mode	76.02	79.03	78.07	78.02	77.04	76.09	78.08	58.13	71.56	77.7	67.05	80.03
Engine Speed	Mean	2362.75	2398.85	2413.96	2373.19	2235.9	2239.22	2143.63	2013.87	2071.15	2306.87	2091.71	2444.41
	Min	1816	2286	1426	1404	1806	1464	1504	1242	1358	1238	1272	1516
	Max	4040	3576	3464	4142	3264	4070	3340	3728	4128	3618	3926	4294
	Stdev	277.31	182.14	254.88	246.81	183.41	276.76	222.65	328.37	227.01	235.14	332.01	234.43
	Median	2286	2352	2344	2346	2236	2184	2150	1964	2070	2294	2064	2406
	Mode	2286	2346	2346	2346	2316	2288	2344	1886	2148	2372	2016	2406
Acceleration Pedal Position	Mean	0.69	0.21	1.06	1.72	9.22	14.09	17.77	21.43	19.87	21.55	17.78	5.06
	Min	0	0	0	0	0	0	0	0	0	0	0	0
	Max	61.5	46.9	56.6	61.6	52.6	62.5	57.1	60.2	62.5	49.5	58	54.1
	Stdev	4.82	2.67	5.5	6.63	11.87	13.64	10.42	9.95	9.43	9.18	12.27	11.06
	Median	0	0	0	0	0	15	19.6	21.1	20.9	22.4	19.7	0
	Mode	0	0	0	0	0	0	0	0	0	0	0	0
Transmission Torque	Mean	110.62	89.52	110.41	87.66	96.07	106.48	93.94	105.06	96.78	102.29	102.19	104.8
	Min	-31	-34	-33	-35	-35	-34	-34	-32	-35	-35	-39	-34
	Max	174	173	168	172	176	182	182	240	196	183	184	176
	Stdev	43.53	45.62	42.36	46.02	52.82	48.27	51.49	49.95	53.9	49.51	51.08	44.52
	Median	120	91	119	90	108	112	103	111	109	113	115	107
	Mode	167	163	163	164	129	172	104	166	-34	116	158	100
Steering Wheel Angle	Mean	-0.03	-0.15	0.14	-0.2	-0.06	-0.09	0.03	-0.09	-0.06	-0.08	-0.01	-0.07
	Min	-11.1	-12.2	-10.5	-12.6	-10.5	-9.9	-9	-8.9	-9.1	-9.9	-11.1	-9.6
	Max	11.5	7.6	11.1	8.2	11.5	8	8.7	7.3	7.6	6.3	9.8	9.3
	Stdev	1.7	1.82	1.69	1.74	1.55	1.5	1.35	1.16	1.26	1.46	1.37	1.69
	Median	0	0	0	0	0	0	0	0	0	0	0	0
	Mode	0	0	0	0	0	0	0	0	0	0	0	0
% Wipers In Use		0	0	0	0	13.62	2.63	0.05	0	0	0	14.11	0.34

Figure 5.2 shows the average vehicle and engine speed for each of the Laramie to Walcott, Wyoming, and Walcott to Laramie trips. The average vehicle speed for each trip varies from approximately 80 MPH to 65 MPH, with the engine speed following in a similar pattern between 2000 RPM and 2500 RPM. As expected, the average vehicle speeds for trips CC1, 2, 3, and 4 are approximately 75MPH (the speed limit along the route) due to the dry conditions illustrated in Figure 5.1 Average TWIS Data for Laramie – Walcott Trips. Actual speed variations along the route for each trip are shown in Appendix D: Vehicle Data Representation.

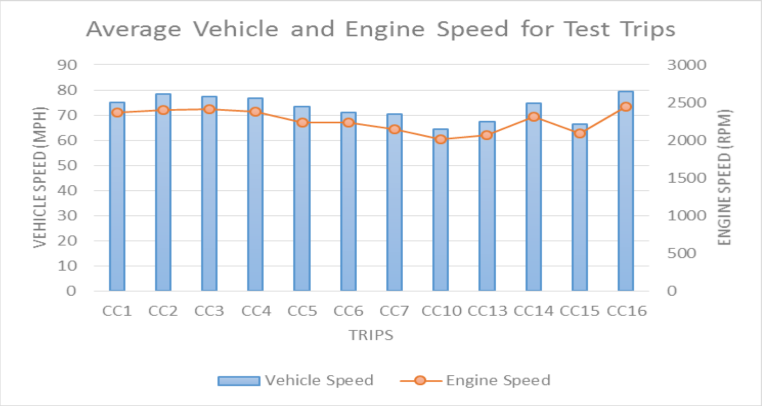


Figure 5.2 Average Vehicle and Engine Speed for Laramie – Walcott, Wyoming, Test Trips

Figure 5.3 displays the average transmission torque over each test trip. Due to the weather and driver consistency and the use of cruise control, Trips CC1 and 3 (originating in Laramie and ending in Walcott, Wyoming) and Trips CC2 and 4 (originating in Walcott and ending in Laramie) resulted in consistent transmission torque values. All other test trips recorded transmission torque values between 88 N*m and 106 N*m. The transmission torque along the route is shown in Appendix D: Vehicle Data Representation.

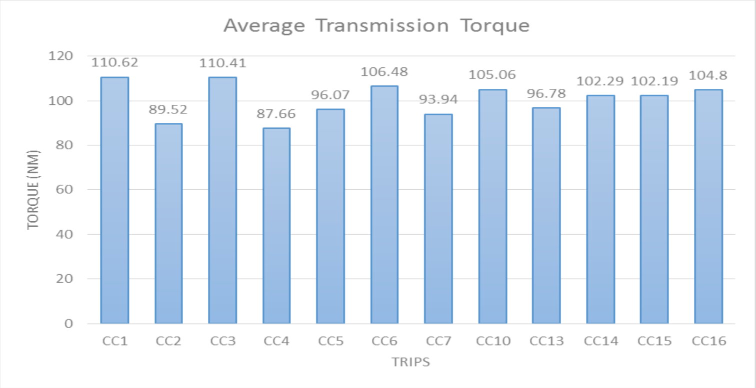


Figure 5.3 Average Transmission Torque for Laramie – Walcott, Wyoming, Test Trips

Figure 5.4 shows the average steering wheel angle for each of the Laramie – Walcott, Wyoming, test trips. The steering angle values are highly dependent on the number of vehicles passed and curvature of the road when passing vehicles. However, if a driver were to lose control on black ice or slush, their reaction would be indicated with a steep change in the steering angle. The average steering wheel values along a route do not provide a complete picture of the potential driver reactions along a route; therefore, Appendix D: Vehicle Data Representation provides the actual steering wheel angle recordings along each trip. Evaluating real-time steering wheel angles could be used to indicate a potential slick-spot or adverse road condition at a specific location if a sudden-change steering wheel angle was detected and supporting ancillary data indicated the existence of adverse weather conditions. While the scope of this project did not allow detailed conclusions concerning a correlation between the steering wheel angle along a route and the presence of weather conditions, detailed studies have resulted in similar conclusions. For example, research covering the effect of driver drowsiness on vehicle parameters such as the steering wheel angle, conducted through the Midwest Transportation Center, concluded that weather conditions may significantly impact the steering wheel angle. Researchers discovered that in rainy conditions the average steering wheel amplitude was lower (Maze & Forkenbrock, 1996).

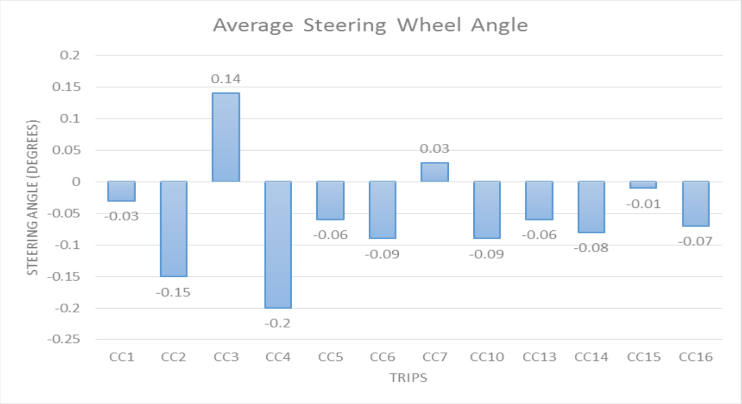


Figure 5.4 Average Steering Wheel Angle for Laramie – Walcott, Wyoming, Test Trips

Figure 5.5 illustrates the average accelerator pedal position for each trip between Laramie and Walcott, Wyoming. Trips CC1, 2, 3, and 4 experience limited accelerator pedal usage through a majority of the trips due to the use of cruise control. While evaluation of the accelerator pedal position along a route is highly dependent on individual driver and vehicle characteristics, an increased use of the accelerator pedal from a driver with a high tendency to use cruise control could indicate adverse roadway conditions. Actual acceleration along the route was calculated and graphed to provide a visual indication of steep acceleration or deceleration during a trip. Acceleration rate data is critical for detecting isolated locations of negative weather conditions as it could indicate a driver slamming on the brakes in response to unexpected road conditions. There are many reasons, aside from weather conditions, in which drivers decelerate quickly. To correlate acceleration rates with weather conditions, vehicle data must be analyzed along with ancillary weather data. Similar to other parameters, the actual accelerator pedal position and acceleration rates along the route is provided in Appendix D: Vehicle Data Representation.

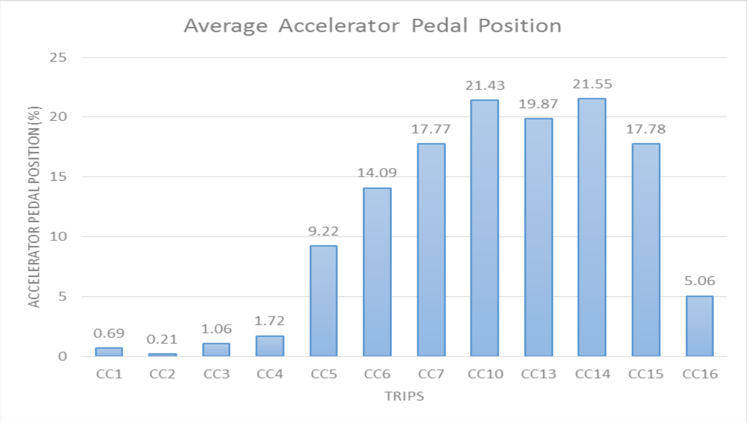


Figure 5.5 Average Accelerator Pedal Position for Laramie – Walcott, Wyoming, Test Trips

The final vehicle parameter evaluated encompasses the use of windshield wipers, as shown in Figure 5.6. Windshield wiper status for each trip was evaluated and the percentage of time the windshield wipers were in use was recorded for each trip. Using the OpenXC Platform hardware and software, the windshield wiper status was provided as "on" and "off" without an indication of speed or frequency. Therefore, the number of windshield wiper activations per mile was calculated and represented in graphical format. This format identified areas in which the windshield wipers were used more frequently or at a higher rate. Ideal representation would include a time dimension so representation would not be dependent on the speed traveled by the vehicle. As indicated in Figure 5.6, Trips CC5 and 15 utilized the windshield wipers most frequently, indicating precipitation during a portion of the trip. The representation of windshield wiper activations per mile for each trip are shown in Appendix D: Vehicle Data Representation.

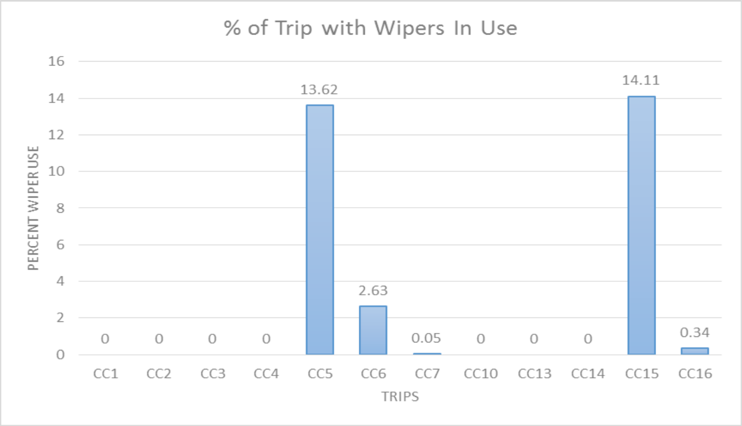


Figure 5.6 Percent of Wiper Usage for Laramie – Walcott, Wyoming, Test Trips

5.3 GIS Visualization

In addition to creating graphics representing collected vehicle data in MatLab, ArcGIS software was used to map conditions and the following vehicle data parameters along the corridor: Vehicle Speed, Engine Speed, Transmission Torque, Accelerator Pedal Position, and Steering Wheel Angle. The maps for each of these parameters is shown in Appendix E: GIS Vehicle Data Representation.

The representation of vehicle data in ArcGIS provided improved visualization of vehicle parameters along the corridor. In addition, it highlighted several data gaps or errors in data collection. The first data gap identified included the lack of vehicle data captured over a limited portion of the route in trips CC9 and 14. Figure 5.7 shows the engine speed data for trip CC9, and from the visual representation, it is clear that engine speed data were not collected along the entire route. Similar errors occurred in trips CC9 and CC14 vehicle speed data collection (Figure E.44 and Figure E.59, respectively).

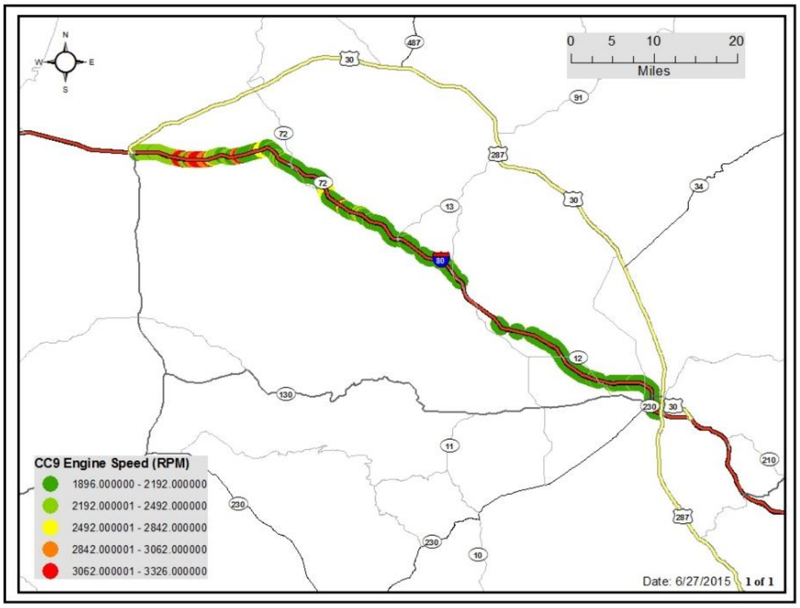


Figure 5.7 CC9 Engine Speed Data – Example of Data Gap

The second data gap was identified in trip CC8, which originated in Laramie, Wyoming, and concluded in Boulder, Colorado. As Figure 5.8 shows, at least eight occurrences of steering wheel angle data were recorded at a location not along the actual route.

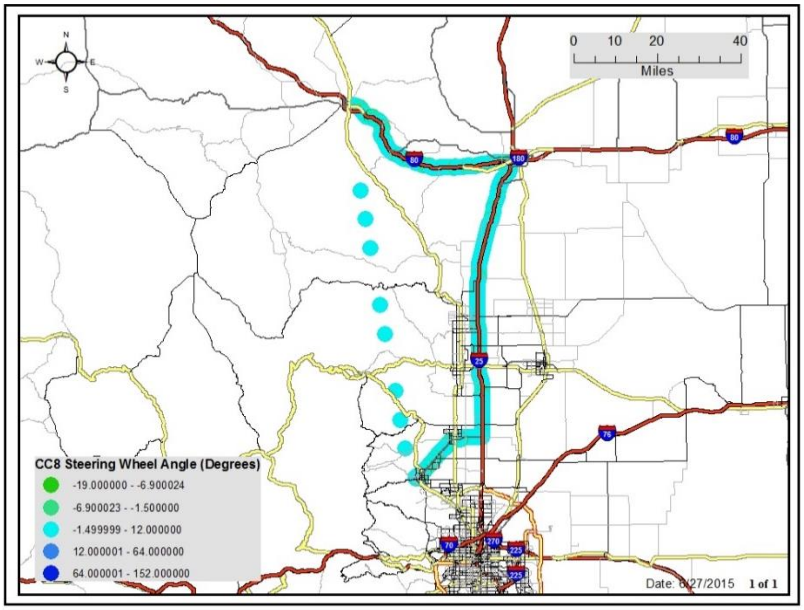


Figure 5.8 Steering Wheel Angle Data – Example of Data Gap

6. CONCLUSIONS & RECOMMENDATIONS

Adverse weather conditions have a significant impact on roadway conditions, vehicle performance, and driver behavior, especially in rural areas. Intelligent Transportation System programs have implemented various applications, such as RWIS, to address dangerous situations caused by adverse weather conditions. Many of these technologically-advanced systems are improving conditions of rural highways and interstates and the rise of connected vehicle technology offers a new method for addressing adverse weather conditions. Connected vehicle technology has the potential to provide continuous real-time information to better inform drivers and transportation management of current weather and road conditions.

In a fully connected world, every vehicle would be equipped with hardware to read and transmit CAN-Bus data. Each vehicle would have the capability of communicating using DSRC technology to roadside devices, nearby vehicles, and other devices, such as smartphones. This would immeasurably increase the safety, mobility, and efficiency of our existing transportation network, but it also would introduce economic issues to overcome. Among these issues are capital and communication costs, data storage, and data processing. The future is moving toward a world consumed and operated by “Big Data”; a world where all applications, specifically in the transportation industry, rely on data production and processing. A fully connected transportation network may seem to be a projection of the far-out future, but much of this technology exists today. The USDOT is encouraging researchers to begin testing and creating connected vehicle applications to jump-start into this new future. Among these technologies are applications that address road weather conditions. These applications are founded on the basis of using vehicle CAN-Bus data to create continuous, higher resolution road condition data. Detailed analyses combining vehicle data and ancillary weather data could produce valuable information describing road conditions.

The purpose of this research was to evaluate feasibility of using open-source or off-the-shelf vehicle interfaces and software to replace or supplement the existing RWIS systems in assigning variable speed limits along the Interstate-80 corridor between Laramie and Rawlins, Wyoming. In other words, can off-the-shelf products be used in the short term to begin reaping the benefits of a connected vehicle application translating the road weather conditions in real-time? Currently, the RWIS system is the primary source of weather data used to assign variable speed limits in Wyoming; however, this system only collects spot-specific weather data at the location of the individual RWIS, rather than continuous weather data. The large gap that exists between RWIS locations could contain variant road conditions that are overlooked using an RWIS system.

The specific research objectives for this report are:

1. Determine the most effective technology for collecting connected vehicle data from vehicles’ CAN-Bus.
2. Investigate the reliability and practicality of ascertaining segmented road condition data from NCAR’s Pikalert system (Drobot, Chapman, Lambi, Wiener, & Anderson, 2011).
3. Determine whether connected vehicle CAN-Bus data are suitable for supporting the data requirements of VSL decision-making algorithms.
4. Make recommendations and identify future research needs regarding the prospective use of connected vehicle data in rural roadway corridors subject to significant weather events.

6.1 First Objective: CAN-Bus Data Collection

The first research objective was met by testing and evaluating a variety of off-the-shelf vehicle interfaces and commercial and open-source software packages. From this evaluation, the CrossChasm C5 vehicle interface paired with the OpenXC open-source software was selected. This research proved that CAN-Bus data can be collected through the use of off-the-shelf products, but feasibility of using that CAN-Bus data to provide road weather data is still a concern. Due to the proprietary nature of certain vehicle parameters, such as ABS braking and traction and stability control, the collection of such data is not available without obtaining a Non-Disclosure Agreement with the automotive manufacturer and maintaining cooperation with the manufacturer to interpret the CAN-Bus data.

6.2 Second Objective: Segmented Road Condition Data

The second research objective was addressed through efforts to implement NCAR's Pikalert system on a University of Wyoming computer environment. UWYO Computer Science Graduate Student, Nels Fisher, assisted research by leading the Pikalert set-up and evaluation. Due to the complexity of the Pikalert system, unknown characteristics of the program, and limited documentation, researchers were not able to set up a UWYO Pikalert system environment. In response, researchers contacted NCAR in an effort to open doors for future collaboration. Initial responses indicated the possibility of running some of the University of Wyoming's vehicle data through NCAR's Pikalert system in Boulder, Colorado. Unfortunately, coordination efforts between the research team and NCAR were unsuccessful and the University of Wyoming's data could not be evaluated from the Pikalert environment.

Currently, research and informal interviews suggest that the only operational Pikalert environment is running on NCAR's computers. While the software is open source, research using Pikalert is sent from the source (for example Michigan or Minnesota DOTs, with IMO project) to NCAR, where the data is processed and returned. Significant efforts to run the system on University of Wyoming servers were unsuccessful. To meet minimum real time operational standards for the use of vehicle data in VSL operations, system modifications are required to allow other agencies to run the system independently.

6.3 Third Objective: Suitability for VSL Assignment

Limited vehicle data for off-the-shelf vehicle interface and software packages, and difficulty analyzing vehicle data with NCAR's Pikalert system mean that few conclusions can be drawn to indicate the success of CV technology improving VSL assignment. While the outcome of this report cannot prove the success of CV technology in improving VSL assignment, the research conducted does prove the feasibility of collecting non-proprietary vehicle data. This data is the first step in determining effectiveness of adding vehicle data to VSL assignment algorithms. A more specific conclusion regarding utilized data could be realized with cooperation by motor companies in gathering proprietary vehicle data and using external sensors to gather additional mobile weather.

In its current form, NCAR's Pikalert VDT primarily serves as a generator of weather safety messages for transmission to travelers and not as a program to translate vehicle data to segmented road weather data. Significant modifications to the Pikalert system would be necessary for incorporation into VSL control logic, because VSL control systems rely on segmented road weather data. In the interim, it is likely that safety messages produced by Pikalert can provide additional notification of weather conditions to VSL system operators and extend the operators' knowledge of road weather conditions beyond the reach of existing RWIS stations.

6.4 Fourth Objective: Future Research

The research conducted for this report indicates that collecting vehicle data are feasible, and that technology to collect, aggregate, communicate, and analyze the data exists today. However, it also raises a question about practicality in this method of collecting continuous roadway data. The proprietary nature of automotive manufacturers' software coding within their vehicles' CAN-Bus requires individual vehicle firmware for each vehicle's manufacturer, make, and model. The different firmware requirements for each individual vehicle imposes serious concern on the practicality of implementing CAN-Bus readers on a wide-scale.

CAN-Bus data from vehicles is valuable in ascertaining roadway conditions, especially in adverse weather conditions; whereas the lack of CAN-Bus code standardization between automotive manufacturers and vehicle makes and models renders difficulty in operating connected vehicle applications. With these concerns in mind, proposed federal regulations will require the standardization of all CAN-Bus messages, and with this standardization, DSRC capabilities also will be required for transmitting data between vehicles (Howden, 2014). In response to the USDOT's advanced notice of vehicle data standardization requirements, Mary Barra, GM's CEO, announced that the 2017 Lansing-built Cadillac CTS would provide a DSRC vehicle to vehicle technology option (Carmody, 2014). Without standardized vehicle data formats from all vehicles, off-the-shelf CAN-Bus technology is not adequate for collecting a complete and robust vehicle data set. Federal requirements are addressing this issue, however, the circumstances make proactive and advanced research difficult. Even with an adequate data set, this research identifies some concern with translating vehicle CAN-Bus data into mobile weather information. The practicality and usability of NCAR's Pikalert system must be evaluated further to fully comprehend the potential for segmented road weather condition data. The current system appears to be successful for producing and distributing road condition advisories and warnings, however, success in producing raw segmented road condition data is unclear. Further, the next steps should be to evaluate complete vehicle data sets during adverse weather events and evaluate the data collection process and Pikalert system to a greater extent.

Due to the current impracticality of collecting firmware for every vehicle make and model, the use of external sensors to gather mobile data should be considered. Mobile weather sensors, such as Weather Cloud (Weather Cloud, 2014), present cost-effective solutions for implementing connected vehicle technologies on a fleet of vehicles, regardless of their make or model. These vehicle sensors can determine the vehicle's speed, windshield wiper status, and tire friction, as well as basic atmospheric data including ambient temperature, dew point temperature, and barometric pressure.

Further research should evaluate how external and internal vehicle sensors could replace data from a fully equipped CAN-Bus reader in the interim period before CAN-Bus data standardization is mandated and implemented. Several questions exist, such as: Would these sensors allow more or less data collection? Is their performance as reliable as data from CAN-Bus readers? Would the benefits of uniform data collection hardware and software for every vehicle outweigh any potential data gaps from not collecting CAN-Bus data?

CV road weather data presents a surplus of new opportunities to better control and evaluate the safety, mobility, and efficiency of rural roadways during adverse weather conditions. The massive amount of data collected through a road weather CV application are both the technology's greatest challenge and advantage. When practice and research efforts merge to support methods for collecting, storing, evaluating, and discarding CV road weather data, the full benefits of the technology will be realized on rural roadways.

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APPENDIX A: VDT OUTPUT DESCRIPTIONS

Table A.1 VDT 3.0 Precipitation Output Description

The Vehicle Data Translator

Drobot, "The VDT V3.0 System Description"

Precipitation Output

Provided Outputs	The Precipitation output provides an assessment of the type and intensity (amount/hour) or the accumulation rate of precipitation types such as rain, snow, ice/mixed, and hail. This output will distinguish between light, moderate, and heavy precipitation rates. A "No Precipitation" output option is also included.
Input Mobile Data used in Algorithm	The *Air Temperature* is used to determine the likely type of precipitation (frozen or liquid).
	The *Front Wiper Status* is an indication of the necessity of removing liquid or ice from a windshield.
	The *Headlight Status* is an indication of precipitation by indicating reduced visibility.
	The *Ratio of vehicle speed to posted speed* is an indication that there is or isn't a problem or hazard. Low speed ratios could indicate heavy precipitation as well as snowy or icy conditions.
	Data mining is used to identify other useful vehicle observations and adjust specific thresholds used within the algorithm.
Input Ancillary Data used in Algorithm	The *Time of Day* is important to determine whether slow speeds are occurring during typical non-congestion times, or if headlights are turned on during a time period that they are not expected.
	The *Date* is important to keep statistical data and in comparing to historical data to determine the types of precipitation that have occurred in similar seasons.
	The *Radar Reflectivity* serves as an indication of whether or not precipitation is occurring and if so, how heavily the precipitation is falling. The Radar detects the precipitation type above the ground rather than at the surface; the farther away the ground is from the radar, the higher the detection is from the ground.
	The *Satellite Cloud Mask* is used to help identify the difference between road splash and real time precipitation.
	The *NRL Cloud Classifier* identifies cloud types that help identify storm cells that are or are not likely to be producing precipitation. This is especially useful in areas where Doppler radar is sparse (high terrain in the Western US).
	Observations from *Dual-Polarization Radar*, when operational, will allow the reflectivity to be analyzed for its ability to infer precipitation type. This application should also improve the rainfall rate estimation which will be useful in alerting drivers of heavy rainfall and high risk of hydroplaning.
Algorithm Format	Currently the algorithm is in the form of a decision tree; however, methods such as fuzzy logic are being considered.
Algorithm Verification	A series of quality checks are built into the VDT to provide a high level of confidence for the ouput road conditions.
	Snowplow drivers can report the precipitation conditions.
	The most reliable method for verification is using Surface Observations such as, ASOS stations, rain gauges, and the NCEP Stave IV analysis. However, before using these stations as quality assurance, it is important that these are not being used as ancillary data inputs for the algorithms as well.

Table A.2 VDT 3.0 Pavement Condition Output Description

The Vehicle Data Translator

Drobot, "The VDT V3.0 System Description"

Pavement Condition Output (from Inference Module)	
Provided Outputs	The Pavement Condition Output provides the pavement condition of a segment of roadway from vehicle observations. Possible pavement Conditions are: dry, wet, road splash, snow, icy/slick, and hydroplaning risk.
Input Mobile Data used in Algorithm	The *Air Temperature* is useful in determining the possibility of the road being covered in snow or ice.
	The *Front Wiper Status* is an indication of the necessity of removing liquid or ice from a windshield (precipitation).
	The *Ratio of vehicle speed to posted speed* is an indication of problem or hazard. Low speed ratios could indicate heavy precipitation.
	The engagement of *Anti-lock brakes/ traction control/ stability control* indicates freezing precipitation because these components are more likely to be enabled on a frozen roadway than on dry pavement.
	The *Latitudinal acceleration, Longitudinal acceleration, Yaw rate, Steering Angle, and Steering Angle Rate* indicate driver behavior in current the current environment. These components are most likely experience a high rate of change when a driver is trying to control a swerving car.
Input Ancillary Data used in Algorithm	The *Radar Reflectivity* serves as an indication of whether or not precipitation is occurring and if so, how heavily the precipitation is falling. The Radar detects the precipitation type above the ground rather than at the surface; the farther away the ground is from the radar, the higher the detection is from the ground.
	The *Satellite Cloud Mask* is used to help identify the difference between road splash and real time precipitation. The different precipitation types would aid in the identification of the road condition.
	The *NRL Cloud Classifier* identifies storm cells that are or are not likely to produce precipitation. This is especially useful in areas where Doppler radar is sparse (high terrain in the Western US). The different precipitation types would aid in the identification of the road condition.
	Observations from *Dual-Polarization Radar*, when operational, will allow the reflectivity to be analyzed for its ability to infer precipitation type. This application should also improve the rainfall rate estimation which will be useful in alerting drivers of heavy rainfall and high risk of hydroplaning.
Algorithm Format	Fuzzy logic and decision trees have been explored to form the pavement algorithm.
	Fuzzy Logic sets would provide each pavement type (dry, wet…) with a set of fuzzy logic functions associated with that type. There would be one function per input parameter (ex: wiper status and temperature) in each set. The value of each function would be assigned a value from [0,1] and summed with the other functions in that set. The most likely pavement type is then the pavement that has the highest sum.
Algorithm Verification	The final output is assigned a confidence level to help the user understand the confidence level of the reported pavement condition.

Table A.3 VDT 3.0 Visibility Output Description

The Vehicle Data Translator

Drobot, "The VDT V3.0 System Description"

Visibility Output (from Inference Module)	
Provided Outputs	The Visibility Output provides visibility information by road segment, with respect to a general decrease in visibility and more specific visibility issues.
	The visibility will be reported as normal or low and will also identify possible specific hazards, such as, dense fog, heavy rain, blowing snow, and smoke.
Input Mobile Data used in Algorithm	The *Air Temperature* is a useful indicator for low visibility due to its inherent relation to relative humidity, and thus haze or fog.
	The *Front Wiper Status* is an indication of the necessity of removing liquid or ice from a windshield (precipitation). Heavy precipitation would be a cause for a reduction in visibility.
	The *Ratio of vehicle speed to posted speed* is an indication of a problem or hazard. When there is low visibility or fog, drivers are more likely to drive below the suggested limit.
	The *Headlight Status* helps identify low visibility and fog because drivers are more likely to activate their low beam headlights or turn on their fog lights when fog or haze is present along the road segment.
Input Ancillary Data used in Algorithm	The *Wind Speed* is useful in identifying the potential for blowing snow and the likelihood of fog being present. Currently, the wind speed is being gathered from the nearest ASOS (Automated Surface Observation Station). The higher the wind speeds, the decreased probability of fog because fog forms when there is minimal air mixing.
	The *Relative Humidity* is useful because humidity levels are related to haze, fog, and precipitation. The relative humidity measurements are taken from the nearest fixed station's dew point temperature, or from the vehicle's air temperature.
	The *NRL Cloud Classifier* identifies storm cells that are or are not likely to produce precipitation. This is especially useful in areas where Doppler radar is sparse (high terrain in the Western US). The Cloud Classifier can identify low clouds that could be associated with reduced visibility.
	Visibility observations from the nearest *ASOS Station* are useful in determining the visibility along a nearby segment.
	Outputs from the *Precipitation Algorithm* could be useful in identifying reductions in visibility.
Algorithm Format	The use of fuzzy logic, data mining, and decision trees have been explored to form the visbility algorithm.
Algorithm Verification	Cameras could be used to verify visibility outputs; however this verification method is time consuming and subjective. Another alternative is that most fixed weather stations report visibility and these stations can be used to very *if they are not being used as input data* .
	The output data will be assigned a confidence level to describe the output's reliability.

APPENDIX B: DATA COLLECTION PHOTOGRAPHS

CC5, 6

CC7

CC15, 16

APPENDIX C: RWIS WEATHER DATA REPRESENTATION

Trips CC1, 2, 3, 4

Table C.1 Trip CC1, 2, 3, 4 RWIS Data

TRIP CC1,2,3,4														
RWIS Weather Data	Statistical Calculations	Herrick Lane	RWIS Stations from Laramie to Walcott											
			Quealy Dome	Strouss Hill	Copper Cove	Arlington East	Arlington	Foote Creek	Wagon-hound	Picture Turnout	Elk Mountain	Halleck Ridge	Mile Marker 249.1	Dana Ridge
Air Temp (F)	Average	53.4	52.1	66.0	51.0	49.4	49.7	46.5	46.7	47.8	50.3	46.7	48.1	47.1
	Standard Deviation	3.0	2.9	2.3	3.3	3.2	2.9	2.8	3.0	3.2	2.7	2.7	2.7	2.5
	Variance	8.8	8.1	5.2	10.6	10.2	8.2	7.6	8.7	10.1	7.4	7.5	7.3	6.3
	Range	11.0	10.0	8.0	10.0	10.0	9.0	8.0	10.0	10.0	9.0	9.0	10.0	9.0
	Median	54.0	53.0	66.0	52.0	51.0	51.0	48.0	48.0	49.0	52.0	47.0	49.0	48.0
Relative Humidity (%)	Average	19.0	19.0	35.1	18.8	21.4	24.9	25.9	31.3	28.7	25.1	29.0	30.1	32.8
	Standard Deviation	3.6	4.3	3.2	4.7	4.7	4.1	4.8	4.5	5.1	3.9	4.2	4.1	3.8
	Variance	12.8	18.8	10.3	22.1	21.8	16.5	23.2	19.8	25.7	15.4	17.9	16.4	14.8
	Range	13.0	16.0	16.0	15.0	16.0	12.0	16.0	16.0	19.0	12.0	16.0	16.0	16.0
	Median	18.0	18.0	36.0	18.0	20.0	23.0	24.0	30.0	27.0	23.0	27.0	29.0	31.0
Dew Point (F)	Average	11.9	10.5	37.6	9.3	11.0	15.5	13.0	17.7	16.5	15.6	16.0	18.0	19.2
	Standard Deviation	1.9	2.8	2.1	3.0	2.4	1.4	2.0	1.3	1.8	1.4	1.0	1.1	0.8
	Variance	3.7	8.1	4.3	9.1	5.5	1.8	4.1	1.7	3.2	1.9	1.0	1.2	0.6
	Range	9.0	11.0	9.0	11.0	9.0	5.0	8.0	6.0	8.0	5.0	5.0	5.0	4.0
	Median	12.0	10.0	38.0	10.0	11.0	15.0	13.0	18.0	17.0	16.0	16.0	18.0	19.0
Average Wind Speed (mph)	Average	21.5	18.5	13.1	18.5	23.0	33.1	34.7	39.0	26.0	26.9	39.4	36.1	33.4
	Standard Deviation	3.2	4.8	2.4	7.5	6.1	4.9	5.2	3.1	1.9	3.3	6.9	5.3	4.3
	Variance	10.0	22.6	5.6	56.6	37.0	24.3	26.5	9.4	3.7	10.6	47.2	28.2	18.2
	Range	14.0	19.0	12.0	23.0	25.0	21.0	22.0	14.0	9.0	13.0	28.0	20.0	17.0
	Median	21.0	19.0	13.0	19.0	22.0	33.0	35.0	39.0	26.0	28.0	40.0	38.0	35.0
Gust Wind Speed (mph)	Average	29.8	25.2	19.2	30.7	36.1	45.8	46.3	46.4	36.0	37.9	49.0	46.5	43.0
	Standard Deviation	4.2	5.8	3.0	9.6	6.2	5.4	5.9	3.2	4.0	4.5	7.0	5.9	5.3
	Variance	17.2	34.1	9.3	92.1	38.9	29.2	34.8	10.1	15.7	20.5	48.3	34.7	27.9
	Range	17.0	24.0	12.0	36.0	27.0	24.0	29.0	14.0	17.0	18.0	30.0	23.0	22.0
	Median	30.0	27.0	19.0	29.0	36.0	46.0	47.0	47.0	35.0	39.0	49.0	49.0	45.0
Precipitation Accumulation (in)	Average	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Standard Deviation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Median	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Precipitation Rate (in/hr)	Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Standard Deviation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Visibility (ft)	Average	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0
	Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Variance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Range	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0
Surface Temperature (F)	Average	62.5	N/A	N/A	60.1	104.0	N/A	55.8	54.8	55.5	N/A	58.2	N/A	58.3
	Standard Deviation	6.2	N/A	N/A	8.3	11.7	N/A	8.3	7.3	6.4	N/A	6.4	N/A	7.1
	Variance	38.5	N/A	N/A	69.0	137.1	N/A	69.2	53.4	40.8	N/A	40.4	N/A	50.8
	Range	27.9	N/A	N/A	25.8	39.6	N/A	27.3	24.0	21.6	N/A	22.7	N/A	26.5
	Median	63.3	N/A	N/A	63.4	109.2	N/A	58.3	57.0	57.6	N/A	60.6	N/A	60.8
Precipitation Type	Percent "None"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Percent "Snow"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Frozen"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Rain"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Yes"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Precipitation Intensity	Percent "None"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Percent "Slight"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Moderate"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Heavy"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Status	Percent "Dry"	100.0	N/A	N/A	100.0	98.9	N/A	100.0	0.0	100.0	N/A	0.0	N/A	100.0
	Percent "Trace Moisture"	0.0	N/A	N/A	0.0	1.1	N/A	0.0	100.0	0.0	N/A	0.0	N/A	0.0
	Percent "Wet"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	24.7	N/A	0.0
	Percent "Ice Warning"	1.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0
	Percent "Chemically Wet"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	75.3	N/A	0.0
	Percent "Snow Watch"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0

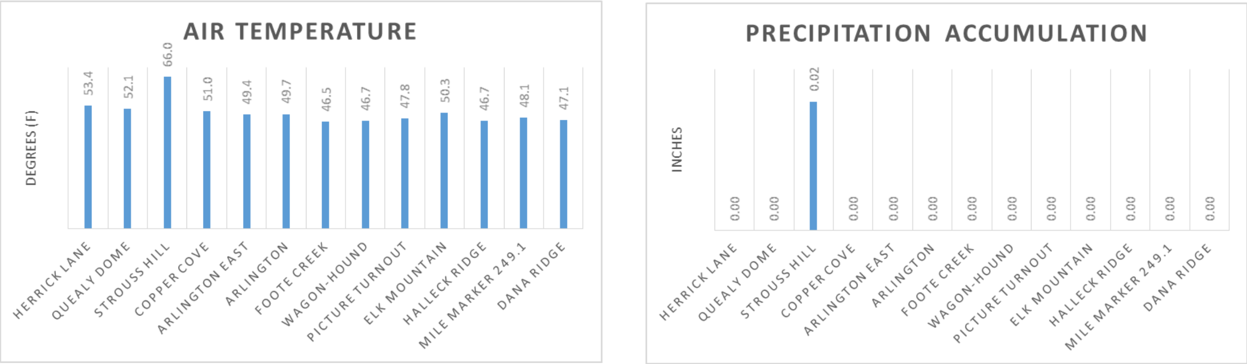


Figure C.1 Trip CC1, 2, 3, 4 Air Temperature and Precipitation Accumulation RWIS Data

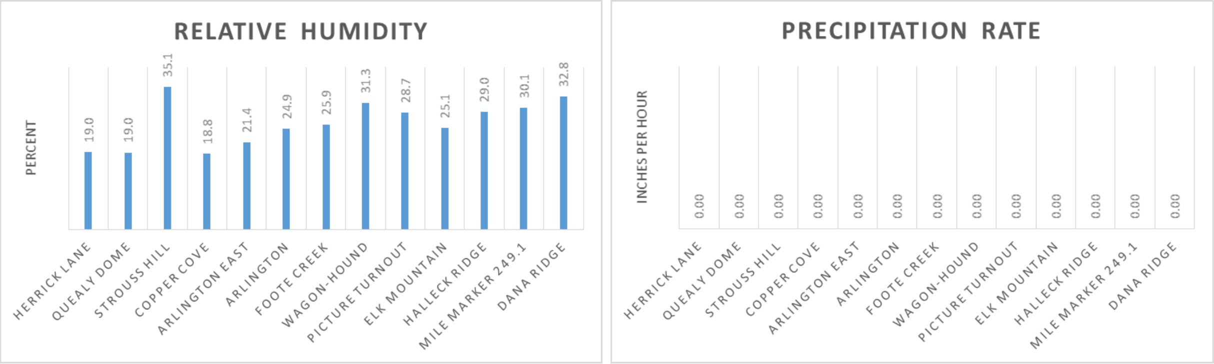


Figure C.2 Trip CC1, 2, 3, 4 Relative Humidity and Precipitation Rate RWIS Data

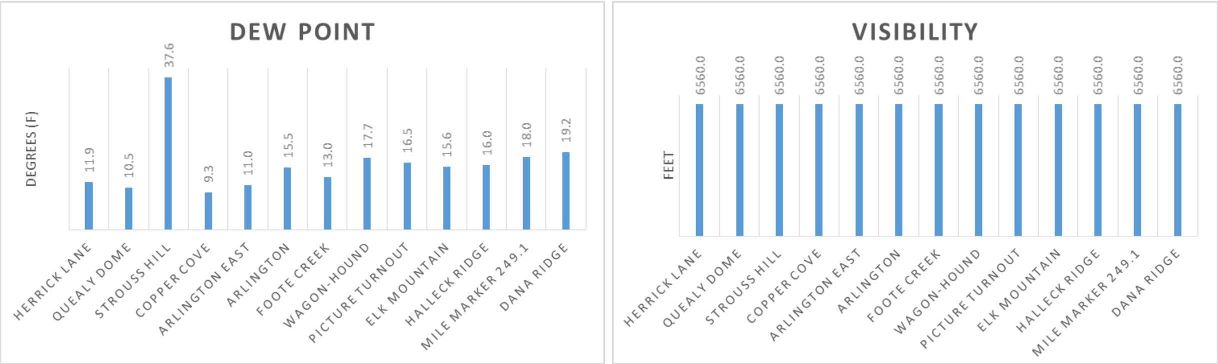


Figure C.3 Trip CC1, 2, 3, 4 Dew Point and Visibility RWIS Data

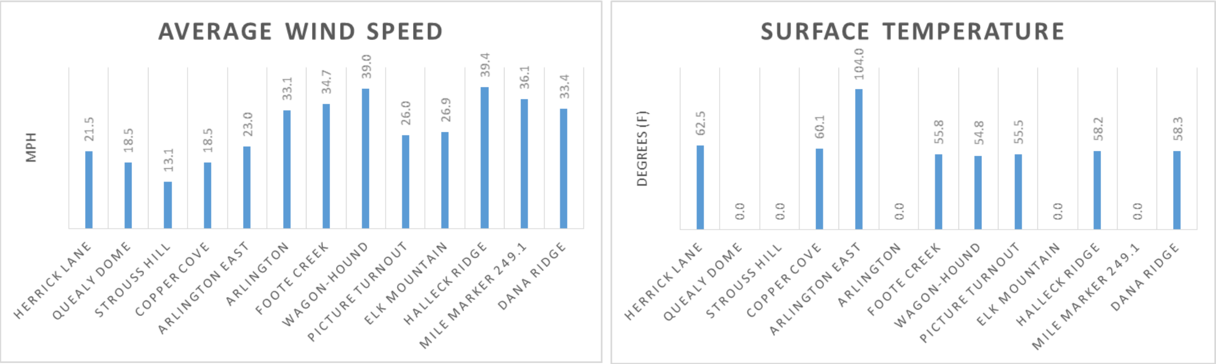


Figure C.4 Trip CC1, 2, 3, 4 Average Wind Speed and Surface Temperature RWIS Data

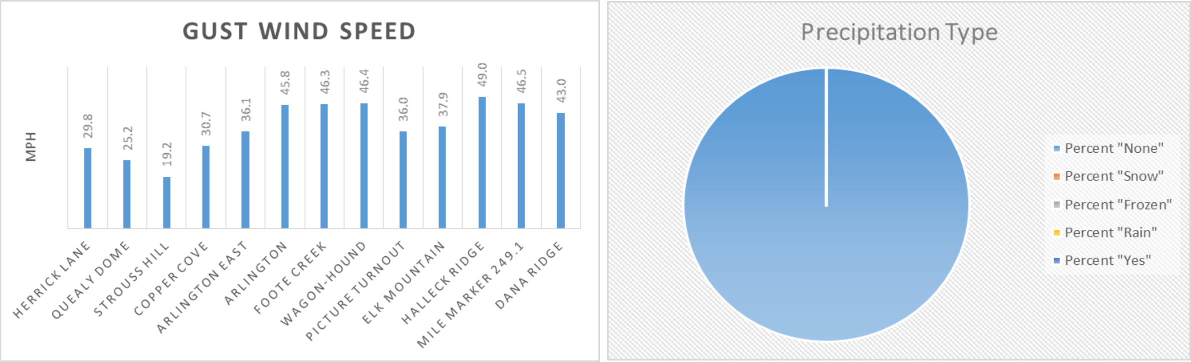


Figure C.5 Trip CC1, 2, 3, 4 Gust Wind Speed and Precipitation Type Data

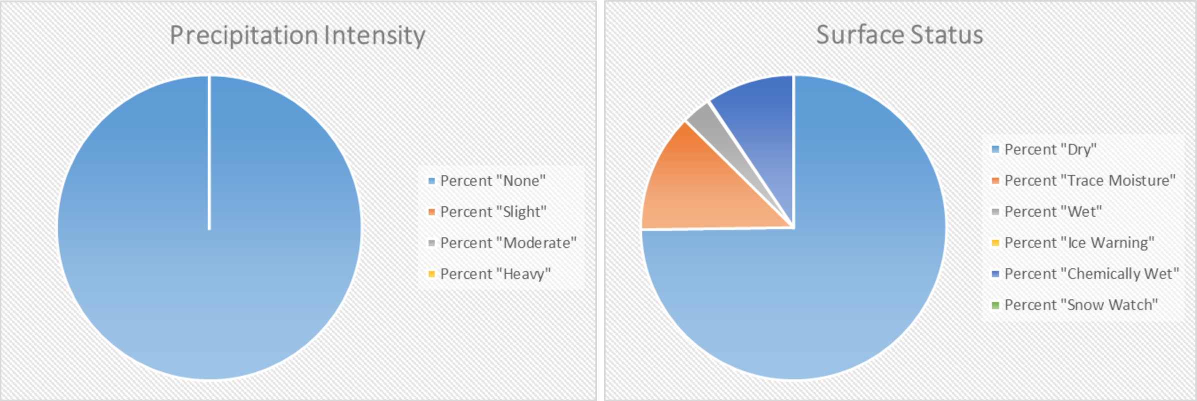


Figure C.6 Trip CC1, 2, 3, 4 Precipitation Intensity and Surface Status RWIS Data

Trips CC5, 6

Table C.2 Trip CC5, 6 RWIS Data

TRIP CC5,6														
RWIS Weather Data	Statistical Calculations	Herrick Lane	RWIS Stations from Laramie to Walcott											
			Quealy Dome	Strouss Hill	Copper Cove	Arlington East	Arlington	Foote Creek	Wagon-hound	Picture Turnout	Elk Mountain	Halleck Ridge	Mile Marker 249.1	Dana Ridge
Air Temp (F)	Average	24.5	24.5	23.8	24.6	24.1	25.1	23.5	25.5	24.4	26.4	24.5	26.0	25.5
	Standard Deviation	0.6	0.5	0.6	2.3	0.7	1.1	0.5	0.8	0.5	0.5	0.5	0.3	0.6
	Variance	0.4	0.3	0.4	5.2	0.4	1.2	0.3	0.6	0.3	0.3	0.3	0.1	0.4
	Range	2.0	1.0	2.0	9.0	2.0	4.0	1.0	2.0	1.0	1.0	1.0	2.0	2.0
	Median	24.0	25.0	24.0	24.0	24.0	25.0	24.0	26.0	24.0	26.0	24.0	26.0	26.0
Relative Humidity (%)	Average	96.9	92.2	96.0	88.8	95.5	92.6	96.7	98.5	97.6	93.6	94.8	95.2	94.2
	Standard Deviation	1.1	1.7	1.7	26.7	0.9	0.5	1.3	0.8	0.6	2.2	1.3	1.6	2.8
	Variance	1.1	3.0	2.8	715.3	0.8	0.2	1.6	0.7	0.4	4.9	1.7	2.6	7.6
	Range	4.0	7.0	7.0	98.0	3.0	1.0	5.0	4.0	2.0	8.0	5.0	7.0	12.0
	Median	97.0	92.0	96.0	97.0	96.0	93.0	97.0	98.0	98.0	94.0	95.0	95.0	94.0
Dew Point (F)	Average	23.9	22.4	22.8	23.9	23.0	23.5	22.7	25.2	23.8	24.7	23.1	24.8	24.0
	Standard Deviation	0.4	0.6	0.6	2.5	0.6	1.0	0.6	0.8	0.5	0.6	0.5	0.5	0.8
	Variance	0.2	0.3	0.3	6.2	0.4	0.9	0.3	0.7	0.3	0.4	0.2	0.3	0.7
	Range	2.0	2.0	2.0	10.0	2.0	4.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0
	Median	24.0	22.0	23.0	23.0	23.0	23.0	23.0	25.0	24.0	25.0	23.0	25.0	24.0
Average Wind Speed (mph)	Average	12.3	9.5	5.9	4.6	5.2	6.0	8.2	7.1	9.5	9.0	10.1	12.0	15.1
	Standard Deviation	2.0	2.1	1.1	2.0	1.0	1.6	2.0	1.0	1.1	0.8	0.9	1.3	2.0
	Variance	4.0	4.3	1.3	4.2	1.0	2.5	4.0	0.9	1.2	0.6	0.8	1.8	4.1
	Range	7.0	7.0	4.0	8.0	3.0	6.0	6.0	4.0	4.0	4.0	3.0	6.0	8.0
	Median	12.0	10.0	6.0	4.0	6.0	7.0	7.0	7.0	10.0	9.0	10.0	12.0	16.0
Gust Wind Speed (mph)	Average	15.8	13.1	8.5	6.8	8.0	9.2	10.9	11.0	12.7	12.4	13.8	16.1	19.5
	Standard Deviation	2.7	2.6	1.5	2.7	1.3	1.7	1.7	1.6	1.3	1.0	1.2	1.5	1.8
	Variance	7.2	6.8	2.3	7.4	1.6	3.0	3.0	2.6	1.6	1.0	1.5	2.3	3.3
	Range	9.0	8.0	5.0	10.0	4.0	8.0	6.0	6.0	3.0	4.0	4.0	5.0	7.0
	Median	16.0	13.0	9.0	7.0	8.0	9.0	11.0	11.0	13.0	12.0	13.0	16.0	19.0
Precipitation Accumulation (in)	Average	0.03	0.05	0.11	0.06	0.12	0.06	0.07	0.06	0.06	0.08	0.04	0.04	0.04
	Standard Deviation	0.00	0.02	0.03	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.01	0.04	0.09	0.10	0.07	0.05	0.03	0.06	0.03	0.04	0.01	0.01	0.02
	Median	0.03	0.06	0.13	0.08	0.13	0.06	0.07	0.06	0.06	0.08	0.04	0.04	0.04
Precipitation Rate (in/hr)	Average	0.00	0.01	0.03	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00
	Standard Deviation	0.00	0.03	0.05	0.03	0.04	0.00	0.03	0.03	0.03	0.03	0.00	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.10	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.00
	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Visibility (ft)	Average	6270.2	5726.9	3799.8	3686.6	4550.0	5561.4	5359.2	5445.9	5777.6	6004.2	6078.9	6177.1	5741.8
	Standard Deviation	787.2	1087.9	1299.5	2127.0	1638.0	1233.6	1555.3	1435.7	1285.8	904.2	982.0	897.6	1227.5
	Variance	619695.8	1183560.3	1688762.6	4524259.7	2683009.1	1521657.6	2418996.4	2061203.0	1653159.3	817653.7	964410.0	805753.4	1506658.8
	Range	3047.0	2880.0	4359.0	6560.0	4582.0	3936.0	4149.0	4175.0	3680.0	2545.0	2736.0	3388.0	3588.0
	Median	6560.0	6560.0	3588.0	3372.0	4740.0	6265.0	6560.0	6038.0	6560.0	6560.0	6560.0	6560.0	6560.0
Surface Temperature (F)	Average	37.0	N/A	N/A	34.9	36.5	N/A	36.4	36.8	38.2	N/A	39.6	N/A	40.8
	Standard Deviation	2.2	N/A	N/A	2.7	2.6	N/A	2.2	2.3	2.1	N/A	2.5	N/A	2.4
	Variance	4.8	N/A	N/A	7.5	6.7	N/A	4.7	5.1	4.5	N/A	6.3	N/A	5.8
	Range	9.6	N/A	N/A	7.9	8.0	N/A	7.3	7.2	6.8	N/A	9.0	N/A	8.4
	Median	37.4	N/A	N/A	34.2	37.4	N/A	36.5	37.4	39.0	N/A	40.5	N/A	40.5
Precipitation Type	Percent "None"	70.3	37.8	5.4	0.3	16.2	0.0	43.2	2.7	35.1	16.2	54.1	32.4	29.7
	Percent "Snow"	29.7	62.2	94.6	0.7	83.8	86.5	51.4	35.1	37.8	21.6	43.2	43.2	35.1
	Percent "Frozen"	0.0	0.0	0.0	0.0	0.0	0.0	5.4	62.2	27.0	62.2	2.7	24.3	35.1
	Percent "Rain"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Yes"	0.0	0.0	0.0	0.0	0.0	13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Precipitation Intensity	Percent "None"	70.3	37.8	5.4	0.4	16.2	0.0	43.2	2.7	35.1	16.2	54.1	32.4	29.7
	Percent "Slight"	29.7	51.4	83.8	0.6	75.7	94.6	48.7	91.9	62.2	81.1	46.0	67.6	70.3
	Percent "Moderate"	0.0	10.8	10.8	0.0	8.1	5.4	8.1	5.4	2.7	2.7	0.0	0.0	0.0
	Percent "Heavy"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Status	Percent "Dry"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0
	Percent "Trace Moisture"	62.2	N/A	N/A	0.3	8.1	N/A	27.0	10.8	29.7	N/A	0.0	N/A	64.9
	Percent "Wet"	37.8	N/A	N/A	0.7	91.9	N/A	73.0	89.2	70.3	N/A	0.0	N/A	35.1
	Percent "Ice Warning"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0
	Percent "Chemically Wet"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	100.0	N/A	0.0
	Percent "Snow Watch"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0

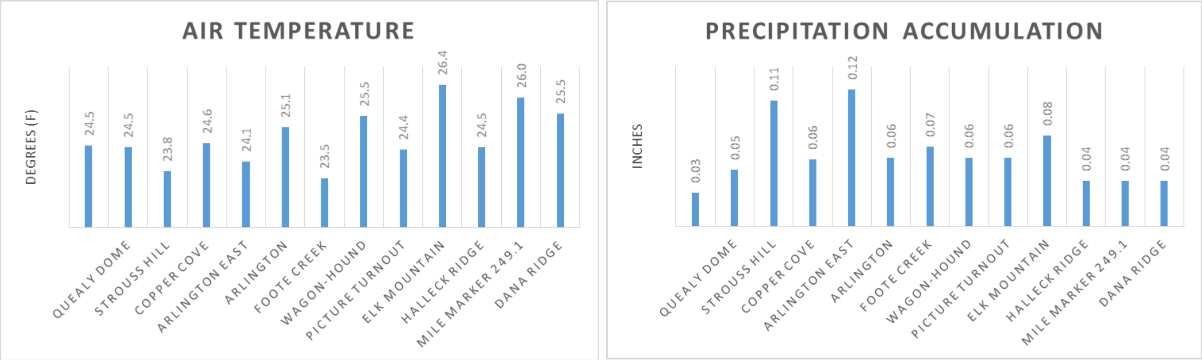


Figure C.7 Trip CC5, 6 Air Temperature and Precipitation Accumulation RWIS Data

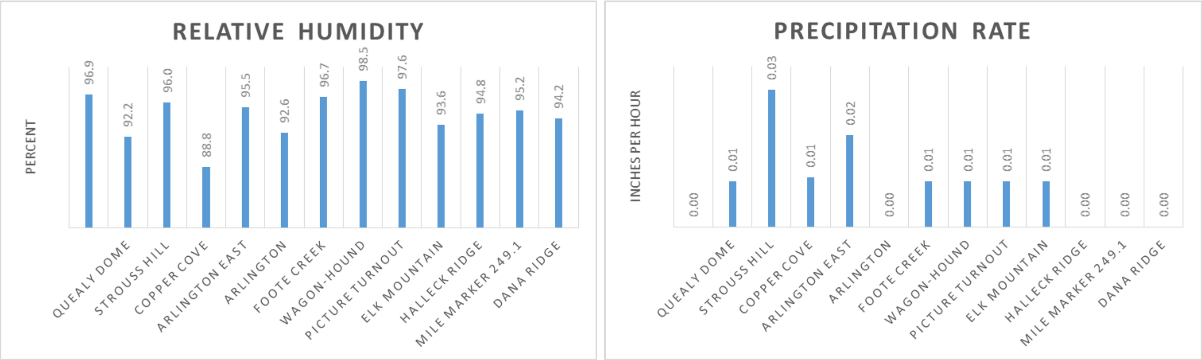


Figure C.8 Trip CC5, 6 Relative Humidity and Precipitation Rate RWIS Data

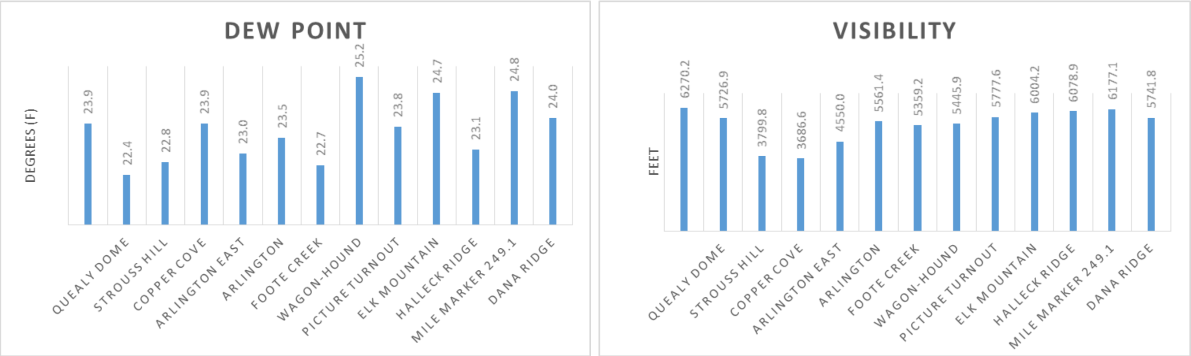


Figure C.9 Trip CC5, 6 Dew Point and Visibility RWIS Data

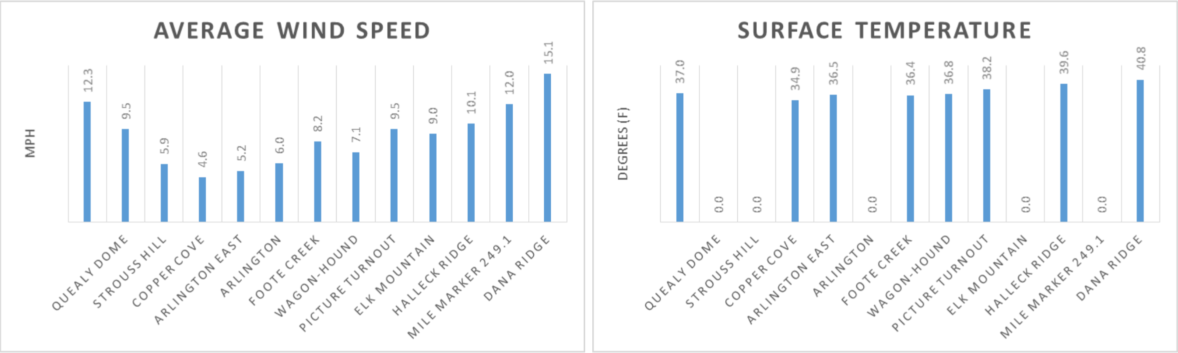


Figure C.10 Trip CC5, 6 Average Wind Speed and Surface Temperature RWIS Data

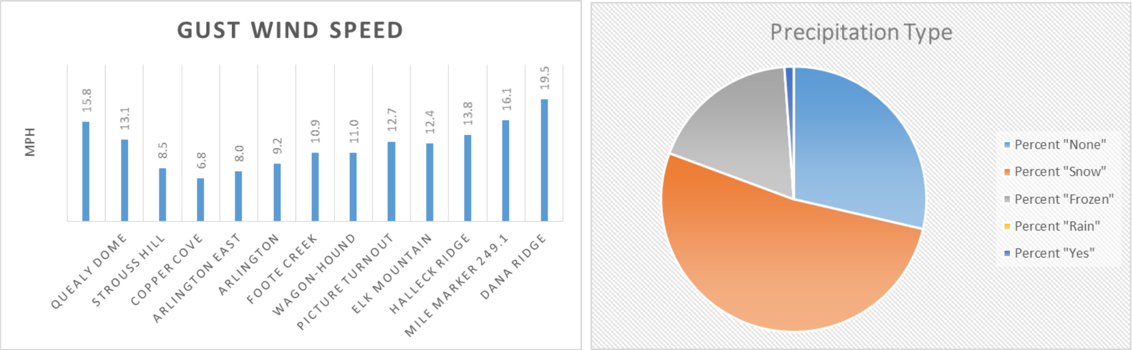


Figure C.11 Trip CC5, 6 Gust Wind Speed and Precipitation Type RWIS Data

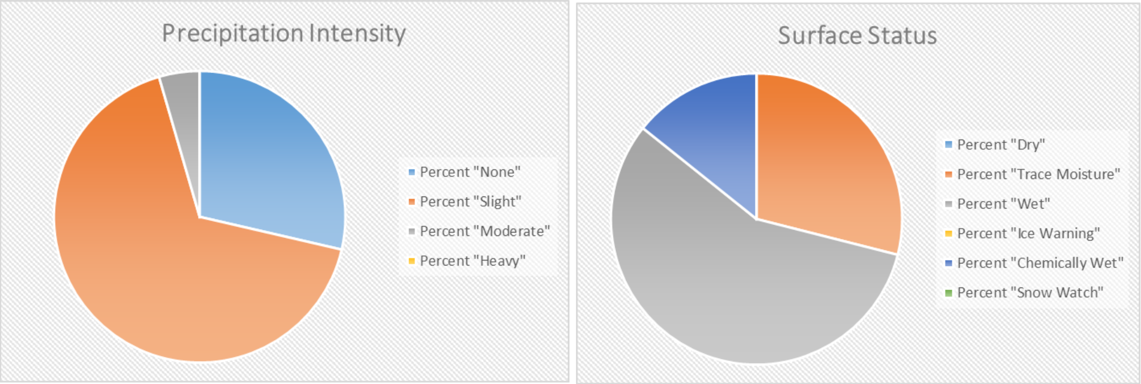


Figure C.12 Trip CC5, 6 Precipitation Intensity and Surface Status RWIS Data

Trip CC7

Table C.3 Trip CC7 RWIS Data

TRIP CC7														
RWIS Weather Data	Statistical Calculations	Herrick Lane	RWIS Stations from Laramie to Walcott											
			Quealy Dome	Strouss Hill	Copper Cove	Arlington East	Arlington	Foote Creek	Wagon-hound	Picture Turnout	Elk Mountain	Halleck Ridge	Mile Marker 249.1	Dana Ridge
Air Temp (F)	Average	13.3	18.2	17.5	15.4	15.2	19.3	16.5	16.9	16.6	18.3	17.6	19.2	18.7
	Standard Deviation	2.5	2.6	0.8	0.8	1.3	2.3	1.6	1.4	0.7	1.2	0.7	1.1	1.3
	Variance	6.2	6.8	0.6	0.7	1.8	5.3	2.6	1.9	0.5	1.4	0.5	1.3	1.6
	Range	8.0	8.0	3.0	3.0	5.0	6.0	5.0	5.0	2.0	4.0	3.0	3.0	4.0
	Median	12.0	19.0	17.0	15.0	15.0	20.0	16.0	17.0	17.0	19.0	18.0	19.0	19.0
Relative Humidity (%)	Average	96.0	93.0	94.1	93.5	95.5	92.7	96.1	98.2	96.8	95.6	96.0	90.1	91.0
	Standard Deviation	1.3	2.1	1.4	1.2	0.7	0.5	0.9	1.3	0.4	0.7	1.2	4.9	5.4
	Variance	1.6	4.4	1.9	1.4	0.5	0.2	0.8	1.6	0.1	0.5	1.4	24.0	28.7
	Range	4.0	7.0	6.0	3.0	2.0	1.0	3.0	4.0	1.0	2.0	5.0	13.0	17.0
	Median	96.0	93.0	94.0	93.0	96.0	93.0	96.0	99.0	97.0	95.0	96.0	93.0	91.0
Dew Point (F)	Average	12.4	16.5	16.0	13.8	14.1	17.5	15.5	16.5	16.0	17.3	16.6	16.8	16.4
	Standard Deviation	2.8	2.6	1.2	1.0	1.4	2.1	1.7	1.1	0.8	1.3	0.8	0.6	0.8
	Variance	7.9	6.5	1.4	1.0	1.9	4.6	2.8	1.3	0.6	1.8	0.7	0.4	0.7
	Range	10.0	8.0	4.0	3.0	5.0	5.0	6.0	4.0	3.0	4.0	4.0	2.0	2.0
	Median	11.0	18.0	15.0	14.0	14.0	18.0	15.0	17.0	16.0	18.0	17.0	17.0	17.0
Average Wind Speed (mph)	Average	1.5	1.7	1.0	3.3	2.0	0.8	0.8	3.2	4.0	2.8	5.9	9.6	12.0
	Standard Deviation	0.6	0.5	0.4	1.6	0.3	0.8	0.5	0.8	0.9	1.4	1.2	0.8	2.2
	Variance	0.4	0.2	0.2	2.5	0.1	0.7	0.3	0.6	0.9	2.0	1.3	0.6	4.7
	Range	2.0	1.0	2.0	5.0	2.0	2.0	2.0	2.0	3.0	4.0	3.0	2.0	8.0
	Median	1.0	2.0	1.0	3.0	2.0	1.0	1.0	3.0	4.0	2.0	6.0	9.0	12.0
Gust Wind Speed (mph)	Average	3.2	3.3	2.0	4.8	3.6	2.7	2.1	4.9	5.9	4.8	9.4	14.0	16.7
	Standard Deviation	0.8	0.7	0.8	1.3	0.6	1.3	0.9	1.1	1.4	1.8	1.6	1.6	3.2
	Variance	0.6	0.5	0.6	1.7	0.4	1.7	0.8	1.2	2.0	3.4	2.5	2.4	10.4
	Range	2.0	2.0	2.0	4.0	2.0	4.0	3.0	3.0	5.0	5.0	5.0	5.0	10.0
	Median	3.0	3.0	2.0	4.0	4.0	3.0	2.0	4.0	6.0	4.0	9.0	14.0	17.0
Precipitation Accumulation (in)	Average	0.04	0.12	0.24	0.00	0.22	0.15	0.12	0.11	0.09	0.15	0.08	0.06	0.08
	Standard Deviation	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
	Median	0.04	0.12	0.24	0.00	0.22	0.15	0.12	0.11	0.09	0.15	0.08	0.06	0.08
Precipitation Rate (in/hr)	Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Standard Deviation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Visibility (ft)	Average	6086.5	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0
	Standard Deviation	1436.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Variance	2063724.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Range	5182.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0
Surface Temperature (F)	Average	27.8	N/A	N/A	24.7	25.2	N/A	25.9	25.3	28.0	N/A	29.5	N/A	28.2
	Standard Deviation	2.6	N/A	N/A	1.9	3.7	N/A	3.8	4.0	3.9	N/A	3.9	N/A	5.2
	Variance	6.8	N/A	N/A	3.8	14.0	N/A	14.3	15.6	15.0	N/A	15.4	N/A	27.0
	Range	8.5	N/A	N/A	6.3	11.7	N/A	11.0	11.5	13.5	N/A	11.5	N/A	15.7
	Median	27.1	N/A	N/A	24.6	26.4	N/A	26.8	25.5	27.9	N/A	29.3	N/A	28.4
Precipitation Type	Percent "None"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	94.7	89.5	100.0
	Percent "Snow"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	10.5	0.0
	Percent "Frozen"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Rain"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Yes"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Precipitation Intensity	Percent "None"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	94.7	89.5	100.0
	Percent "Slight"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	10.5	0.0
	Percent "Moderate"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Heavy"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Status	Percent "Dry"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	89.5	0.0	N/A	0.0	N/A	94.7
	Percent "Trace Moisture"	84.2	N/A	N/A	31.6	94.7	N/A	73.7	10.5	100.0	N/A	57.9	N/A	5.3
	Percent "Wet"	0.0	N/A	N/A	0.0	5.3	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0
	Percent "Ice Warning"	0.0	N/A	N/A	68.4	0.0	N/A	26.3	0.0	0.0	N/A	0.0	N/A	0.0
	Percent "Chemically Wet"	15.8	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	42.1	N/A	0.0
	Percent "Snow Watch"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0

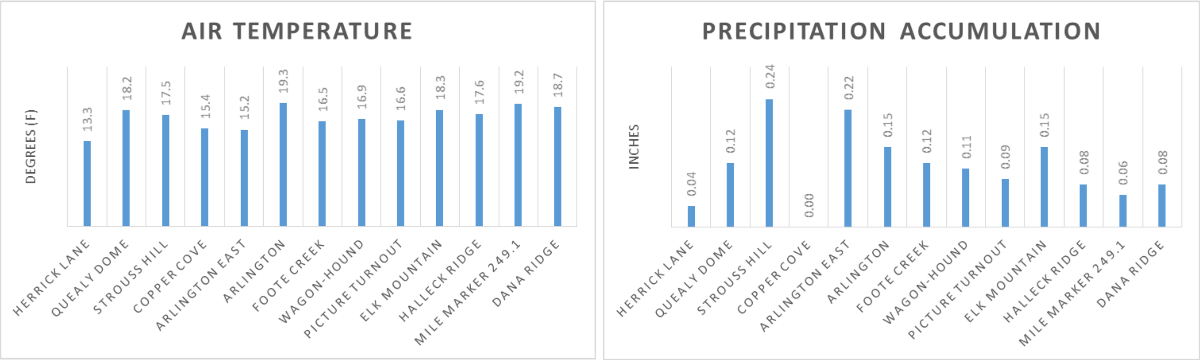


Figure C.13 Trip CC7 Air Temperature and Precipitation Accumulation RWIS Data

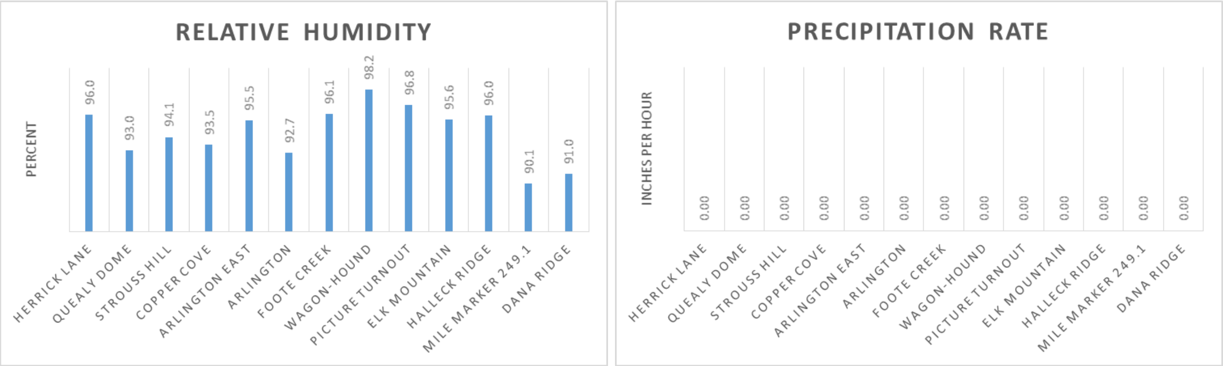


Figure C.14 Trip CC7 Relative Humidity and Precipitation Rate RWIS Data

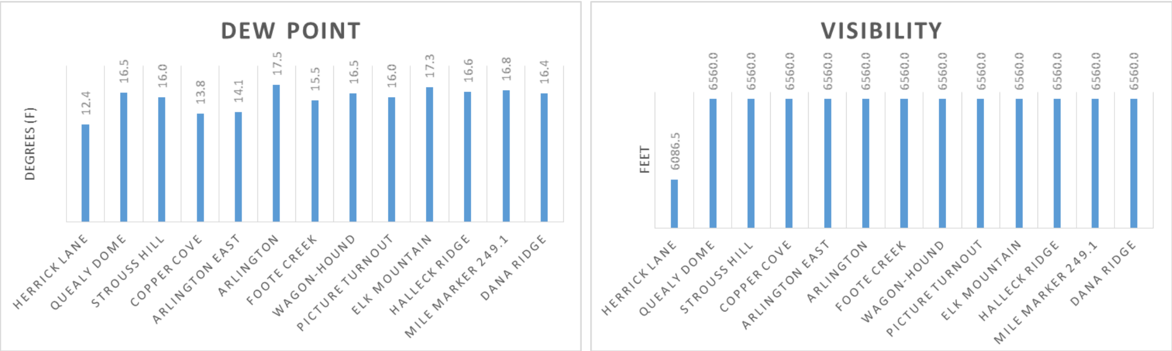


Figure C.15 Trip CC7 Dew Point and Visibility RWIS Data

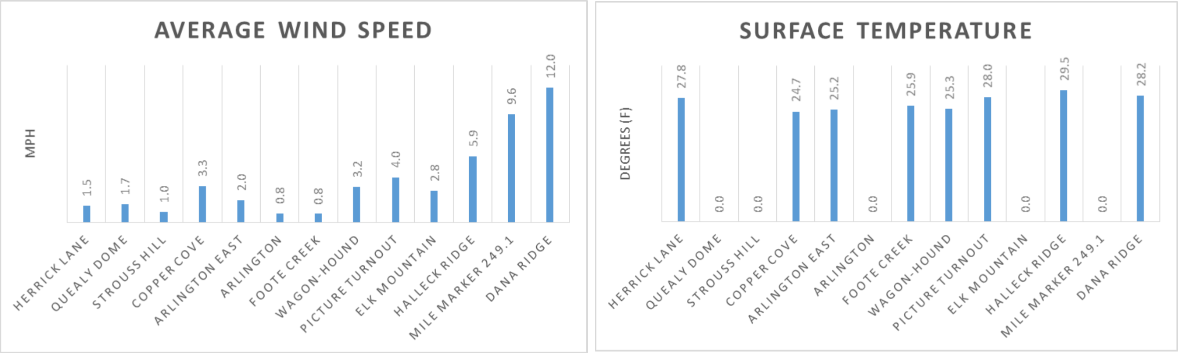


Figure C.16 Trip CC7 Average Wind Speed and Surface Temperature RWIS Data

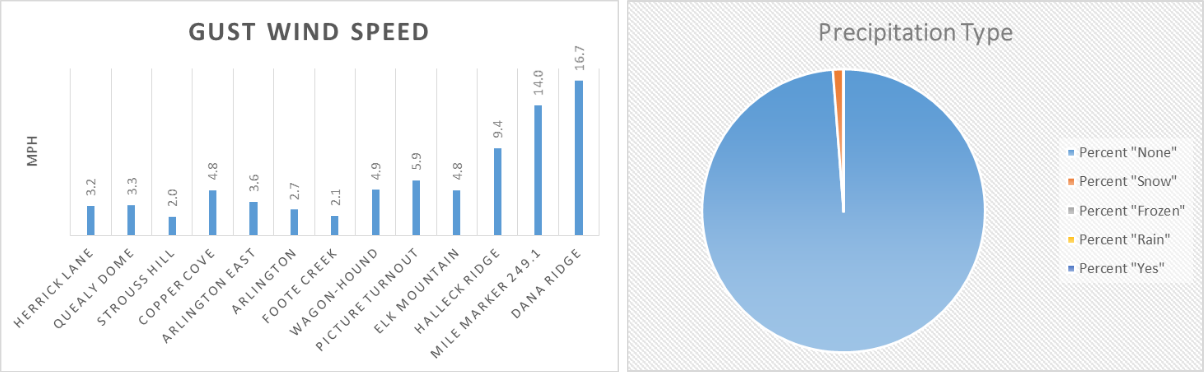


Figure C.17 Trip CC7 Gust Wind Speed and Precipitation Type RWIS Data

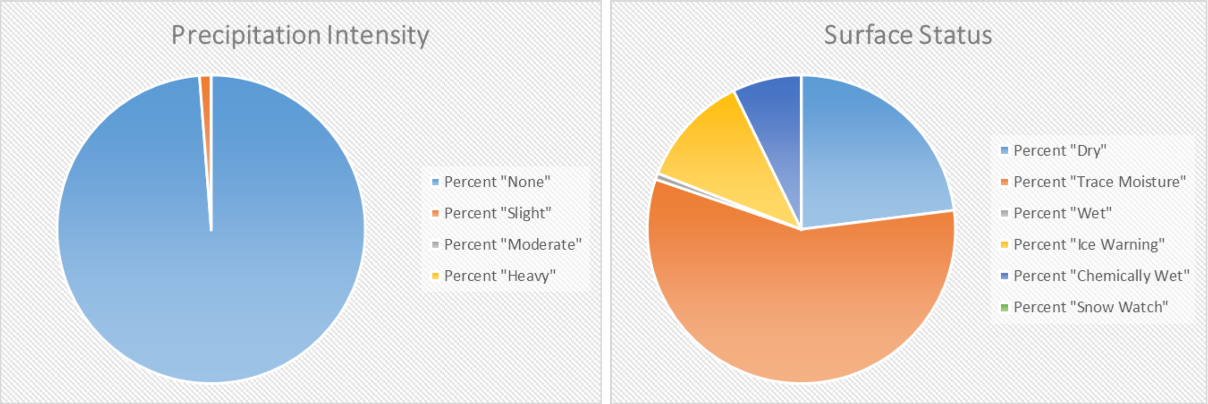


Figure C.18 Trip CC7 Precipitation Intensity and Surface Status RWIS Data

Trip CC8

This trip originated in Laramie, Wyoming, and concluded in Boulder, Colorado. No RWIS weather data was collected for this route as it was not along I-80 between Laramie and Rawlins, Wyoming.

Trips CC9, 10

Table C.4 Trip CC9, 10 RWIS Data

TRIP CC9,10														
RWIS Weather Data	Statistical Calculations	Herrick Lane	RWIS Stations from Laramie to Walcott											
			Quealy Dome	Strouss Hill	Copper Cove	Arlington East	Arlington	Foote Creek	Wagon-hound	Picture Turnout	Elk Mountain	Halleck Ridge	Mile Marker 249.1	Dana Ridge
Air Temp (F)	Average	7.8	7.2	5.5	6.7	6.1	6.8	5.6	6.7	6.0	7.0	5.1	6.7	6.7
	Standard Deviation	1.2	1.1	1.2	1.1	1.3	1.1	0.7	0.8	1.4	2.1	1.9	2.2	2.4
	Variance	1.5	1.3	1.3	1.3	1.7	1.2	0.6	0.6	2.0	4.6	3.8	4.7	5.8
	Range	4.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	4.0	6.0	5.0	6.0	6.0
	Median	8.0	7.0	6.0	7.0	6.0	7.0	6.0	7.0	6.0	6.0	4.0	6.0	6.0
Relative Humidity (%)	Average	83.0	86.6	86.5	90.8	90.1	90.7	89.8	90.4	89.2	87.2	88.4	87.5	86.8
	Standard Deviation	3.5	1.6	0.5	0.6	1.1	1.0	1.0	1.7	2.3	3.0	1.2	2.1	2.3
	Variance	11.9	2.5	0.3	0.4	1.3	1.1	1.0	3.0	5.3	8.9	1.3	4.6	5.1
	Range	11.0	6.0	1.0	2.0	4.0	4.0	4.0	7.0	7.0	9.0	5.0	7.0	8.0
	Median	83.0	87.0	86.5	91.0	90.5	91.0	90.0	91.0	90.0	89.0	89.0	88.0	88.0
Dew Point (F)	Average	3.7	3.9	2.4	4.6	3.9	4.8	3.4	4.6	3.5	4.0	2.6	3.9	3.7
	Standard Deviation	0.6	0.9	1.1	1.1	1.4	1.2	0.9	1.1	0.9	1.7	1.7	1.8	1.8
	Variance	0.4	0.8	1.2	1.3	2.0	1.4	0.8	1.2	0.8	2.8	2.7	3.1	3.3
	Range	2.0	3.0	3.0	4.0	5.0	4.0	3.0	4.0	3.0	4.0	4.0	4.0	5.0
	Median	4.0	4.0	3.0	5.0	4.0	5.0	4.0	5.0	3.0	4.0	2.0	4.0	4.0
Average Wind Speed (mph)	Average	11.4	12.4	12.0	14.4	12.2	12.4	15.7	15.1	16.6	13.7	18.7	22.0	19.8
	Standard Deviation	1.2	1.0	1.5	2.9	3.9	1.2	2.0	1.0	1.3	1.3	2.1	1.2	1.5
	Variance	1.3	0.9	2.2	8.2	15.0	1.5	4.0	1.1	1.6	1.7	4.3	1.4	2.3
	Range	5.0	4.0	6.0	10.0	12.0	5.0	6.0	4.0	6.0	5.0	6.0	5.0	6.0
	Median	12.0	12.0	12.0	14.0	11.0	12.0	16.0	15.0	17.0	14.0	19.0	22.0	20.0
Gust Wind Speed (mph)	Average	17.5	16.3	16.2	20.0	18.1	17.2	21.4	20.7	21.1	18.1	27.6	27.6	27.8
	Standard Deviation	1.5	0.9	2.6	2.9	4.4	1.4	2.2	1.3	1.6	1.4	2.4	2.2	1.5
	Variance	2.3	0.8	6.7	8.5	19.5	1.8	4.6	1.8	2.5	2.1	5.7	4.7	2.3
	Range	6.0	4.0	8.0	13.0	11.0	6.0	8.0	7.0	8.0	5.0	10.0	8.0	6.0
	Median	17.0	16.5	15.5	20.0	16.0	17.0	22.0	21.0	21.0	18.0	27.0	28.0	28.0
Precipitation Accumulation (in)	Average	0.02	0.04	0.08	0.04	0.19	0.11	0.11	0.04	0.03	0.05	0.02	0.02	0.01
	Standard Deviation	0.00	0.00	0.01	0.01	0.05	0.02	0.03	0.02	0.02	0.01	0.01	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.00	0.03	0.02	0.13	0.07	0.11	0.05	0.07	0.04	0.01	0.01	0.01
	Median	0.02	0.04	0.07	0.05	0.21	0.11	0.12	0.04	0.02	0.06	0.02	0.02	0.01
Precipitation Rate (in/hr)	Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Standard Deviation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Visibility (ft)	Average	6560.0	6227.8	6460.0	6325.4	6490.6	6306.2	6560.0	6560.0	6560.0	6249.6	6519.1	6425.0	6560.0
	Standard Deviation	0.0	657.1	289.8	590.0	247.1	551.3	0.0	0.0	0.0	738.9	181.7	406.3	0.0
	Variance	0.0	431786.6	83977.4	348116.7	61041.8	303976.1	0.0	0.0	0.0	546010.8	32995.8	165081.5	0.0
	Range	0.0	2460.0	1200.0	2444.0	1227.0	1896.0	0.0	0.0	0.0	2627.0	902.0	1929.0	0.0
	Median	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0
Surface Temperature (F)	Average	22.2	N/A	N/A	21.1	21.4	N/A	20.0	20.9	24.0	N/A	20.0	N/A	24.4
	Standard Deviation	3.6	N/A	N/A	4.4	5.4	N/A	5.6	5.6	5.1	N/A	5.0	N/A	6.3
	Variance	12.7	N/A	N/A	19.7	29.1	N/A	31.6	31.4	25.9	N/A	25.0	N/A	39.1
	Range	11.0	N/A	N/A	15.1	18.0	N/A	18.3	16.9	15.8	N/A	15.9	N/A	20.5
	Median	22.6	N/A	N/A	21.2	20.3	N/A	18.8	19.9	23.0	N/A	19.2	N/A	23.3
Precipitation Type	Percent "None"	100.0	92.5	97.5	95.0	87.5	7.5	100.0	100.0	100.0	72.5	100.0	100.0	100.0
	Percent "Snow"	0.0	7.5	2.5	5.0	12.5	92.5	0.0	0.0	0.0	27.5	0.0	0.0	0.0
	Percent "Frozen"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Rain"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Yes"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Precipitation Intensity	Percent "None"	100.0	92.5	97.5	95.0	87.5	7.5	100.0	100.0	100.0	72.5	100.0	100.0	100.0
	Percent "Slight"	0.0	7.5	2.5	5.0	12.5	92.5	0.0	0.0	0.0	27.5	0.0	0.0	0.0
	Percent "Moderate"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Heavy"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Status	Percent "Dry"	0.0	N/A	N/A	0.0	7.5	N/A	15.0	22.5	100.0	N/A	0.0	N/A	100.0
	Percent "Trace Moisture"	100.0	N/A	N/A	52.5	92.5	N/A	62.5	57.5	0.0	N/A	100.0	N/A	0.0
	Percent "Wet"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0
	Percent "Ice Warning"	0.0	N/A	N/A	42.5	0.0	N/A	22.5	20.0	0.0	N/A	0.0	N/A	0.0
	Percent "Chemically Wet"	0.0	N/A	N/A	5.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0
	Percent "Snow Watch"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0

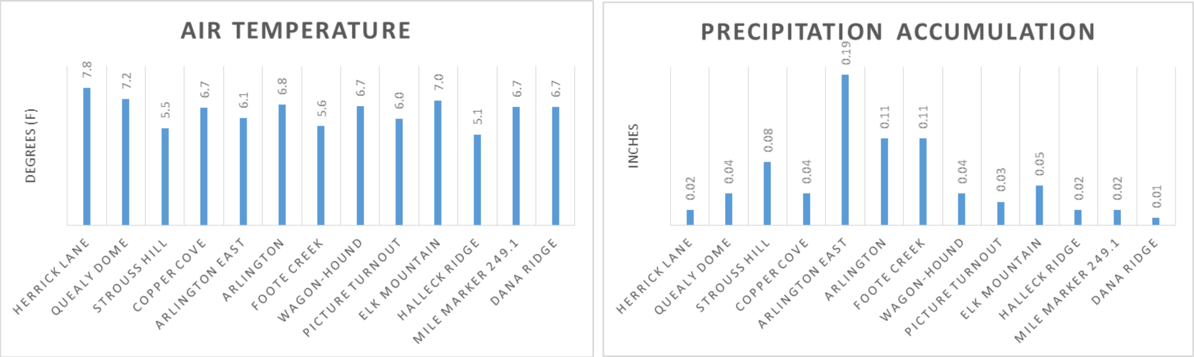


Figure C.19 Trip CC9, 10 Air Temperature and Precipitation Accumulation RWIS Data

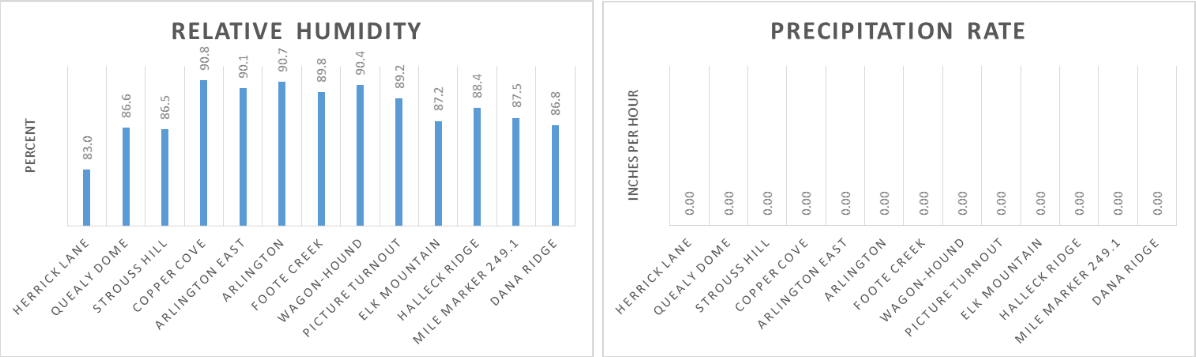


Figure C.20 Trip CC9, 10 Relative Humidity and Precipitation Rate RWIS Data

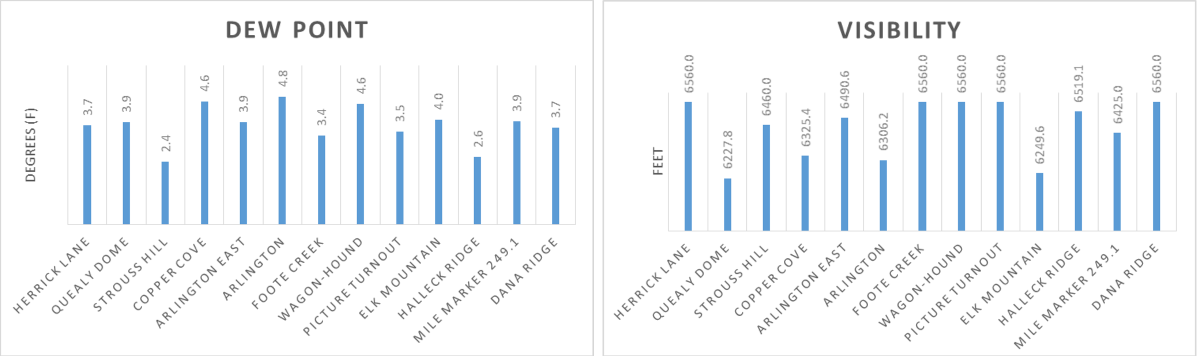


Figure C.21 Trip CC9, 10 Dew Point and Visibility RWIS Data

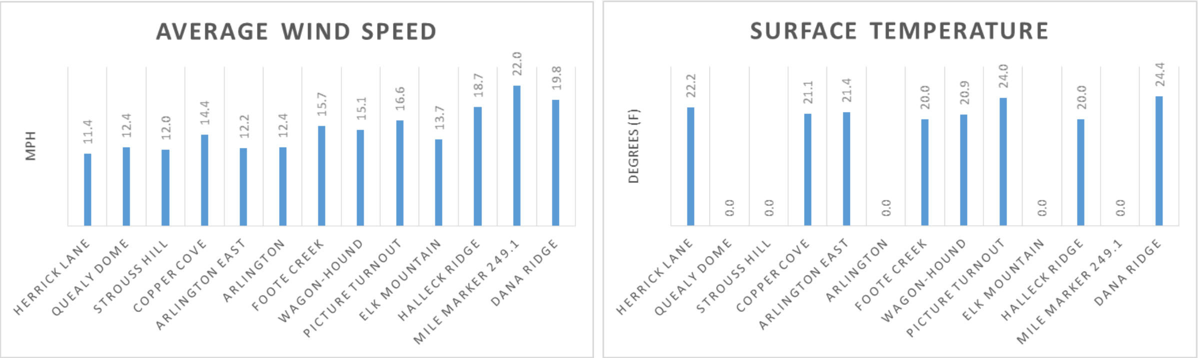


Figure C.22 Trip CC9, 10 Average Wind Speed and Surface Temperature RWIS Data

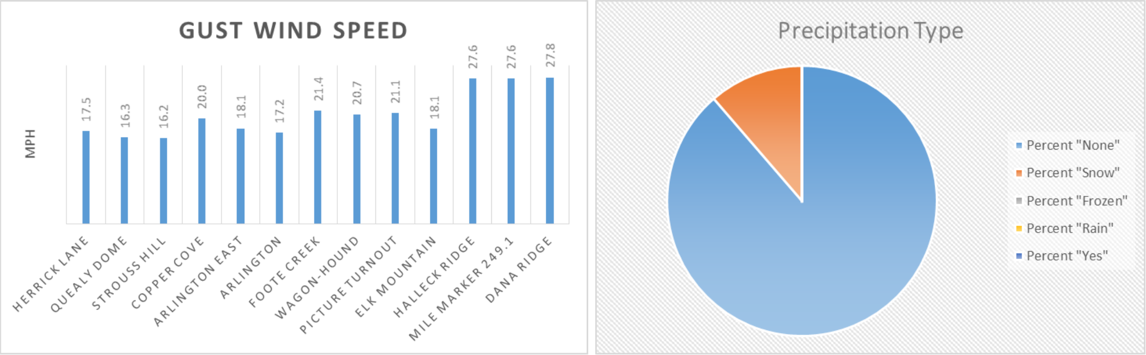


Figure C.23 Trip CC9, 10 Gust Wind Speed and Precipitation Type RWIS Data

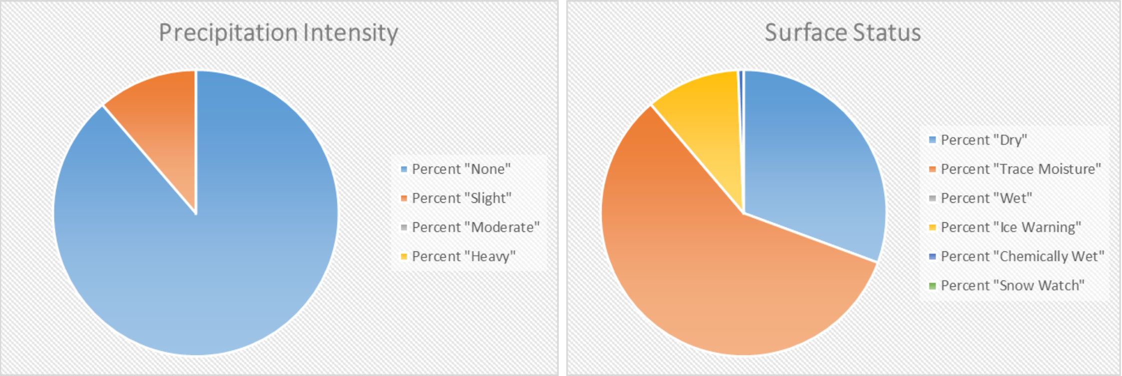


Figure C.24 Trip CC9, 10 Precipitation Intensity and Surface Status RWIS Data

Trips CC11, 12

Trip CC11 originated in Laramie, Wyoming, and ended at Herrick Lane, while Trip CC12 originated at Herrick Lane and ended in Laramie. For this reason, the data collected only represents the weather conditions between Laramie and Herrick Lane.

Table C.5 Trip CC11, 12 RWIS Data

TRIP CC11,12		
RWIS Weather Data	**Statistical Calculations**	**Herrick Lane**
Air Temp (F)	**Average**	2.8
	Standard Deviation	0.9
	Variance	0.8
	Range	2.0
	Median	2.5
Relative Humidity (%)	**Average**	90.3
	Standard Deviation	0.5
	Variance	0.2
	Range	1.0
	Median	90.0
Dew Point (F)	**Average**	0.6
	Standard Deviation	0.8
	Variance	0.6
	Range	2.0
	Median	0.0
Average Wind Speed (mph)	**Average**	8.9
	Standard Deviation	1.3
	Variance	1.7
	Range	4.0
	Median	9.0
Gust Wind Speed (mph)	**Average**	12.0
	Standard Deviation	1.7
	Variance	2.9
	Range	6.0
	Median	12.0
Precipitation Accumulation (in)	**Average**	0.07
	Standard Deviation	0.00
	Variance	0.00
	Range	0.01
	Median	0.07
Precipitation Rate (in/hr)	**Average**	0.00
	Standard Deviation	0.00
	Variance	0.00
	Range	0.00
	Median	0.00
Visibility (ft)	**Average**	6560.0
	Standard Deviation	0.0
	Variance	0.0
	Range	0.0
	Median	6560.0
Surface Temperature (F)	**Average**	18.1
	Standard Deviation	1.0
	Variance	1.0
	Range	2.7
	Median	18.2
Precipitation Type	**Percent "None"**	100.0
	Percent "Snow"	0.0
	Percent "Frozen"	0.0
	Percent "Rain"	0.0
	Percent "Yes"	0.0
Precipitation Intensity	**Percent "None"**	100.0
	Percent "Slight"	0.0
	Percent "Moderate"	0.0
	Percent "Heavy"	0.0
Surface Status	**Percent "Dry"**	0.0
	Percent "Trace Moisture"	66.7
	Percent "Wet"	0.0
	Percent "Ice Warning"	33.3
	Percent "Chemically Wet"	0.0
	Percent "Snow Watch"	0.0

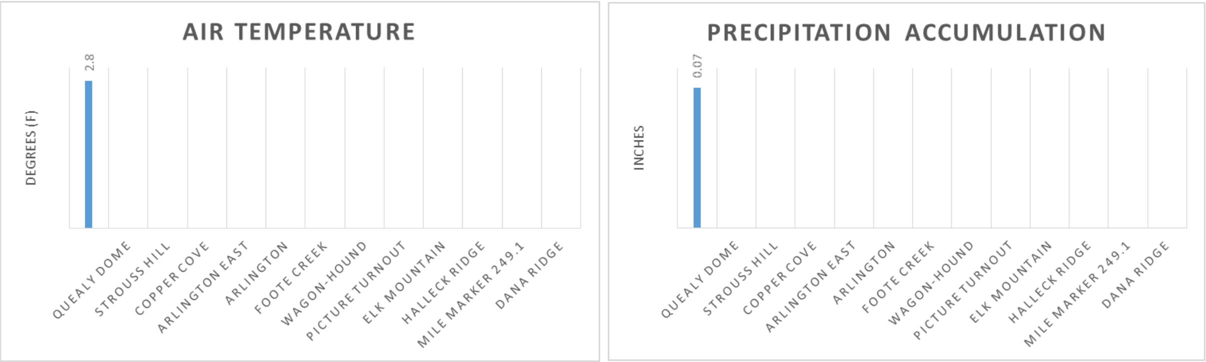


Figure C.25 Trip CC11, 12 Air Temperature and Precipitation Accumulation RWIS Data

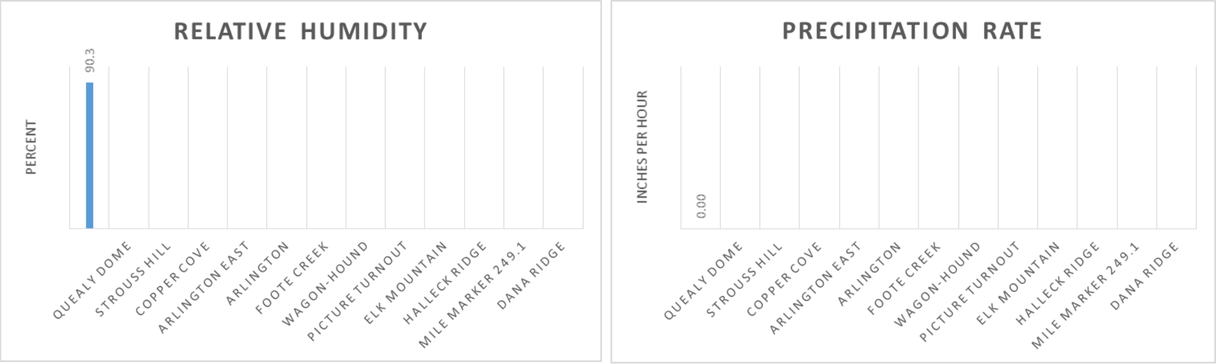


Figure C.26 Trip CC11, 12 Relative Humidity and Precipitation Rate RWIS Data

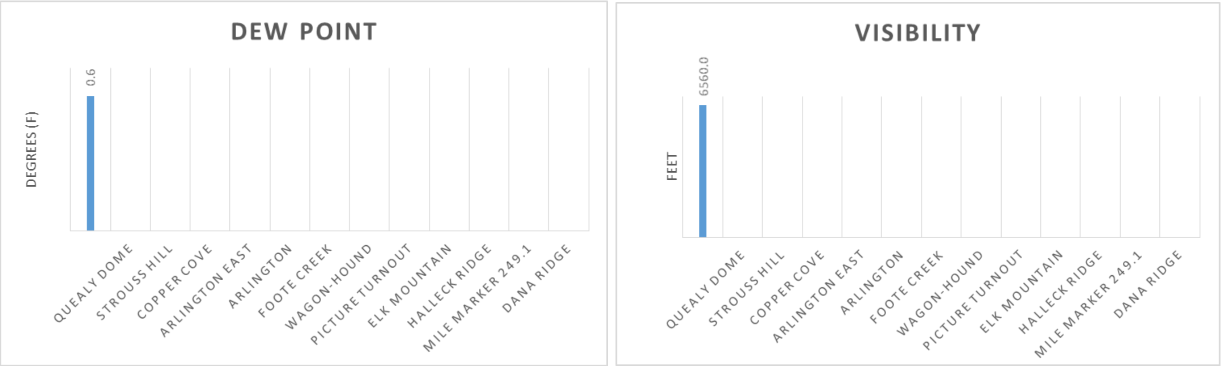


Figure C.27 Trip CC11, 12 Dew Point and Visibility RWIS Data

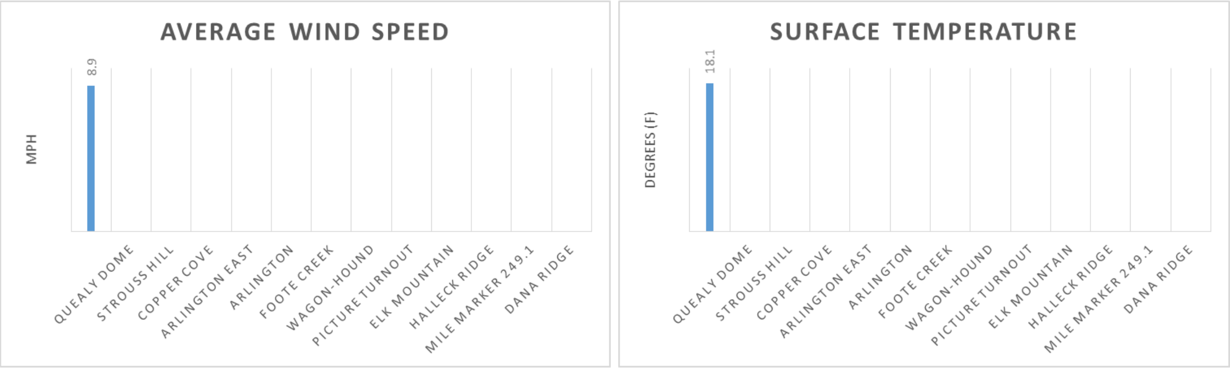


Figure C.28 Trip CC11, 12 Average Wind Speed and Surface Temperature RWIS Data

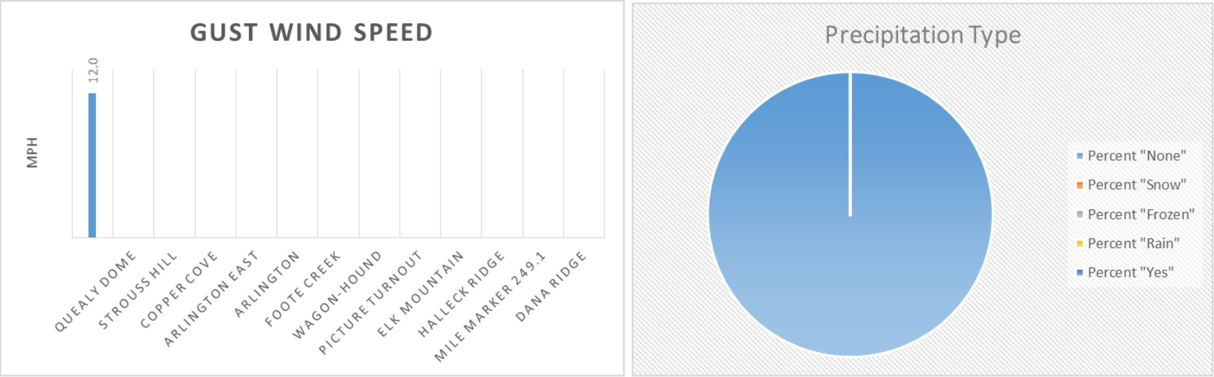


Figure C.29 Trip CC11, 12 Gust Wind Speed and Precipitation Type RWIS Data

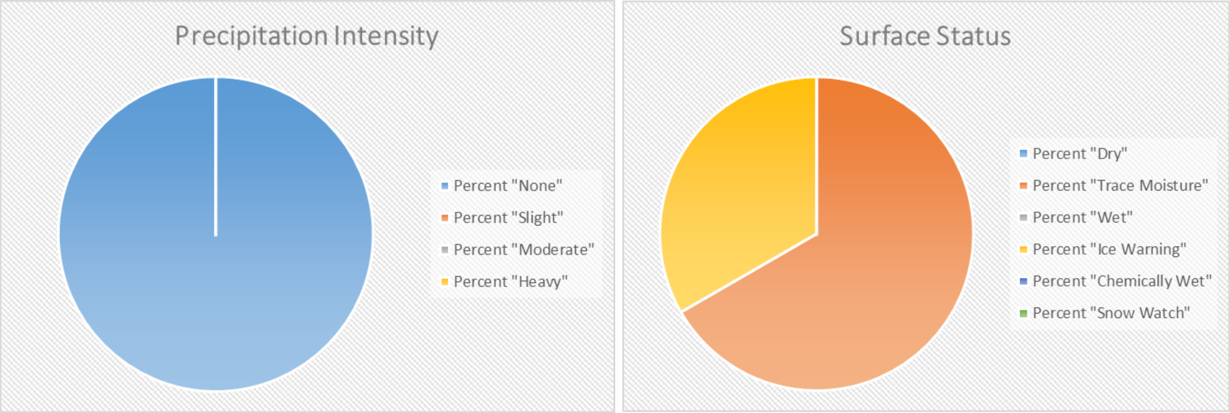


Figure C.30 Trip CC11, 12 Precipitation Intensity and Surface Status RWIS Data

Trips CC13, 14

Table C.6 Trip CC13, 14 RWIS Data

TRIP CC13,14														
RWIS Weather Data	Statistical Calculations	Herrick Lane	RWIS Stations from Laramie to Walcott											
			Quealy Dome	Strouss Hill	Copper Cove	Arlington East	Arlington	Foote Creek	Wagon-hound	Picture Turnout	Elk Mountain	Halleck Ridge	Mile Marker 249.1	Dana Ridge
Air Temp (F)	Average	8.0	7.5	6.4	5.2	5.5	12.9	4.0	7.7	7.0	8.2	3.7	4.4	5.4
	Standard Deviation	3.0	1.5	2.1	1.3	0.6	2.1	0.7	1.0	2.4	2.0	1.3	1.7	1.2
	Variance	9.2	2.2	4.2	1.6	0.3	4.5	0.5	1.1	5.5	3.9	1.7	2.9	1.5
	Range	10.0	7.0	10.0	5.0	2.0	7.0	2.0	5.0	9.0	8.0	5.0	5.0	4.0
	Median	9.0	7.0	6.0	5.5	5.0	13.0	4.0	8.0	6.0	8.0	4.0	4.0	6.0
Relative Humidity (%)	Average	78.9	51.9	65.7	73.9	66.5	54.9	78.9	91.5	91.4	88.1	90.2	91.4	91.6
	Standard Deviation	6.4	6.5	7.3	9.6	8.9	10.2	7.9	1.9	1.8	4.2	0.6	0.7	0.6
	Variance	40.8	41.6	53.5	91.2	78.6	104.2	61.9	3.4	3.1	17.8	0.4	0.5	0.4
	Range	22.0	23.0	26.0	29.0	30.0	30.0	26.0	6.0	12.0	16.0	2.0	3.0	3.0
	Median	78.0	51.5	64.5	69.5	64.0	50.0	82.0	92.0	91.0	88.5	90.0	91.0	92.0
Dew Point (F)	Average	2.7	-6.7	-2.9	-1.5	-3.4	-0.6	-1.1	5.7	5.0	5.4	1.4	2.4	3.4
	Standard Deviation	2.2	2.8	3.5	2.0	2.9	2.4	1.7	1.1	2.3	2.5	1.4	1.7	1.3
	Variance	5.0	7.6	11.9	4.0	8.1	5.8	3.0	1.1	5.2	6.0	1.9	2.8	1.6
	Range	9.0	9.0	13.0	7.0	10.0	9.0	6.0	4.0	9.0	10.0	5.0	6.0	4.0
	Median	2.0	-6.0	-3.5	-2.0	-4.0	-1.0	0.0	5.5	4.0	6.0	1.0	2.0	4.0
Average Wind Speed (mph)	Average	3.2	3.3	4.5	8.8	8.7	8.0	7.5	3.9	3.2	2.0	8.7	6.2	4.5
	Standard Deviation	1.5	2.2	2.8	4.3	3.6	2.0	1.8	3.0	1.6	1.8	2.3	1.7	0.8
	Variance	2.2	4.8	7.8	18.5	12.9	4.0	3.4	8.8	2.6	3.4	5.4	2.8	0.6
	Range	5.0	6.0	7.0	12.0	11.0	5.0	6.0	9.0	4.0	8.0	9.0	8.0	2.0
	Median	3.0	2.0	6.0	10.0	9.5	7.0	8.0	2.5	2.0	1.0	9.0	6.0	4.0
Gust Wind Speed (mph)	Average	5.9	5.6	7.3	11.4	11.0	10.1	9.2	6.0	4.4	3.4	10.4	7.7	6.4
	Standard Deviation	1.7	2.6	3.6	4.4	3.8	2.4	2.0	3.1	1.7	2.7	2.2	1.7	1.0
	Variance	2.9	6.8	12.9	19.5	14.2	5.6	4.2	9.3	2.8	7.1	4.8	2.8	1.0
	Range	7.0	10.0	9.0	13.0	13.0	7.0	7.0	9.0	5.0	10.0	10.0	7.0	4.0
	Median	6.0	4.0	9.0	11.5	11.5	10.0	9.5	5.0	4.0	2.0	11.0	7.0	6.0
Precipitation Accumulation (in)	Average	0.03	0.11	0.15	0.08	0.23	0.13	0.14	0.13	0.11	0.09	0.09	0.05	0.10
	Standard Deviation	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.03	0.02	0.02	0.00	0.01	0.01
	Median	0.03	0.11	0.15	0.08	0.23	0.13	0.14	0.13	0.11	0.09	0.09	0.05	0.10
Precipitation Rate (in/hr)	Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Standard Deviation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Visibility (ft)	Average	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0
	Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Variance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Range	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0
Surface Temperature (F)	Average	35.9	N/A	N/A	31.1	32.3	N/A	35.8	31.9	32.6	N/A	32.9	N/A	34.7
	Standard Deviation	5.5	N/A	N/A	6.4	6.0	N/A	6.7	7.6	5.8	N/A	5.7	N/A	6.3
	Variance	30.4	N/A	N/A	41.2	35.7	N/A	44.6	58.1	33.4	N/A	32.0	N/A	39.1
	Range	18.9	N/A	N/A	20.3	19.4	N/A	21.4	23.9	19.1	N/A	18.9	N/A	19.7
	Median	35.5	N/A	N/A	31.6	33.0	N/A	36.7	33.4	33.1	N/A	33.6	N/A	35.6
Precipitation Type	Percent "None"	100.0	100.0	100.0	97.1	100.0	76.5	100.0	100.0	100.0	100.0	97.1	88.2	94.1
	Percent "Snow"	0.0	0.0	0.0	2.9	0.0	23.5	0.0	0.0	0.0	0.0	2.9	11.8	5.9
	Percent "Frozen"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Rain"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Yes"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Precipitation Intensity	Percent "None"	100.0	100.0	100.0	97.1	100.0	76.5	100.0	100.0	100.0	100.0	97.1	88.2	94.1
	Percent "Slight"	0.0	0.0	0.0	2.9	0.0	23.5	0.0	0.0	0.0	0.0	2.9	11.8	5.9
	Percent "Moderate"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Heavy"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Status	Percent "Dry"	0.0	N/A	N/A	2.9	38.2	N/A	52.9	0.0	82.4	N/A	0.0	N/A	23.5
	Percent "Trace Moisture"	100.0	N/A	N/A	91.2	52.9	N/A	32.4	50.0	17.7	N/A	2.9	N/A	76.5
	Percent "Wet"	0.0	N/A	N/A	0.0	8.8	N/A	11.8	50.0	0.0	N/A	0.0	N/A	0.0
	Percent "Ice Warning"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	38.2	N/A	0.0
	Percent "Chemically Wet"	0.0	N/A	N/A	5.9	0.0	N/A	2.9	0.0	0.0	N/A	58.8	N/A	0.0
	Percent "Snow Watch"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0

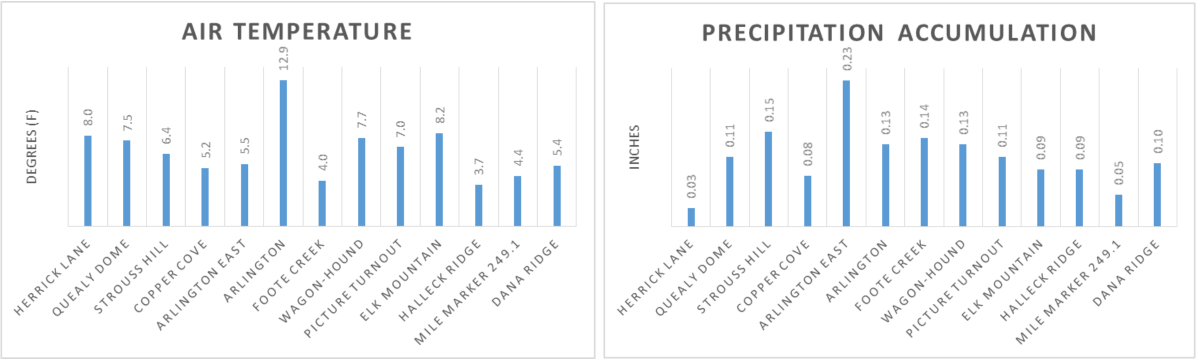


Figure C.31 Trip CC13, 14 Air Temperature and Precipitation Accumulation RWIS Data

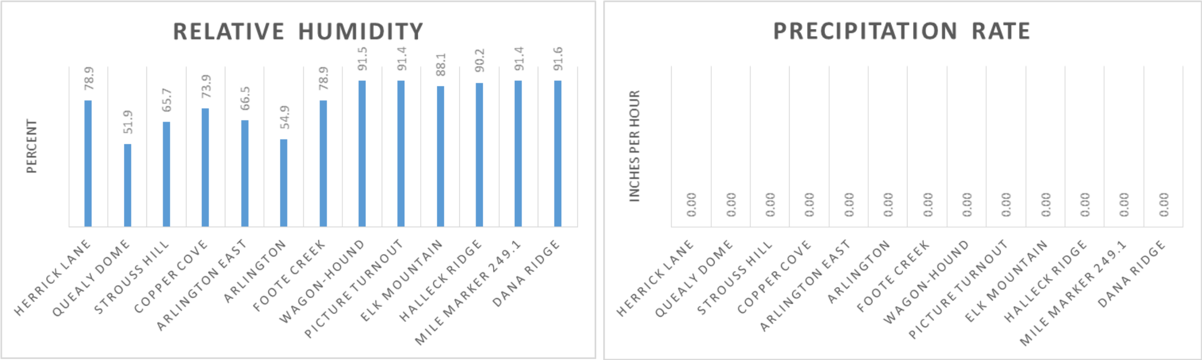


Figure C.32 Trip CC13, 14 Relative Humidity and Precipitation Rate RWIS Data

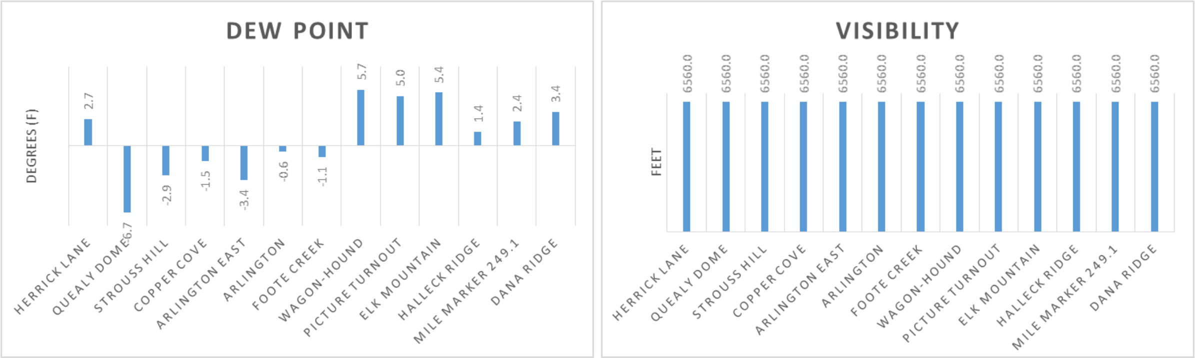


Figure C.33 Trip CC13, 14 Dew Point and Visibility RWIS Data

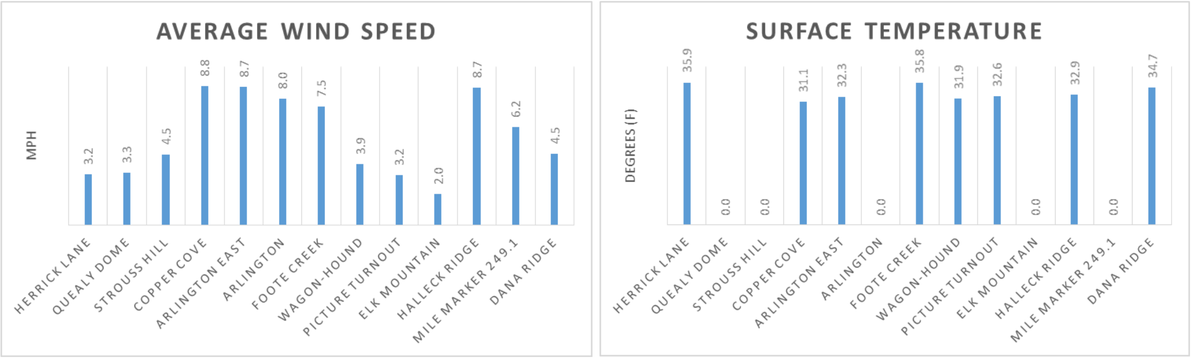


Figure C.34 Trip CC13, 14 Average Wind Speed and Surface Temperature RWIS Data

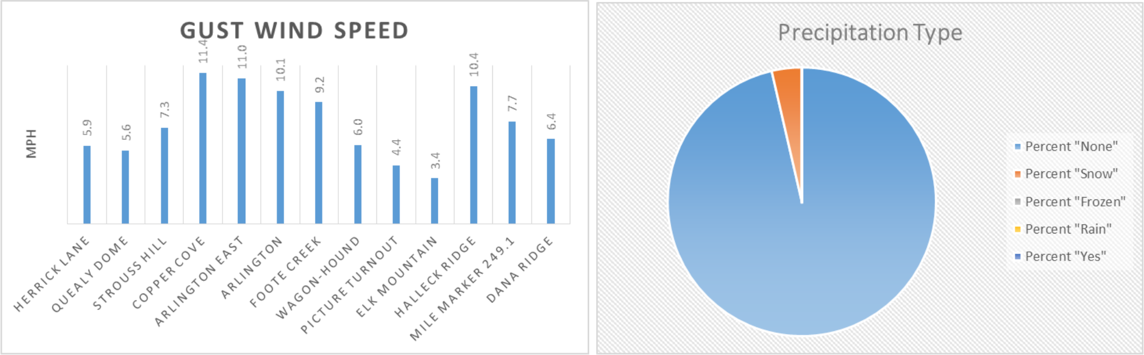


Figure C.35 Trip CC13, 14 Gust Wind Speed and Precipitation Type RWIS Data

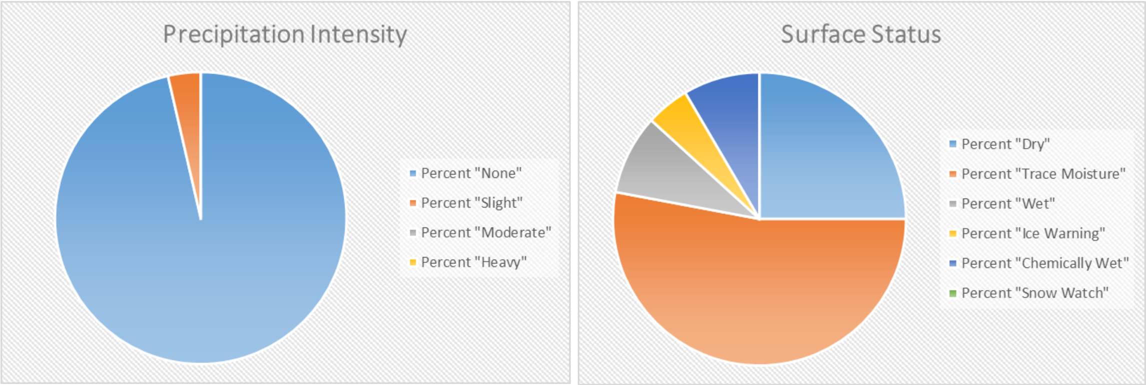


Figure C.36 Trip CC13, 14 Precipitation Intensity and Surface Status RWIS Data

Trips CC 15, 16

Table C.7 Trip CC15, 16 RWIS Data

TRIP CC15,16													
RWIS Weather Data	Statistical Calculations	Herrick Lane	RWIS Stations from Laramie to Walcott										
			Quealy Dome	Strouss Hill	Copper Cove	Arlington East	Arlington	Foote Creek	Wagon-hound	Picture Turnout	Elk Mountain	Halleck Ridge	Mile Marker 249.1	Dana Ridge
Air Temp (F)	Average	28.7	29.3	27.7	27.5	26.7	29.4	25.0	26.4	26.7	27.7	25.0	25.9	25.6
	Standard Deviation	1.8	1.7	1.4	1.2	1.0	1.4	1.1	1.5	2.1	1.7	1.7	2.2	1.8
	Variance	3.4	3.0	1.8	1.5	0.9	2.0	1.3	2.2	4.2	2.8	2.7	4.7	3.4
	Range	6.0	5.0	4.0	4.0	4.0	6.0	5.0	5.0	8.0	6.0	4.0	6.0	6.0
	Median	28.0	29.0	28.0	27.0	27.0	29.0	25.0	26.0	26.0	28.0	25.0	26.0	26.0
Relative Humidity (%)	Average	90.5	75.6	74.7	82.2	80.6	81.7	88.1	89.4	85.0	82.6	90.8	90.3	93.9
	Standard Deviation	7.7	4.2	4.1	4.1	3.1	2.1	3.3	3.5	6.5	4.5	4.8	5.9	2.7
	Variance	59.7	17.5	16.4	16.5	9.3	4.6	10.9	12.3	42.6	20.0	22.9	35.1	7.2
	Range	23.0	20.0	15.0	15.0	14.0	8.0	13.0	13.0	19.0	14.0	14.0	16.0	10.0
	Median	93.0	76.0	74.0	83.0	81.0	82.0	89.0	90.0	87.0	84.0	91.0	92.0	94.0
Dew Point (F)	Average	26.4	22.4	20.8	22.8	21.5	24.8	21.9	23.7	22.6	23.1	22.6	23.2	24.1
	Standard Deviation	1.4	1.3	1.1	0.9	0.7	1.3	0.9	0.8	0.6	0.8	0.6	0.7	1.3
	Variance	1.9	1.7	1.1	0.8	0.5	1.7	0.7	0.6	0.3	0.6	0.4	0.5	1.7
	Range	5.0	5.0	3.0	3.0	2.0	4.0	3.0	3.0	2.0	3.0	3.0	3.0	5.0
	Median	26.0	22.0	21.0	23.0	22.0	25.0	22.0	24.0	23.0	23.0	23.0	23.0	24.0
Average Wind Speed (mph)	Average	13.7	12.7	14.7	13.3	11.3	10.9	12.7	9.8	7.9	10.2	11.4	11.0	7.3
	Standard Deviation	1.0	1.6	2.0	1.7	1.4	2.2	2.2	1.4	2.3	1.0	1.4	1.4	1.1
	Variance	1.0	2.4	3.8	2.9	1.8	4.7	4.8	1.9	5.2	1.0	1.9	1.9	1.3
	Range	4.0	5.0	7.0	7.0	4.0	8.0	7.0	5.0	7.0	3.0	5.0	4.0	3.0
	Median	14.0	13.0	15.0	14.0	12.0	11.0	12.0	10.0	9.0	10.0	12.0	12.0	7.0
Gust Wind Speed (mph)	Average	18.0	17.2	18.3	17.1	16.1	15.0	16.2	13.4	11.7	14.3	15.4	14.6	10.8
	Standard Deviation	1.3	1.7	2.2	2.1	1.5	2.1	2.2	1.5	2.1	1.4	1.8	2.0	1.8
	Variance	1.7	2.8	5.0	4.5	2.3	4.5	4.9	2.2	4.4	1.9	3.1	3.9	3.1
	Range	5.0	7.0	9.0	9.0	5.0	6.0	7.0	4.0	7.0	5.0	6.0	7.0	5.0
	Median	18.0	17.0	19.0	18.0	16.0	16.0	17.0	14.0	12.0	14.0	16.0	15.0	11.0
Precipitation Accumulation (in)	Average	0.02	0.08	0.26	0.28	0.73	1.02	0.46	0.24	0.18	0.19	0.43	0.29	0.16
	Standard Deviation	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.00	0.00	0.01	0.03	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.00
	Median	0.02	0.08	0.26	0.28	0.74	1.02	0.46	0.24	0.18	0.19	0.43	0.29	0.16
Precipitation Rate (in/hr)	Average	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00
	Standard Deviation	0.00	0.00	0.00	0.02	0.03	0.02	0.02	0.00	0.00	0.00	0.00	0.02	0.00
	Variance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Range	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.00
	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Visibility (ft)	Average	6232.7	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6505.4	6560.0
	Standard Deviation	900.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	303.9	0.0
	Variance	810155.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	92350.5	0.0
	Range	3628.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1692.0	0.0
	Median	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0	6560.0
Surface Temperature (F)	Average	42.0	N/A	N/A	42.2	42.0	N/A	41.1	40.9	44.9	N/A	43.5	N/A	45.8
	Standard Deviation	7.6	N/A	N/A	7.2	8.8	N/A	7.2	7.7	8.7	N/A	7.9	N/A	7.0
	Variance	58.4	N/A	N/A	51.7	77.4	N/A	51.3	59.8	75.5	N/A	61.7	N/A	48.6
	Range	21.8	N/A	N/A	25.6	28.3	N/A	25.4	26.1	26.8	N/A	24.1	N/A	23.2
	Median	42.1	N/A	N/A	41.5	41.7	N/A	39.4	38.3	44.6	N/A	43.2	N/A	46.9
Precipitation Type	Percent "None"	87.1	96.8	96.8	80.7	35.5	9.7	48.4	93.6	100.0	96.9	90.3	74.2	96.8
	Percent "Snow"	12.9	3.2	3.2	19.4	64.5	90.3	51.6	6.5	0.0	3.1	9.7	25.8	3.2
	Percent "Frozen"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Rain"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percent "Yes"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Precipitation Intensity	Percent "None"	87.1	96.8	96.8	80.7	35.5	9.7	48.4	93.6	100.0	96.9	90.3	74.2	96.8
	Percent "Slight"	12.9	3.2	3.2	19.4	64.5	90.3	51.6	6.5	0.0	3.1	9.7	22.6	3.2
	Percent "Moderate"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0
	Percent "Heavy"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Surface Status	Percent "Dry"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	25.8	N/A	0.0	N/A	54.8
	Percent "Trace Moisture"	87.1	N/A	N/A	100.0	35.5	N/A	25.8	67.7	74.2	N/A	0.0	N/A	45.2
	Percent "Wet"	9.7	N/A	N/A	0.0	29.0	N/A	71.0	32.3	0.0	N/A	0.0	N/A	0.0
	Percent "Ice Warning"	0.0	N/A	N/A	0.0	0.0	N/A	0.0	0.0	0.0	N/A	0.0	N/A	0.0
	Percent "Chemically Wet"	3.2	N/A	N/A	0.0	29.0	N/A	0.0	0.0	0.0	N/A	100.0	N/A	0.0
	Percent "Snow Watch"	0.0	N/A	N/A	0.0	6.5	0.0	3.2	0.0	0.0	N/A	0.0	N/A	0.0

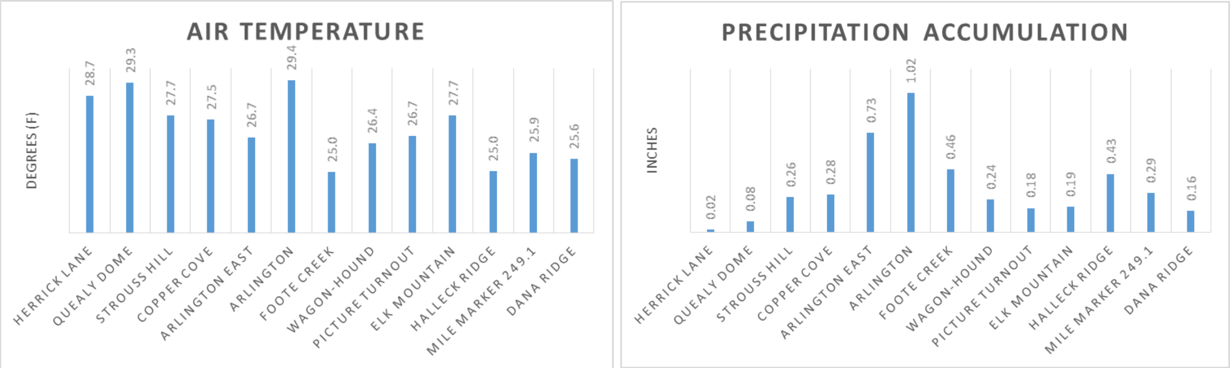


Figure C.37 Trip CC15, 16 Air Temperature and Precipitation Accumulation RWIS Data

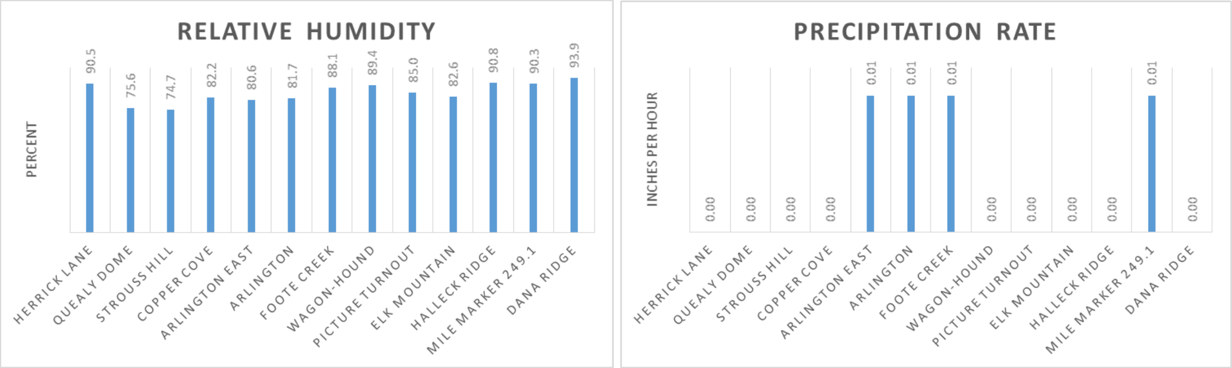


Figure C.38 Trip CC15, 16 Relative Humidity and Precipitation Rate RWIS Data

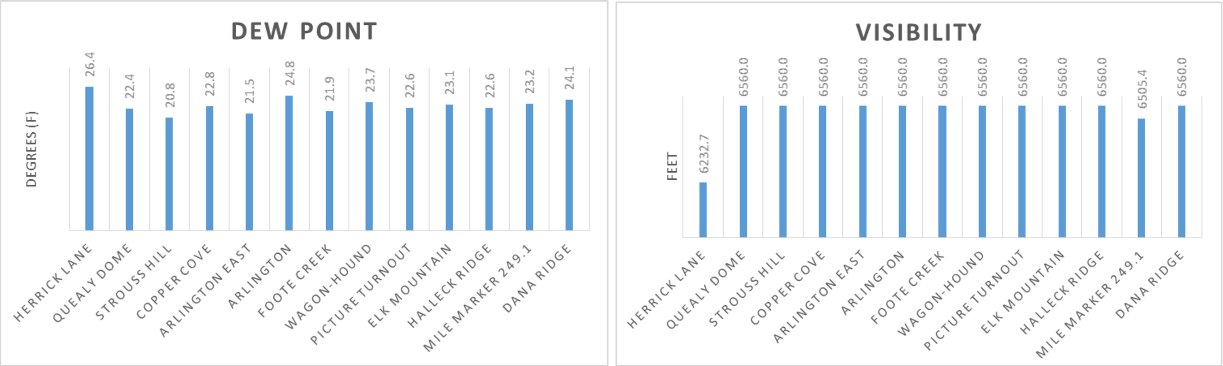


Figure C.39 Trip CC15, 16 Dew Point and Visibility RWIS Data

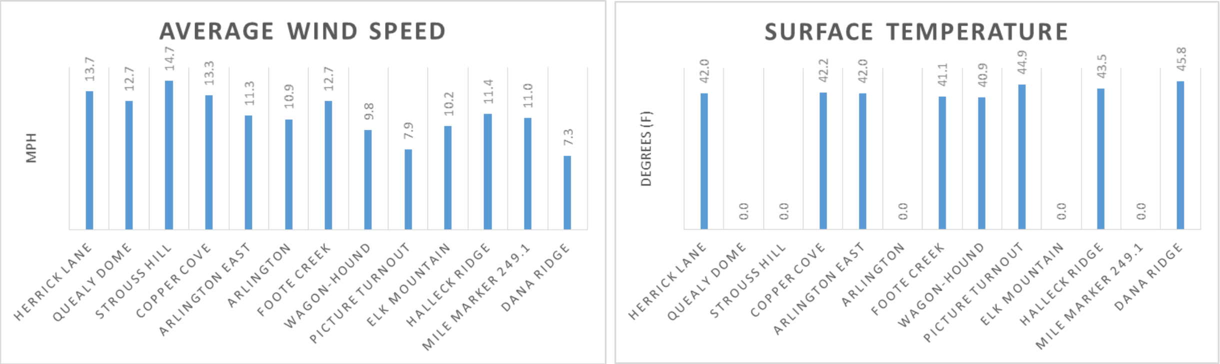


Figure C.40 Trip CC15, 16 Average Wind Speed and Surface Temperature RWIS Data

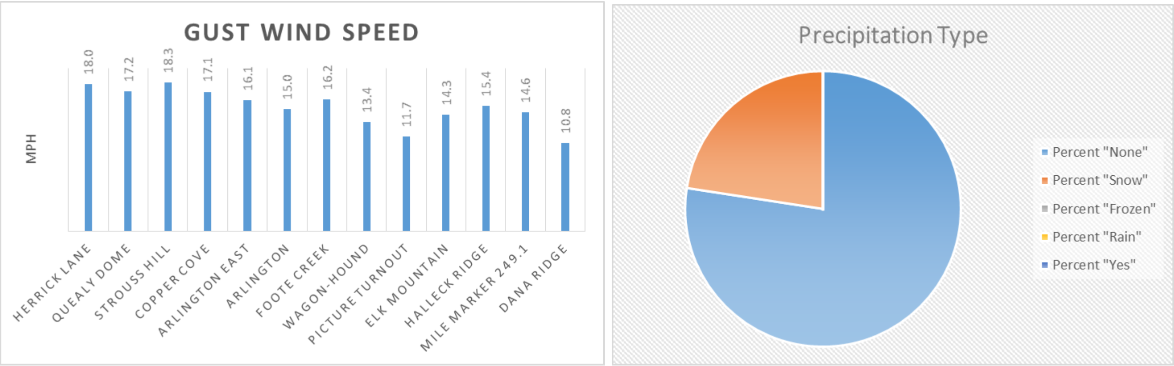


Figure C.41 Trip CC15, 16 Gust Wind Speed and Precipitation Type RWIS Data

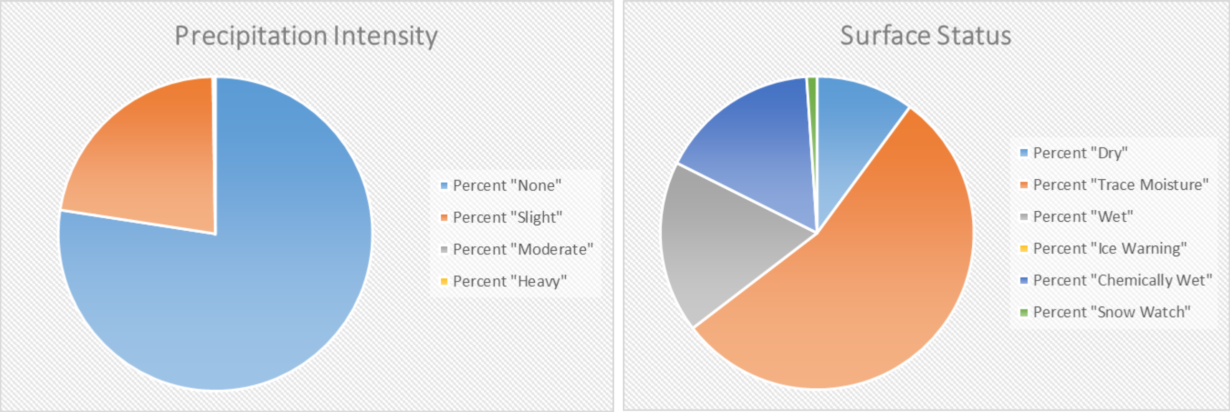


Figure C.42 Trip CC15, 16 Precipitation Intensity and Surface Status RWIS Data

APPENDIX D: VEHICLE DATA REPRESENTATION

Trip CC1

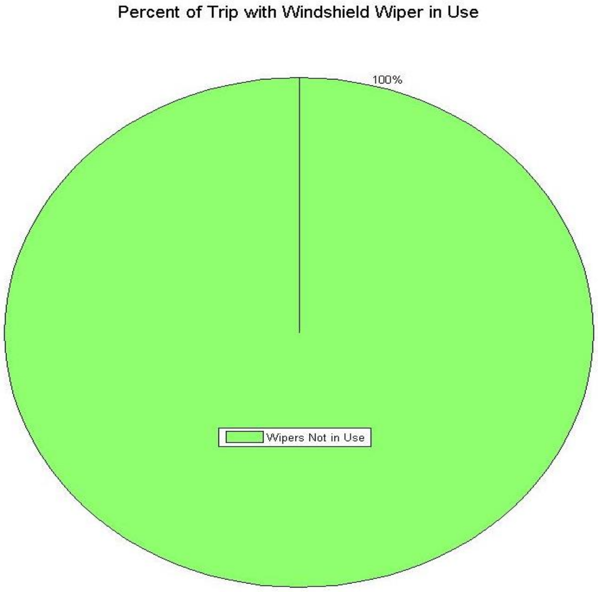


Figure D.1 CC1 Percent Windshield Wiper Use

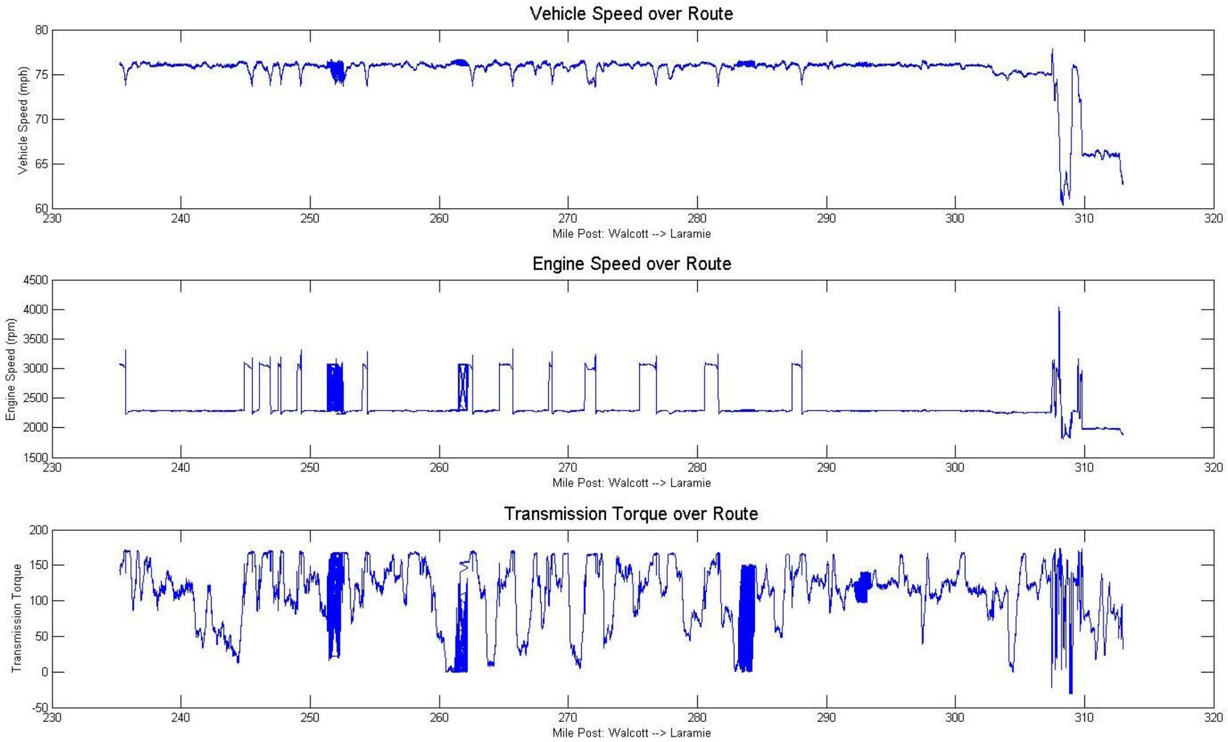
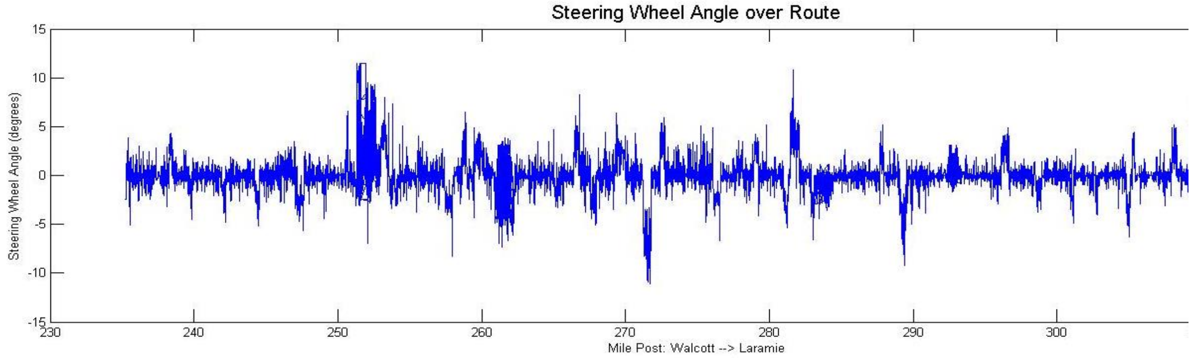


Figure D.2 CC1 Vehicle Speed, Engine Speed, and Transmission Torque



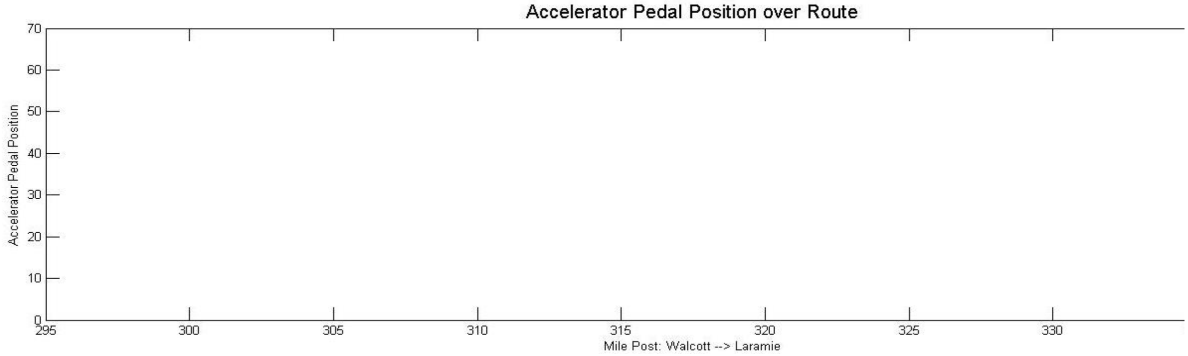


Figure D.3 CC1 Steering Wheel Angle and Accelerator Pedal Position

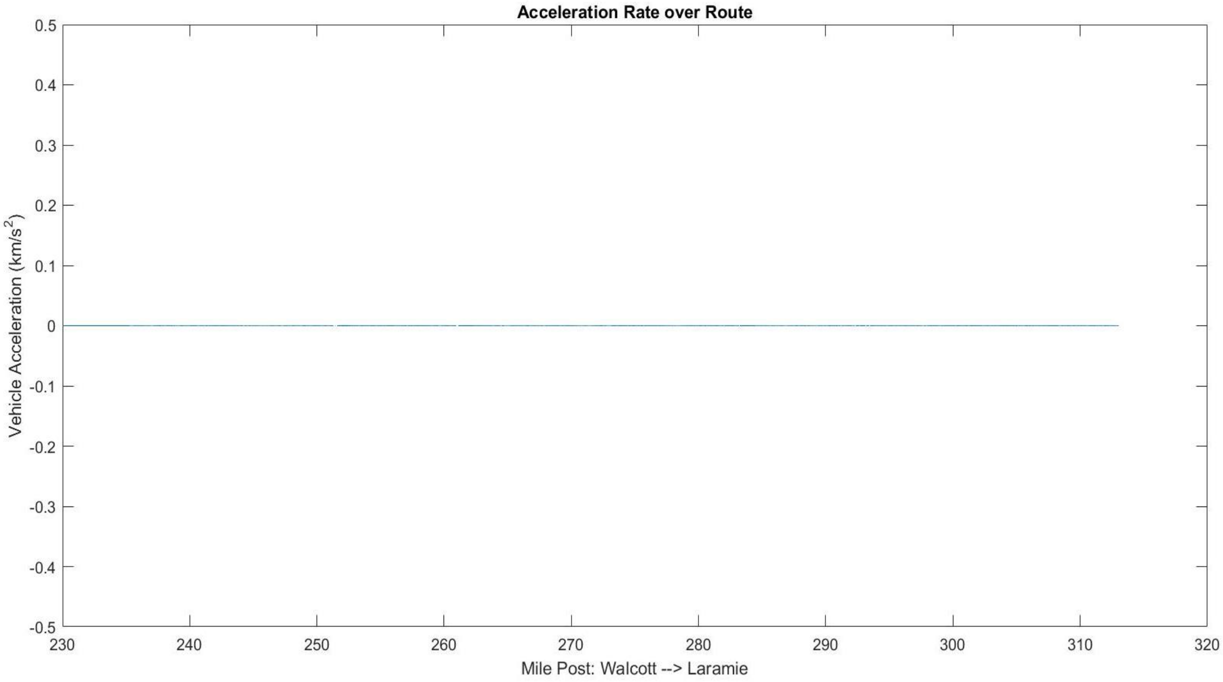


Figure D.4 CC1 Acceleration/Deceleration Rate

Trip CC2

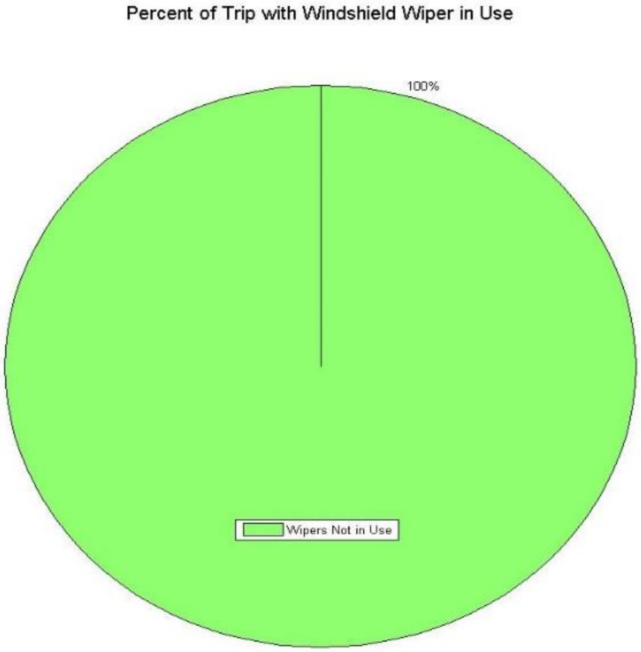


Figure D.5 CC2 Percent Windshield Wiper Use

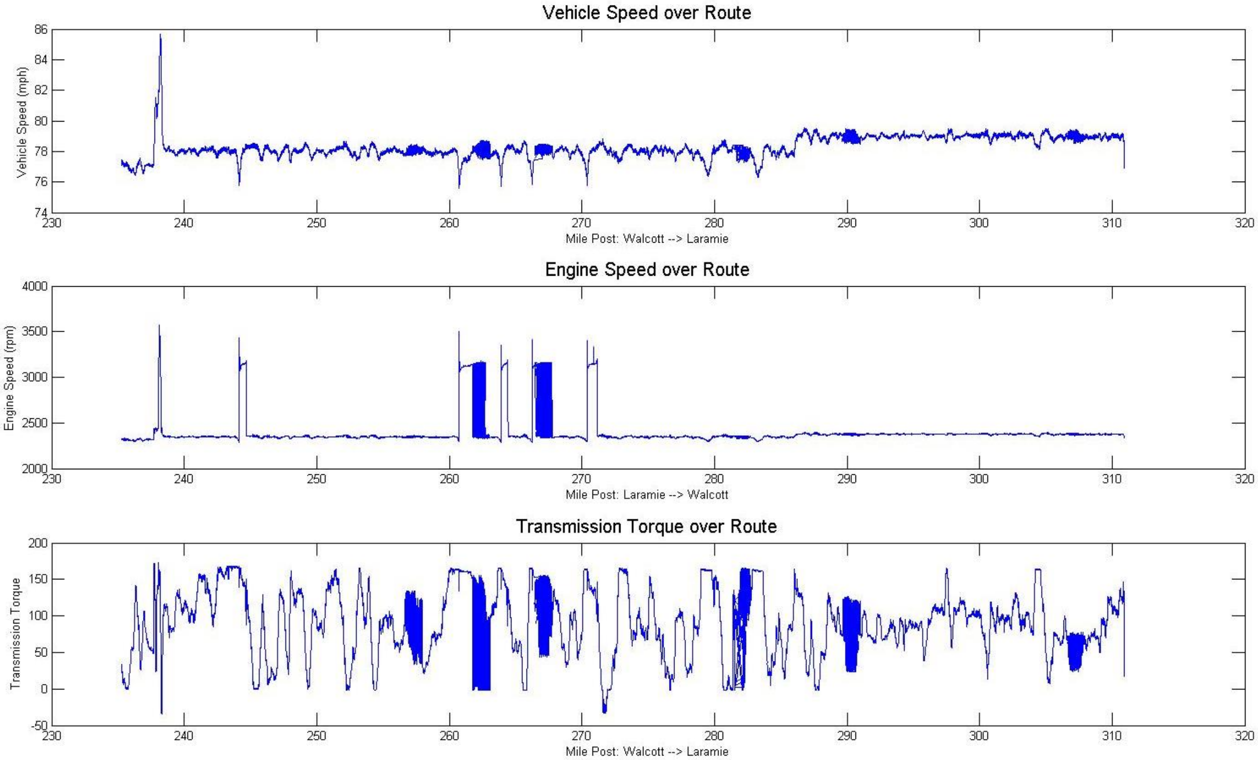
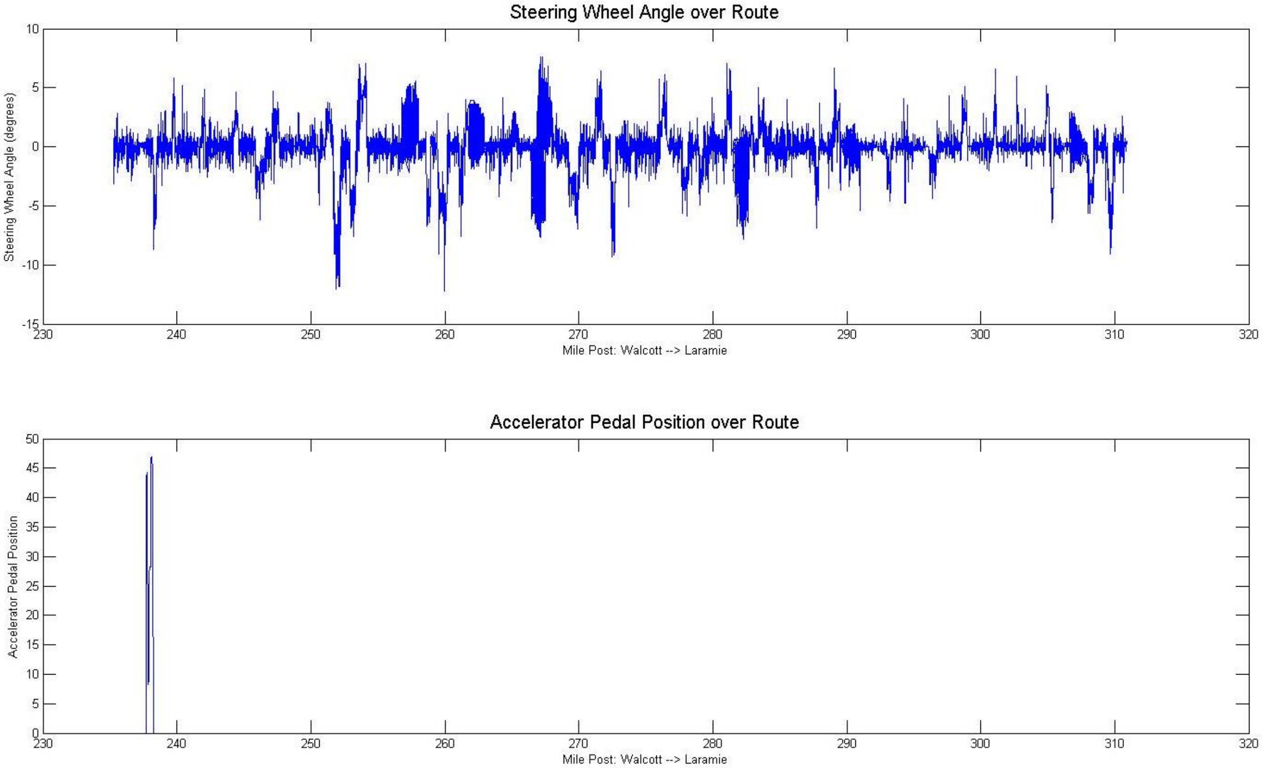


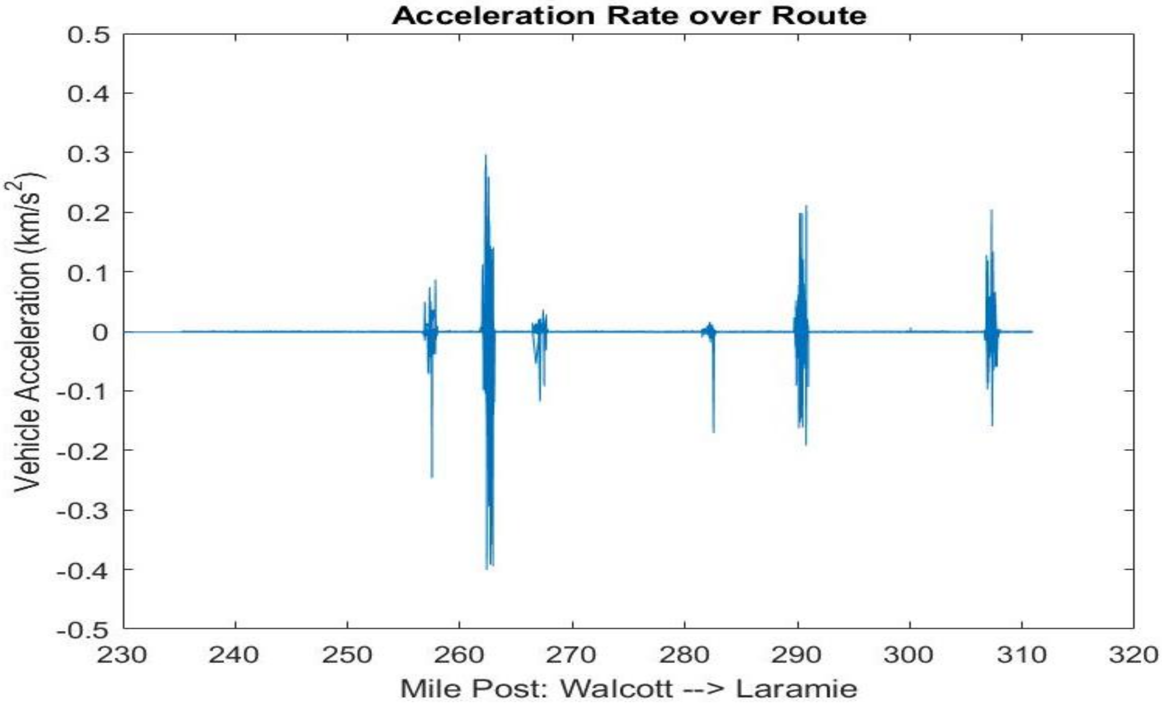
Figure D.6 CC2 Vehicle Speed, Engine Speed, and Transmission Torque



Steering Wheel Angle over Route

Accelerator Pedal Position over Route

Figure D.7 CC2 Steering Wheel Angle and Accelerator Pedal Position



Acceleration Rate over Route

Figure D.8 CC2 Acceleration/Deceleration Rate

Trip CC3

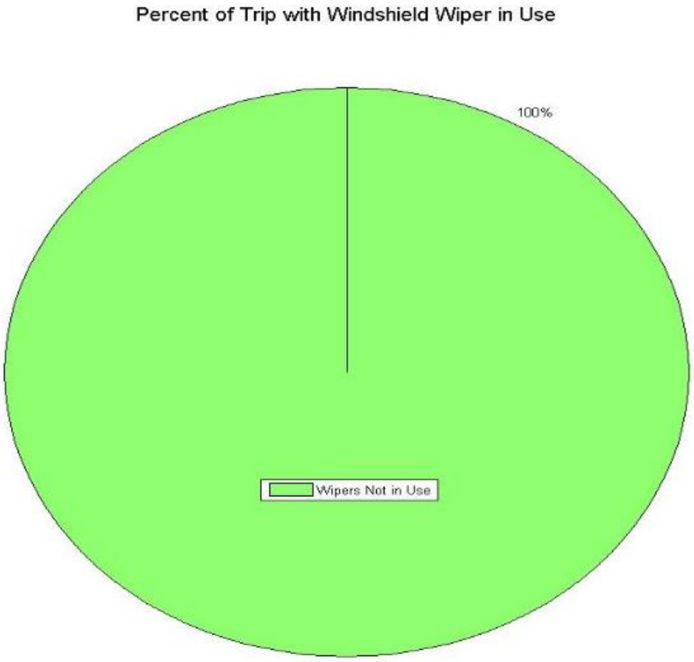


Figure D.9 CC3 Percent Windshield Wiper Use

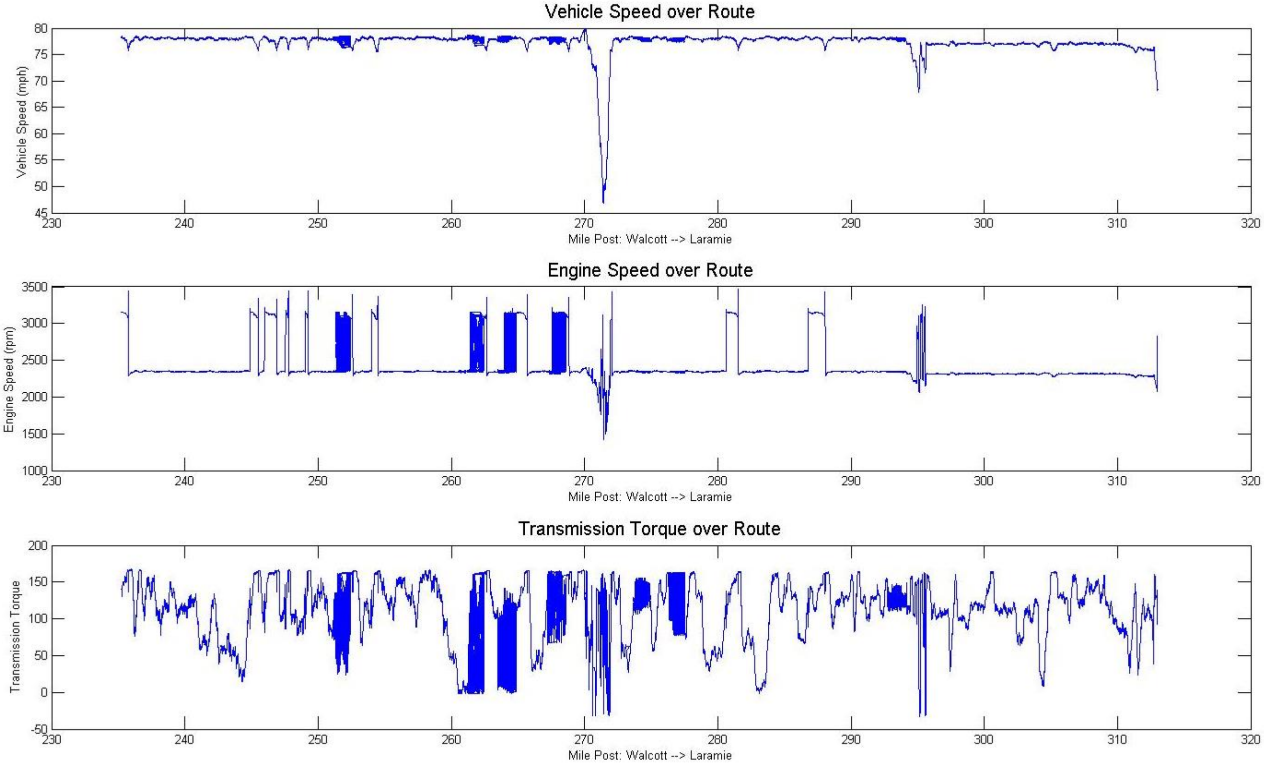


Figure D.10 CC3 Vehicle Speed, Engine Speed, Transmission Torque

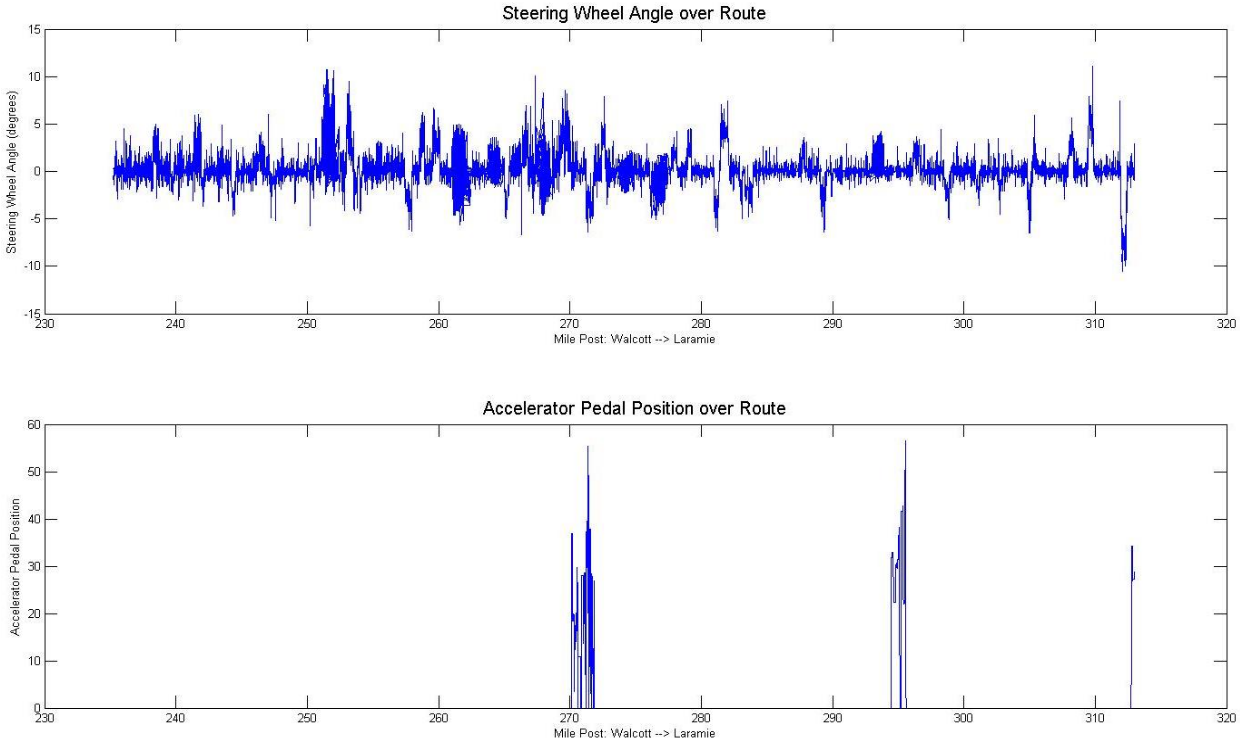


Figure D.11 CC3 Steering Wheel Angle and Accelerator Pedal Position

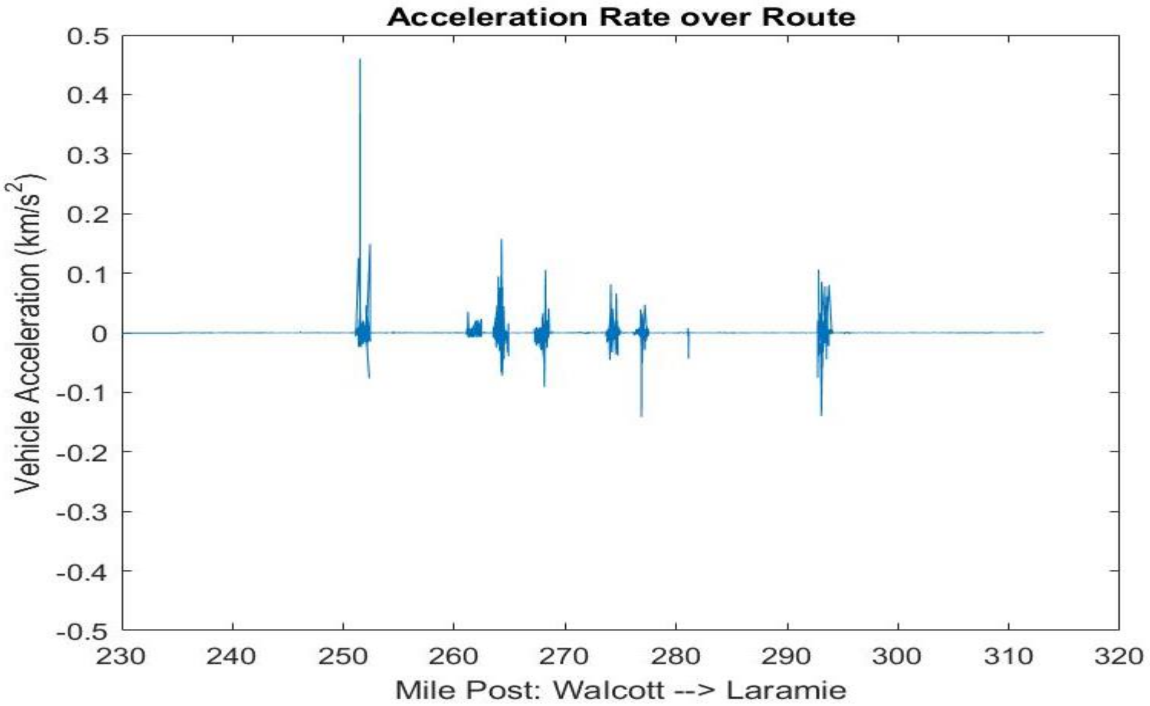


Figure D.12 CC3 Acceleration/Deceleration Rate

Trip CC4

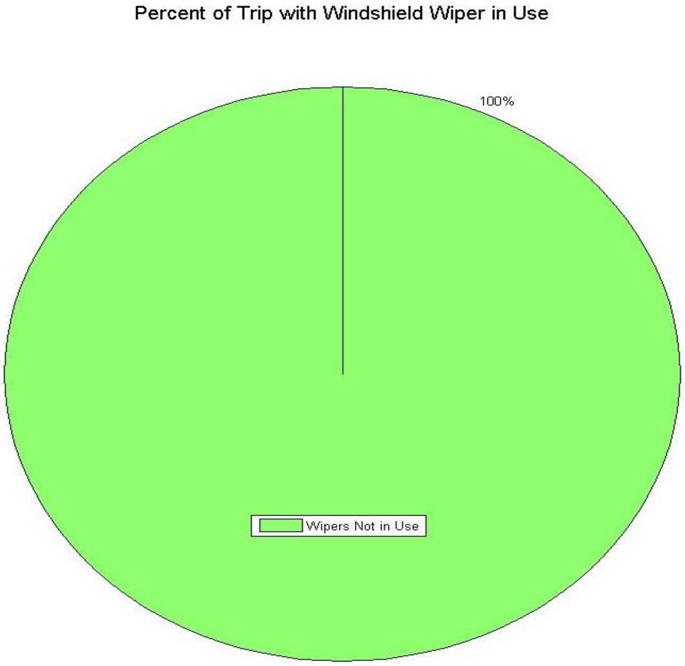


Figure D.13 CC4 Percent Windshield Wiper Use

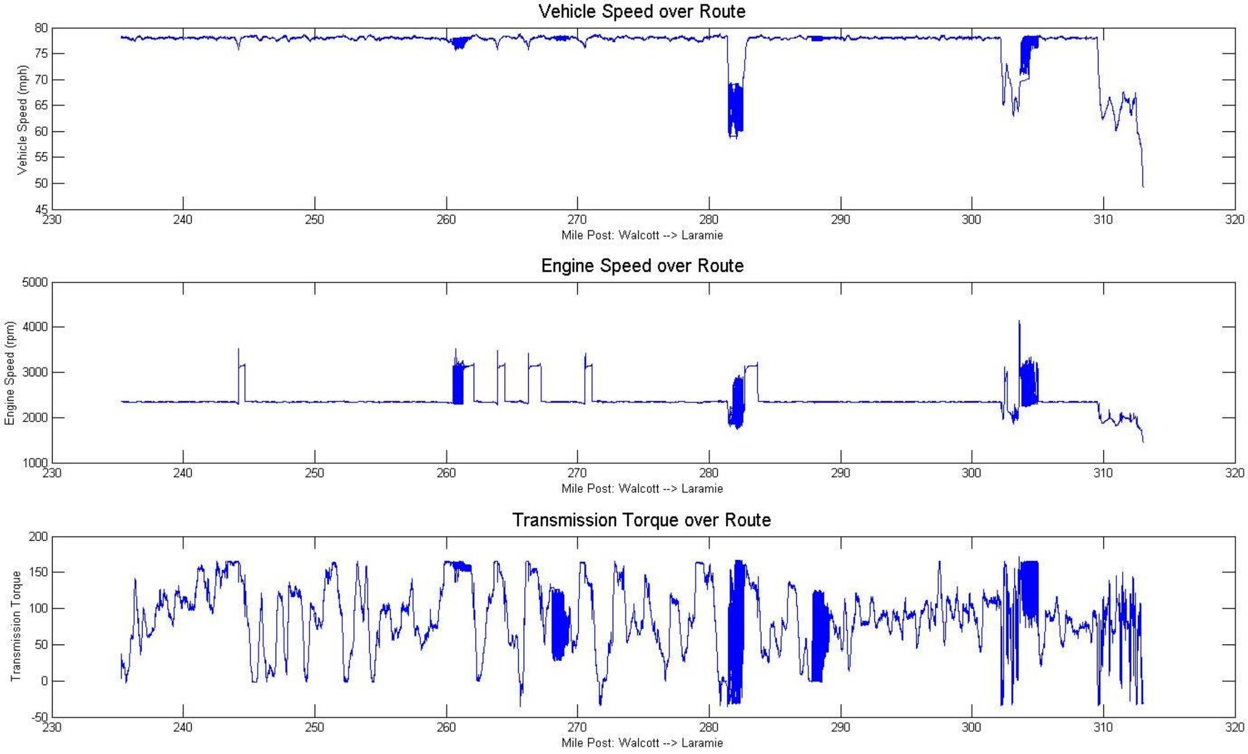


Figure D.14 CC4 Vehicle Speed, Engine Speed, and Transmission Torque

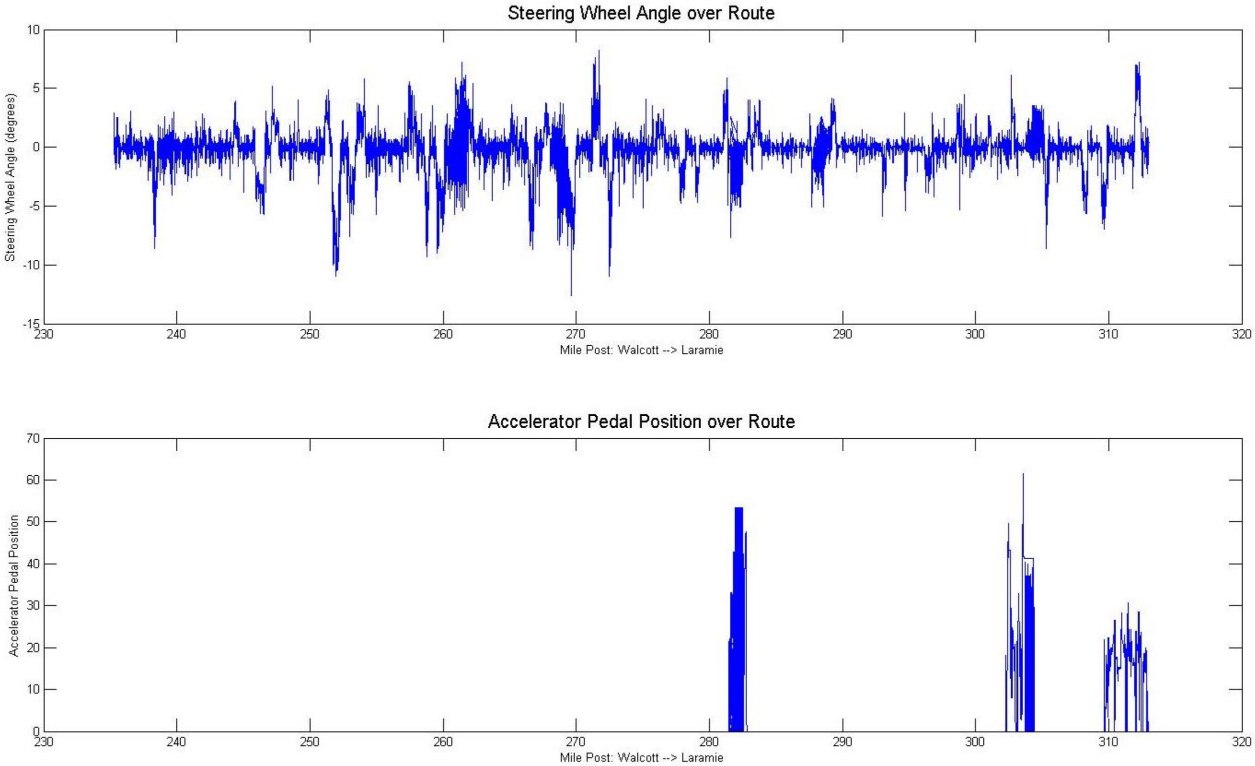


Figure D.15 CC4 Steering Wheel Angle and Accelerator Pedal Position

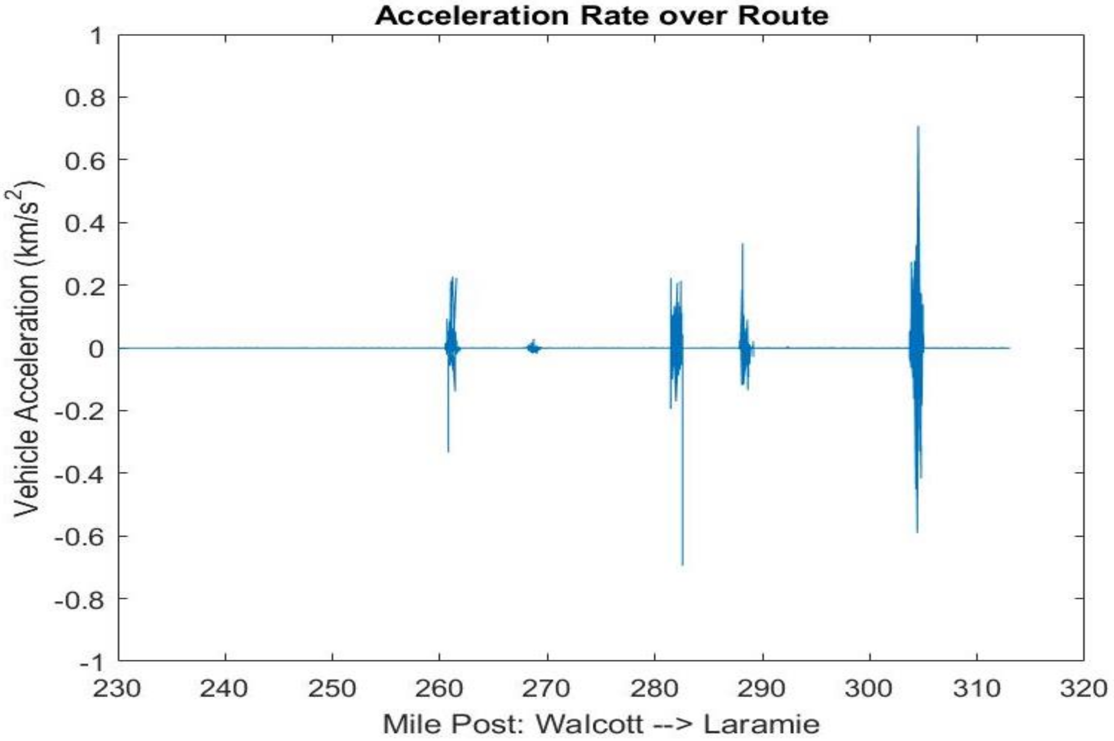


Figure D.16 CC4 Acceleration/Deceleration Rate

Trip CC5

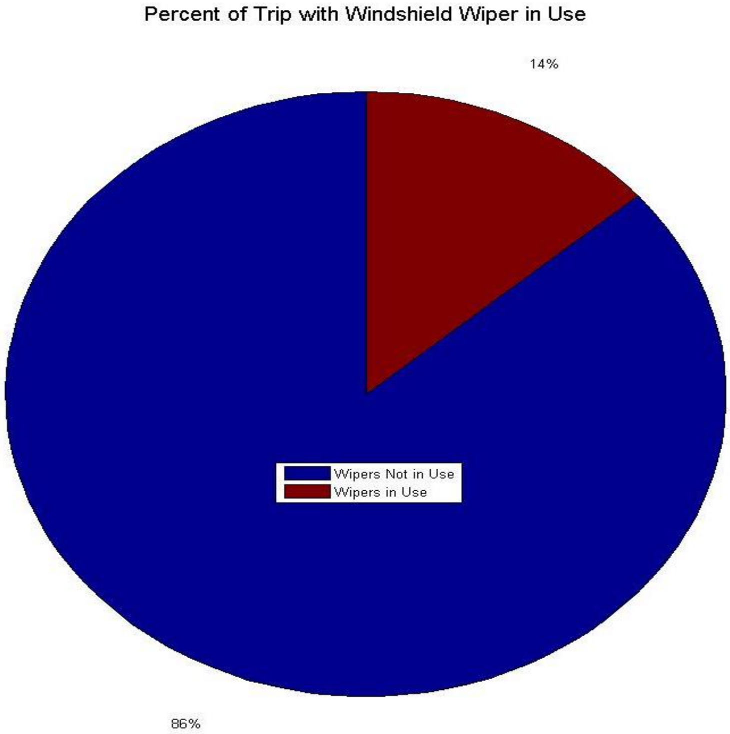


Figure D.17 CC5 Percent Windshield Wiper Use

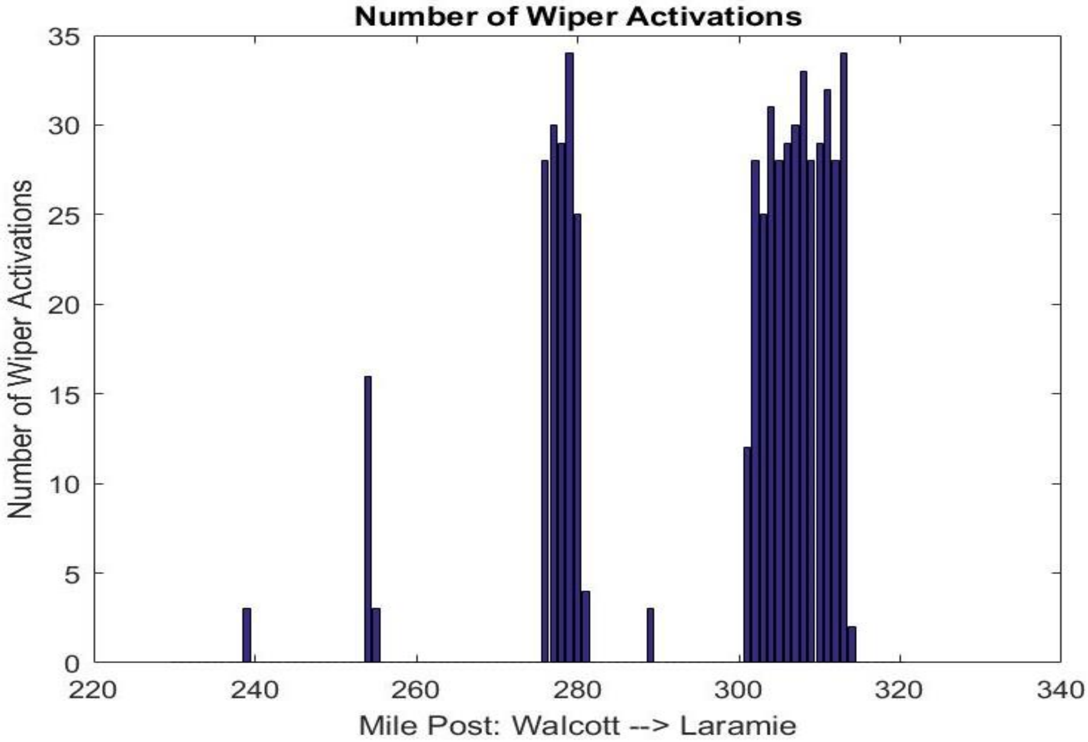


Figure D.18 CC5 Wiper Activation Frequency

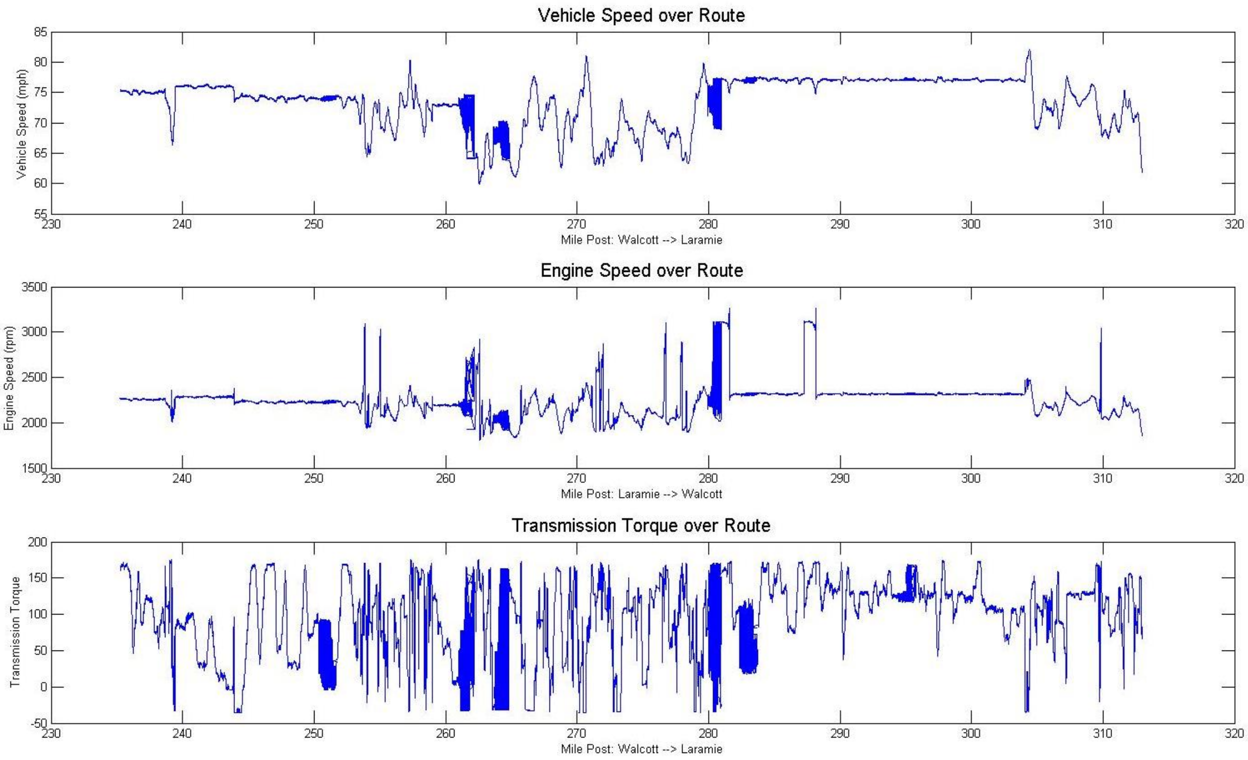


Figure D.19 CC5 Vehicle Speed, Engine Speed, and Transmission Torque

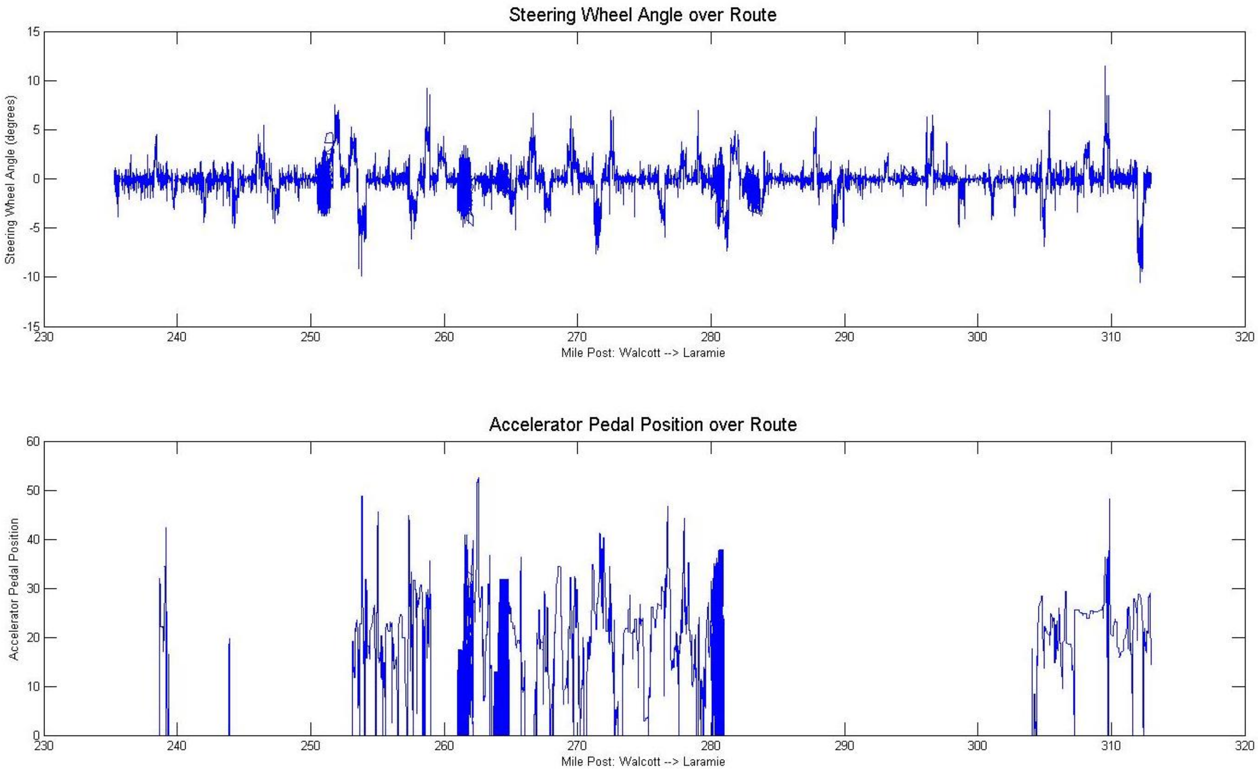


Figure D.20 CC5 Steering Wheel Angle and Accelerator Pedal Position

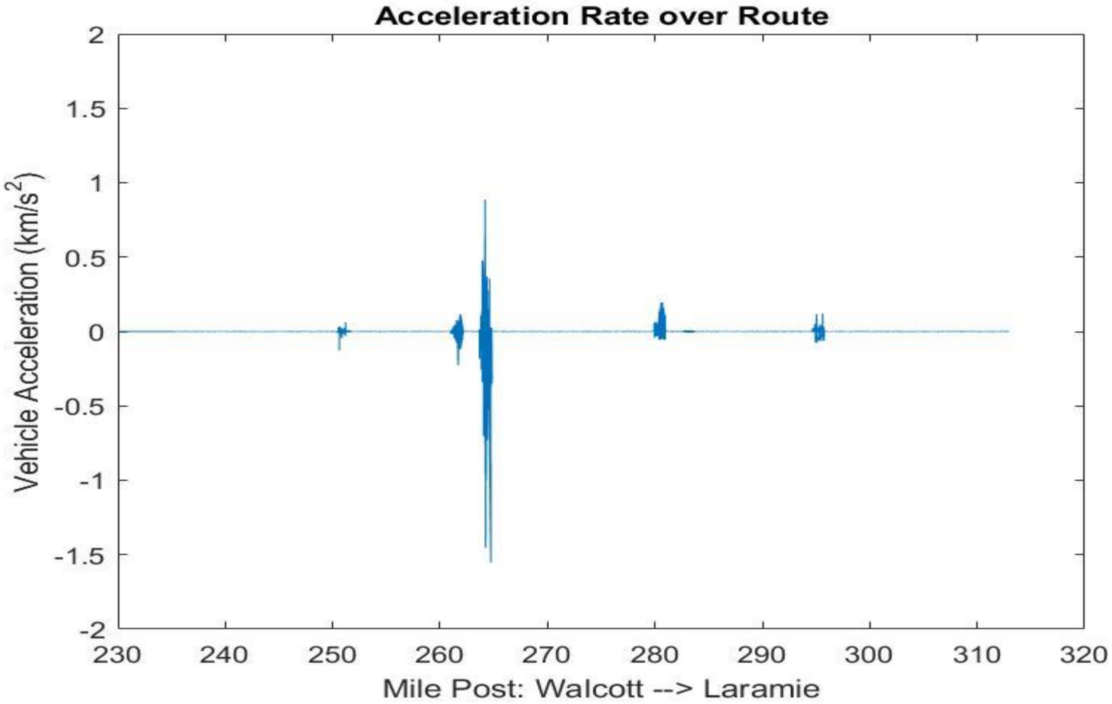


Figure D.21 CC5 Acceleration/Deceleration Rate

Trip CC6

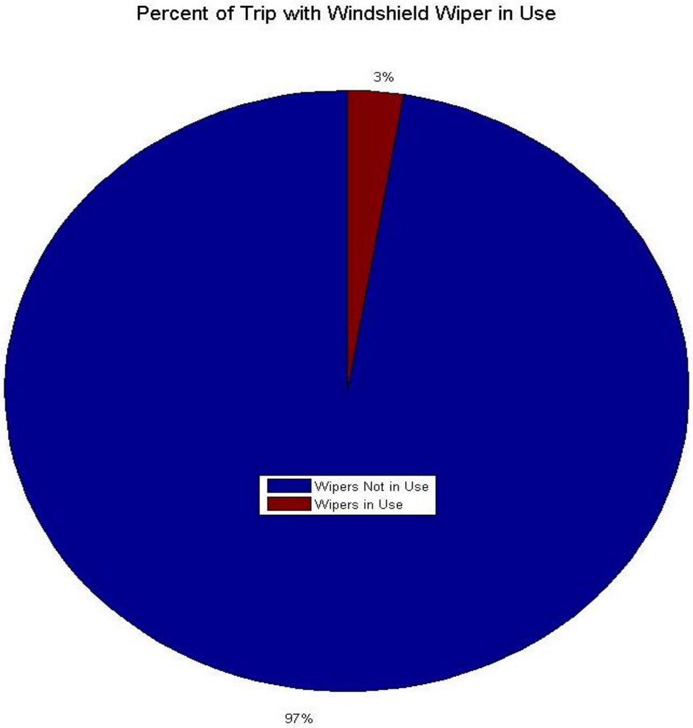


Figure D.22 CC6 Percent Windshield Wiper Use

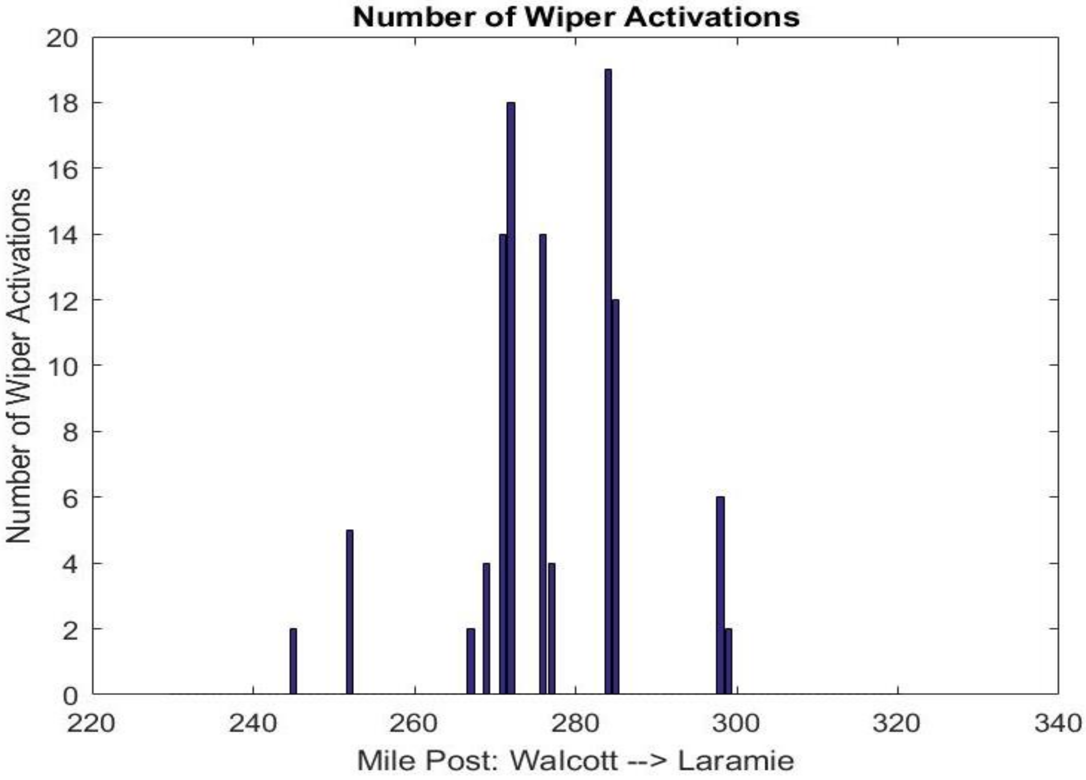


Figure D.23 CC6 Wiper Activation Frequency

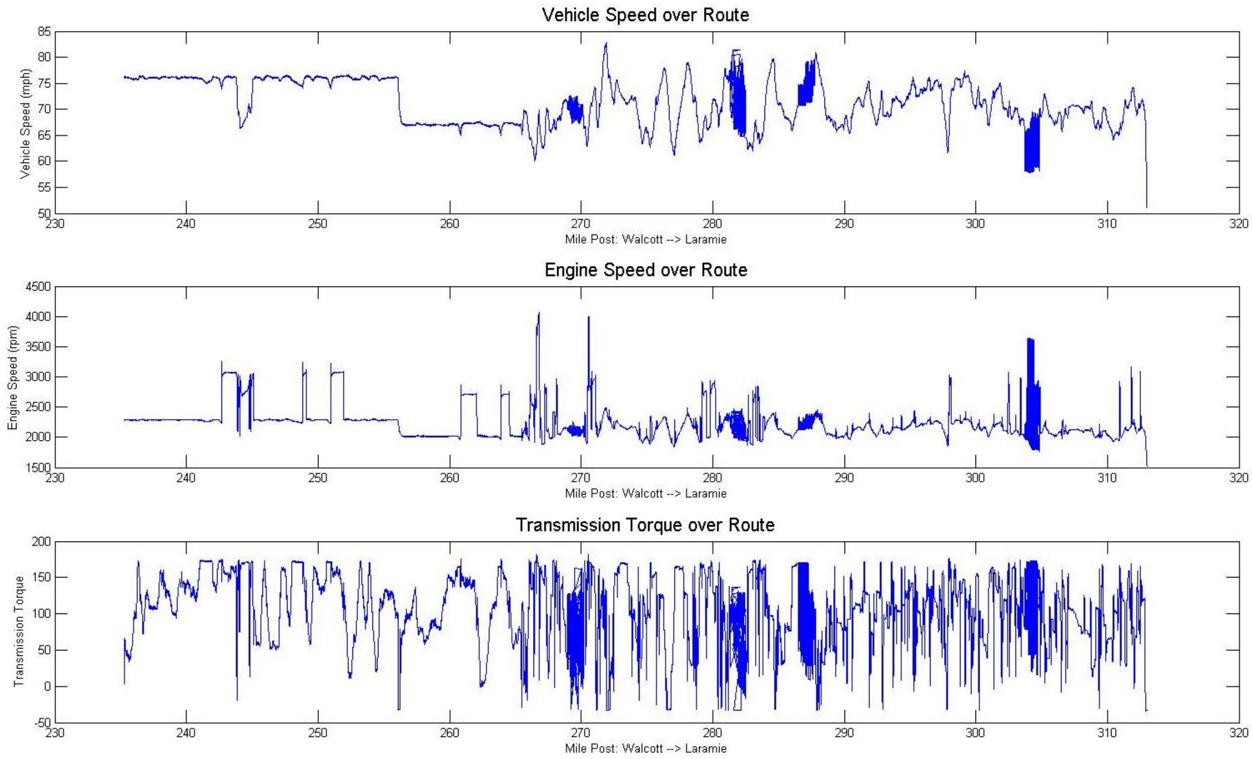


Figure D.24 CC6 Vehicle Speed, Engine Speed, and Transmission Torque

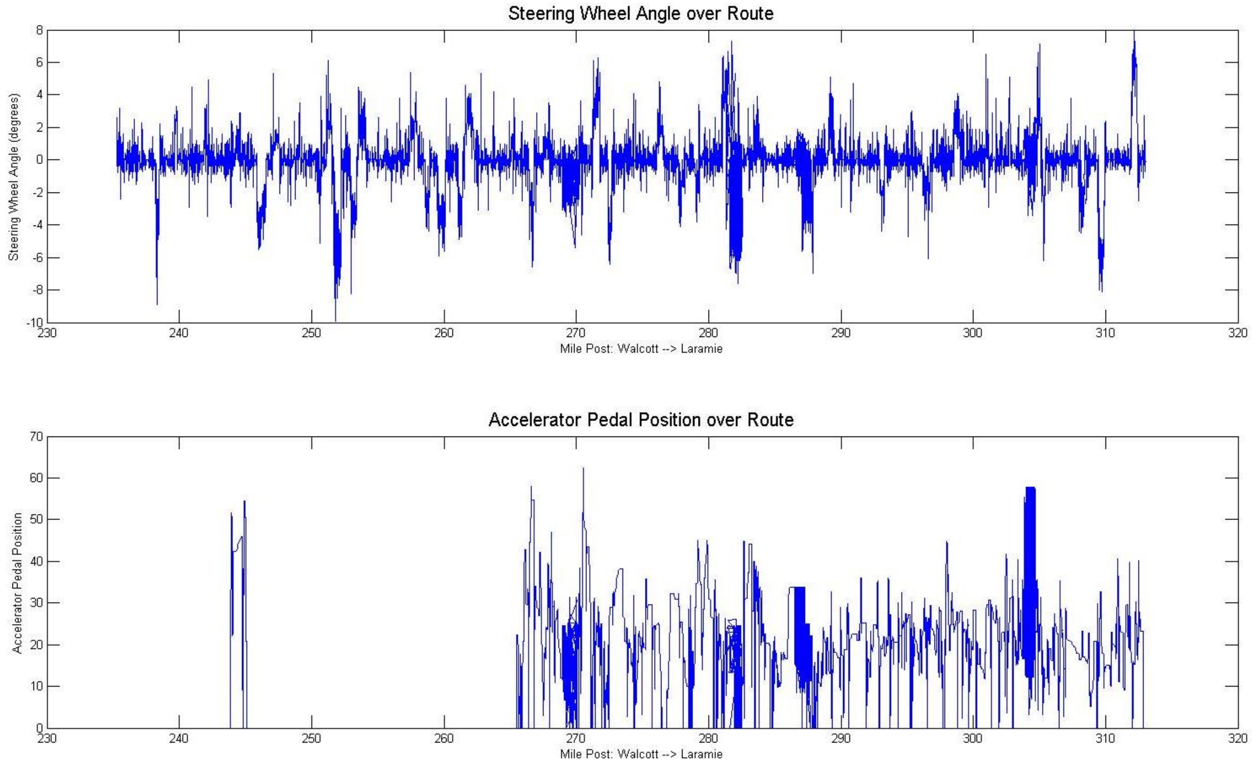


Figure D.25 CC6 Steering Wheel Angle and Accelerator Pedal Position

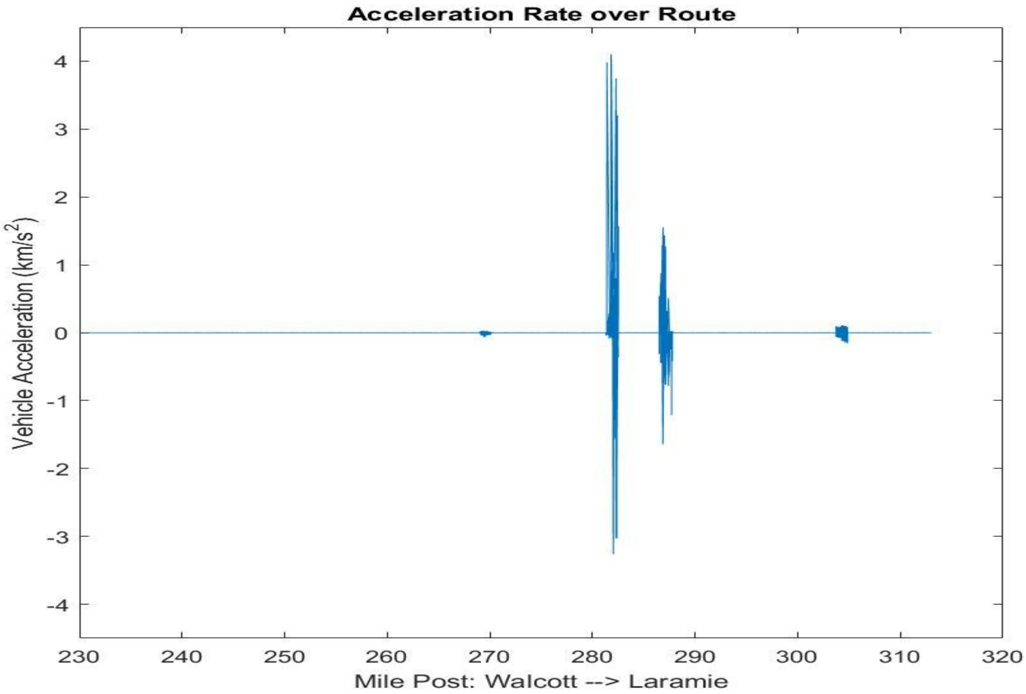


Figure D.26 CC6 Acceleration/Deceleration Rate

Trip CC7

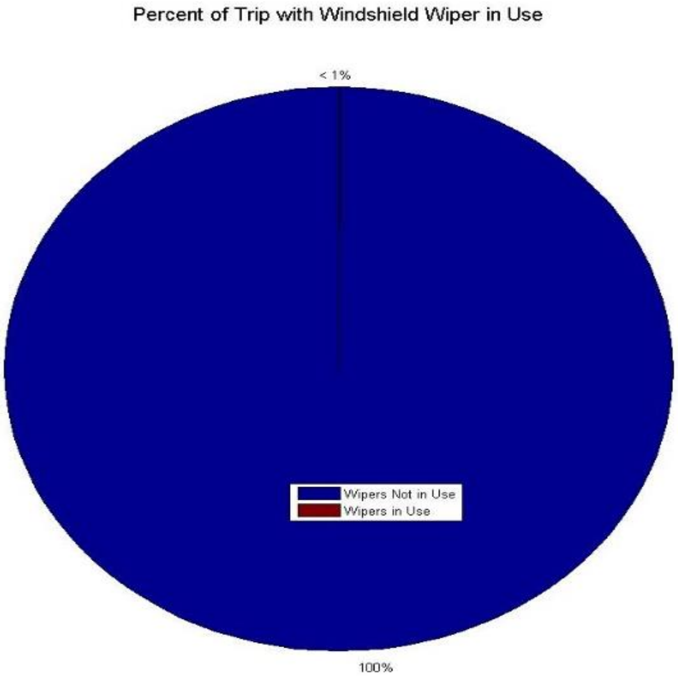


Figure D.27 CC7 Percent Windshield Wiper Use

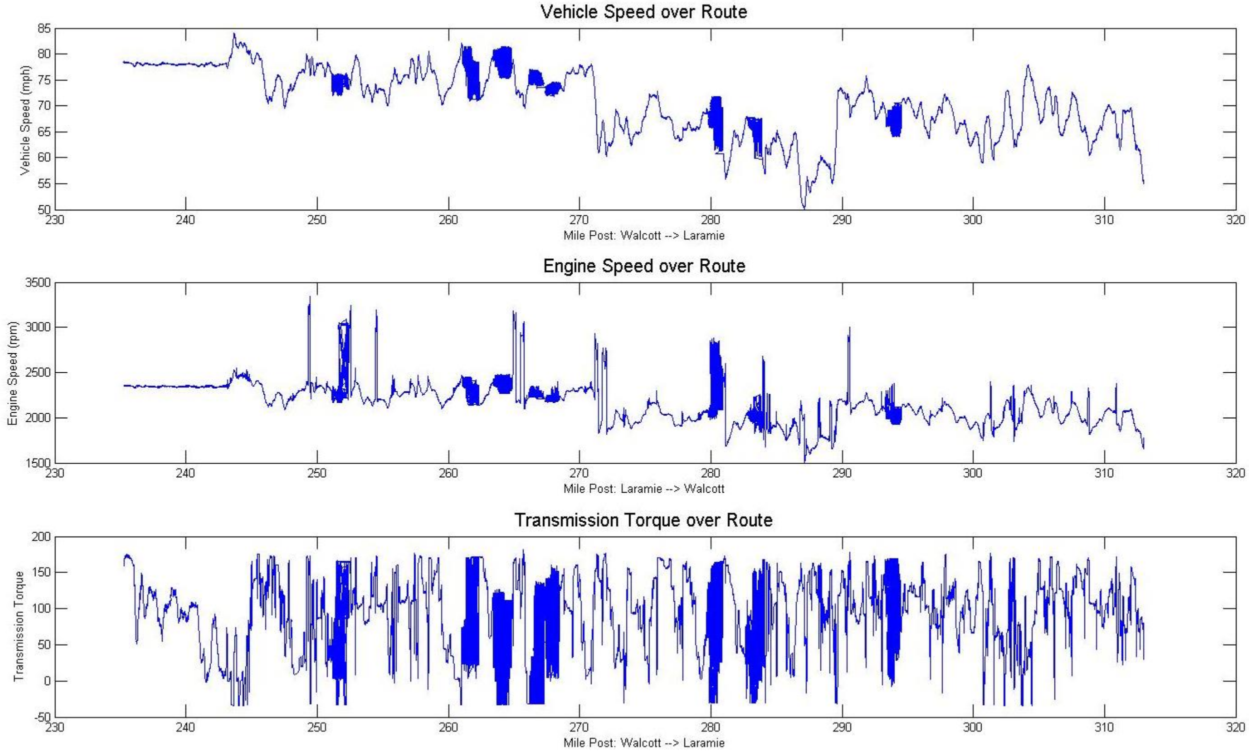


Figure D.28 CC7 Vehicle Speed, Engine Speed, and Transmission Torque

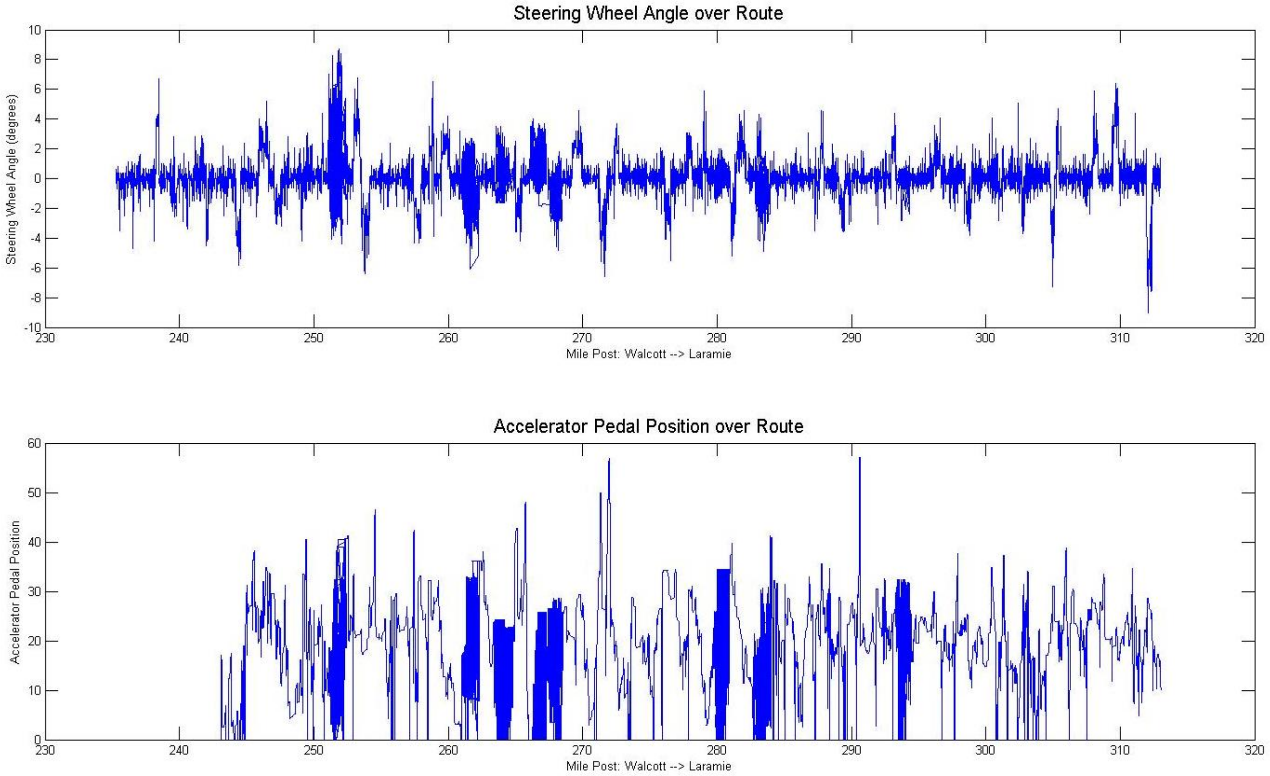


Figure D.29 CC7 Steering Wheel Angle and Accelerator Pedal Position

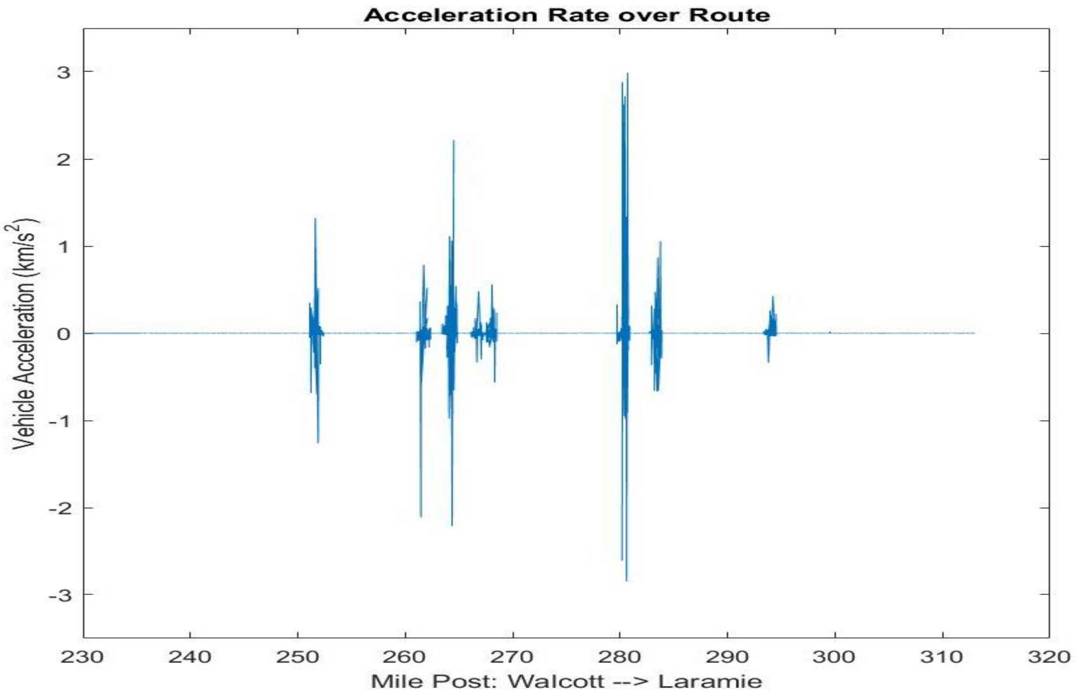


Figure D.30 CC7 Acceleration/Deceleration Rate

Trip CC8

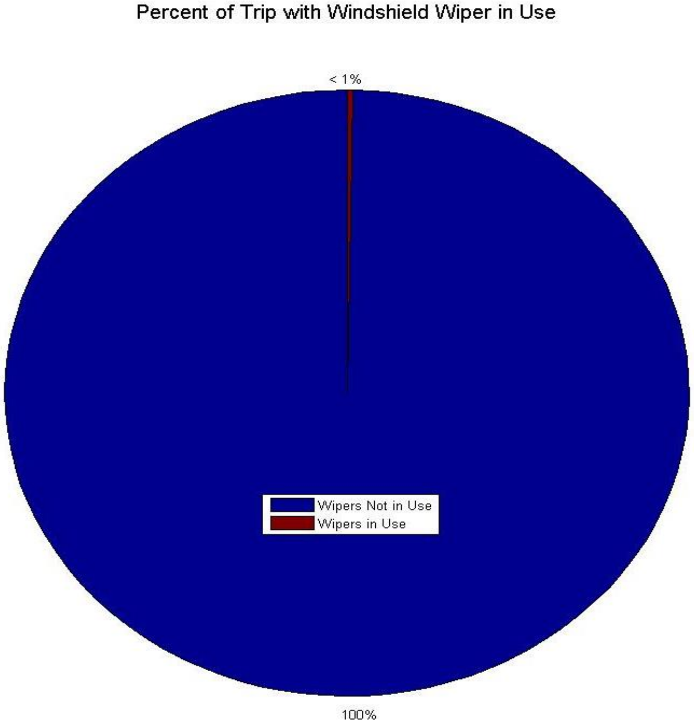


Figure D.31 CC8 Percent Windshield Wiper Use

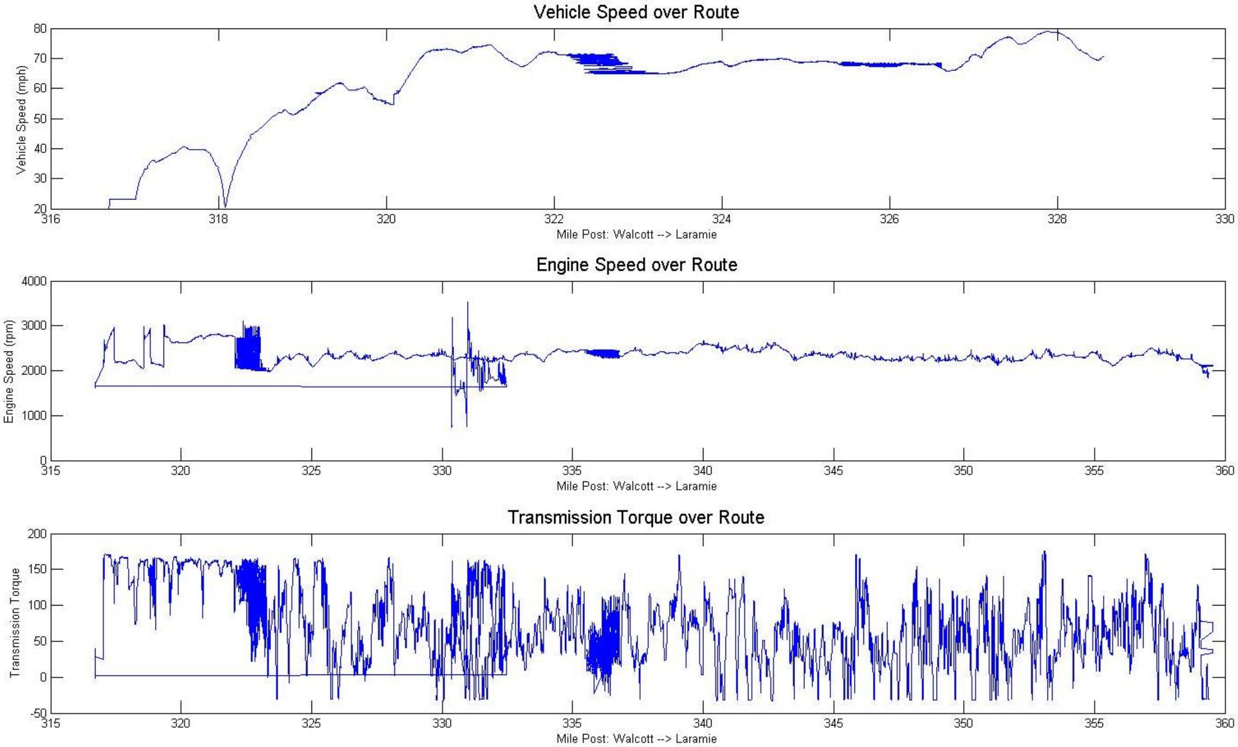


Figure D.32 CC8 Vehicle Speed, Engine Speed, and Transmission Torque

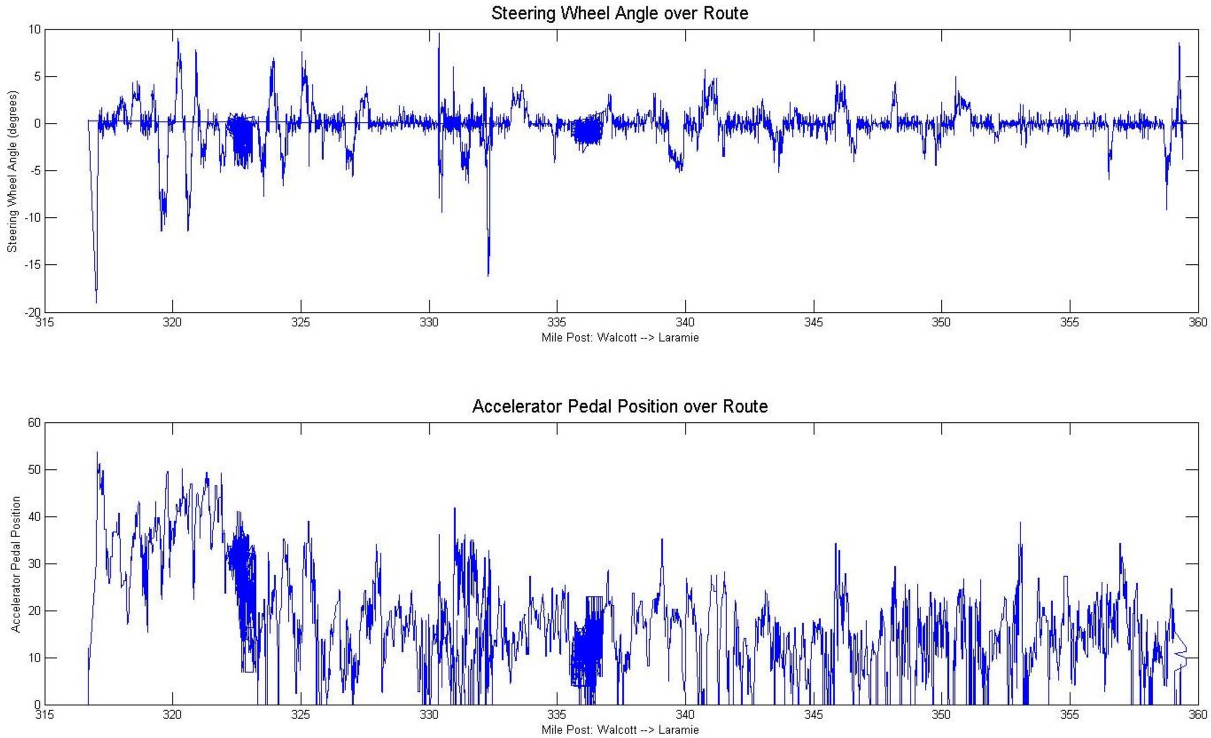
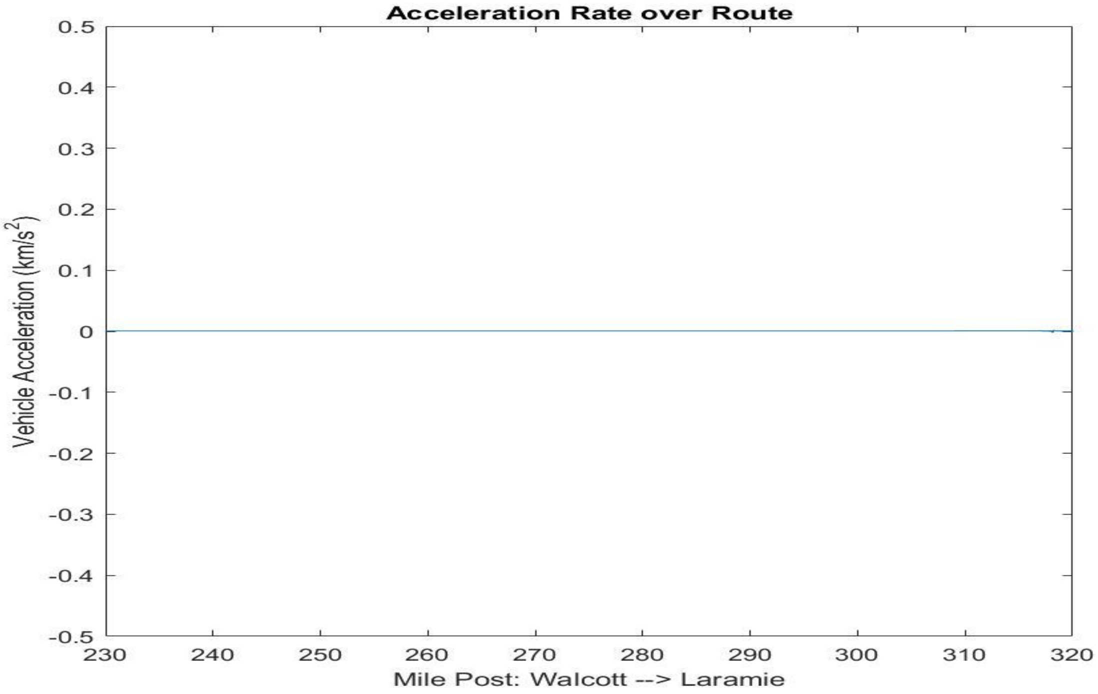


Figure D.33 CC8 Steering Wheel Angle and Accelerator Pedal Position



D.34 CC8 Acceleration/Deceleration Rate

Trip CC9

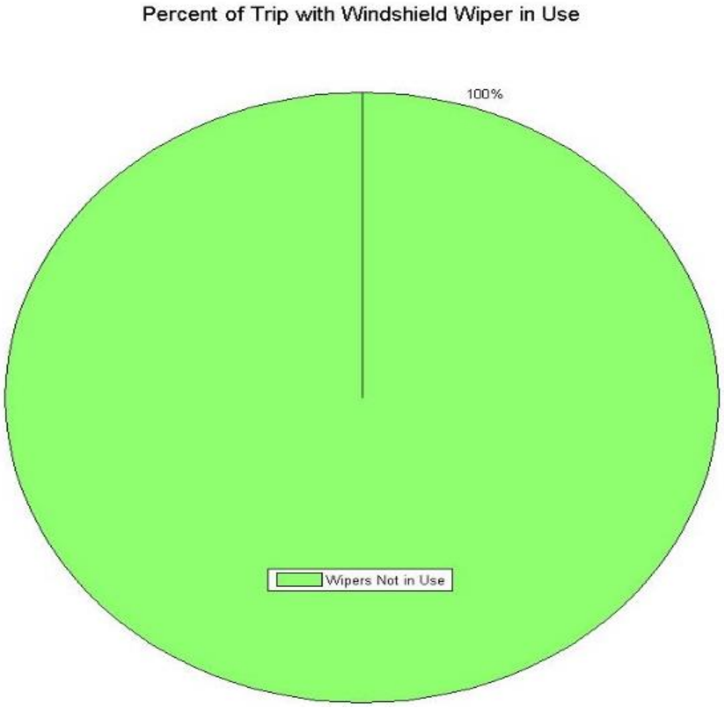


Figure D.35 CC9 Percent Windshield Wiper Use

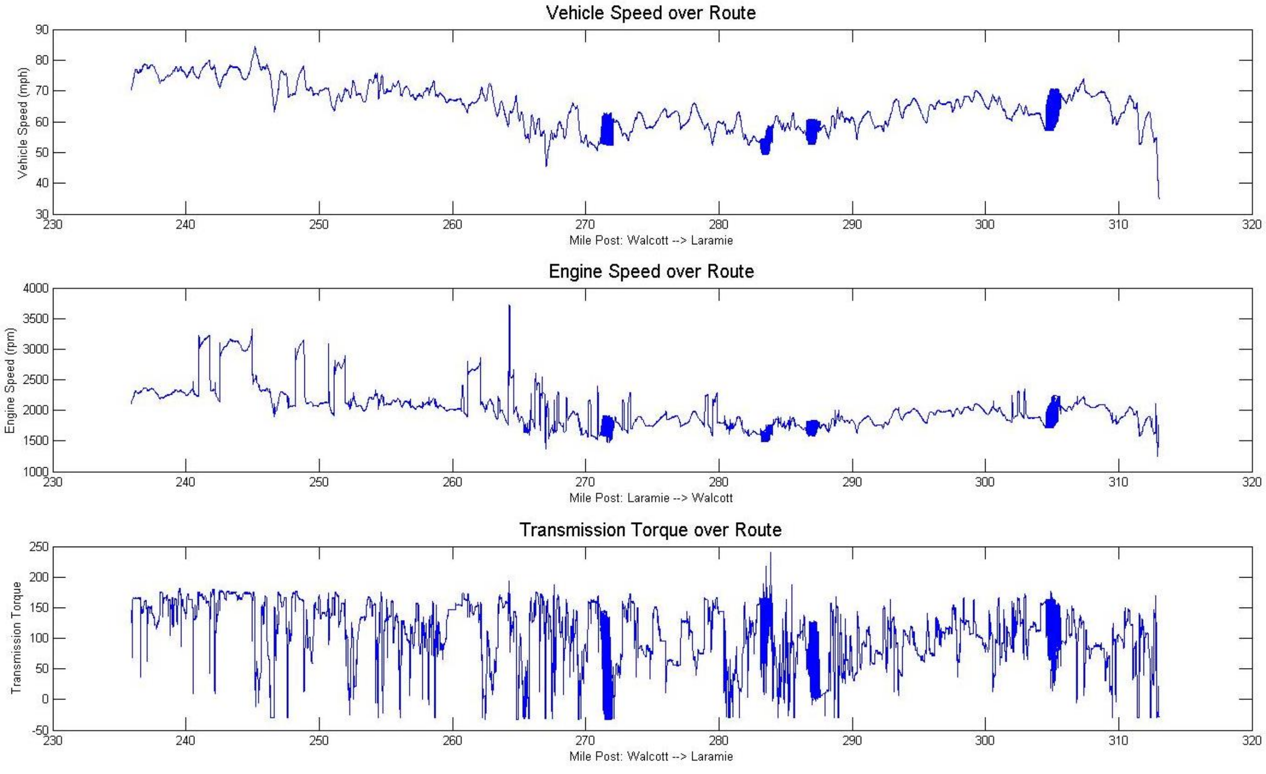


Figure D.36 CC9 Vehicle Speed, Engine Speed, Transmission Torque

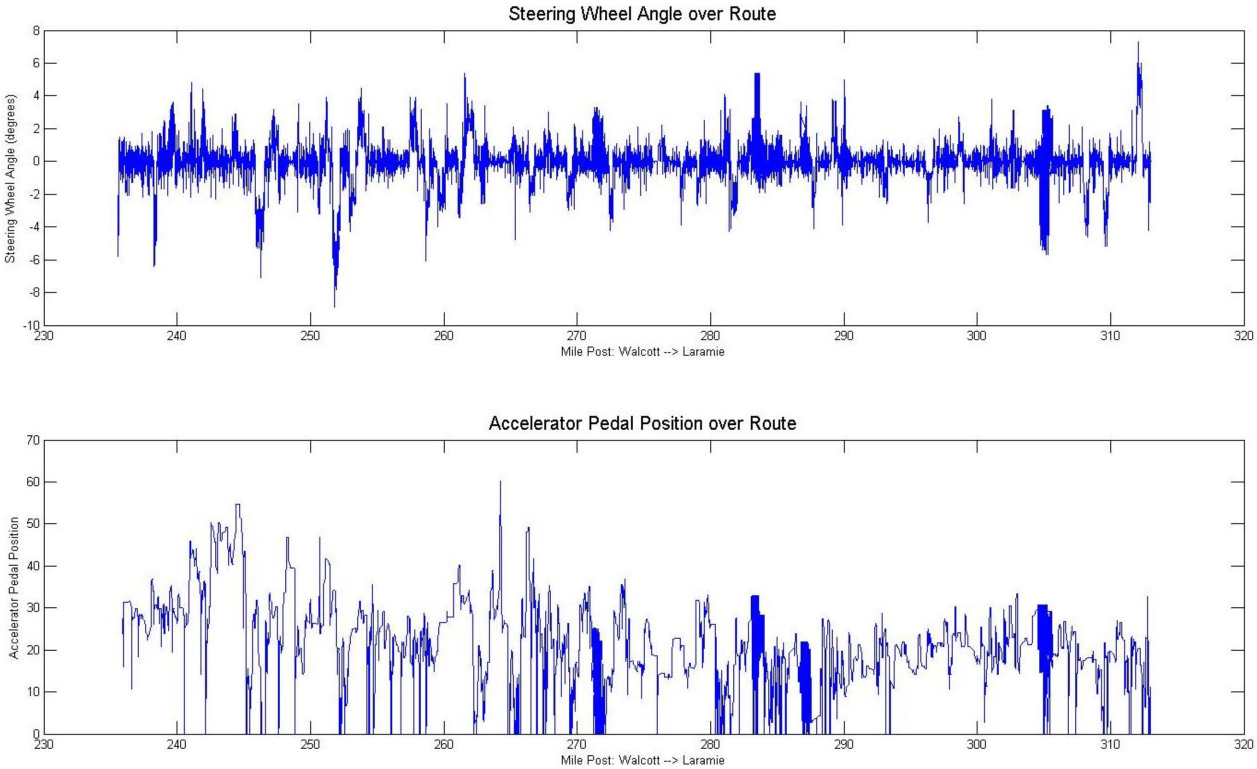


Figure D.37 CC9 Steering Wheel Angle and Accelerator Pedal Position

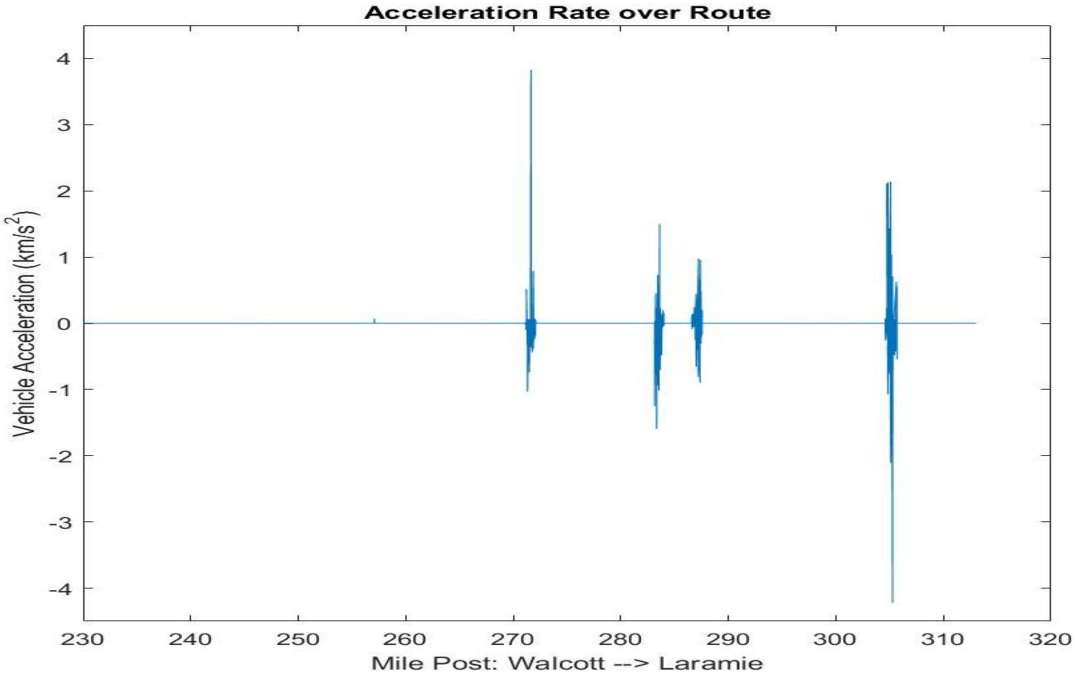


Figure D.38 CC9 Acceleration/Deceleration Rate

Trip CC11

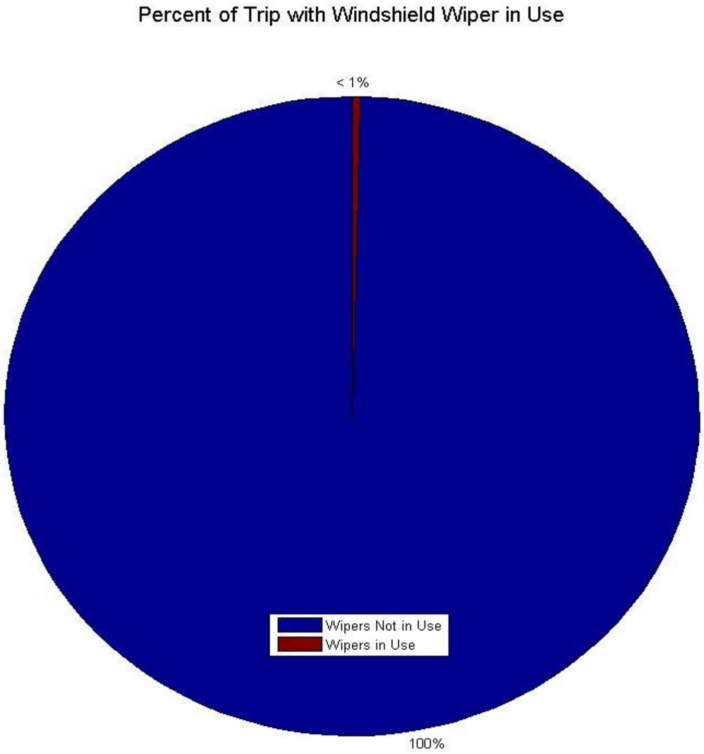


Figure D.39 CC11 Percent Windshield Wiper Use

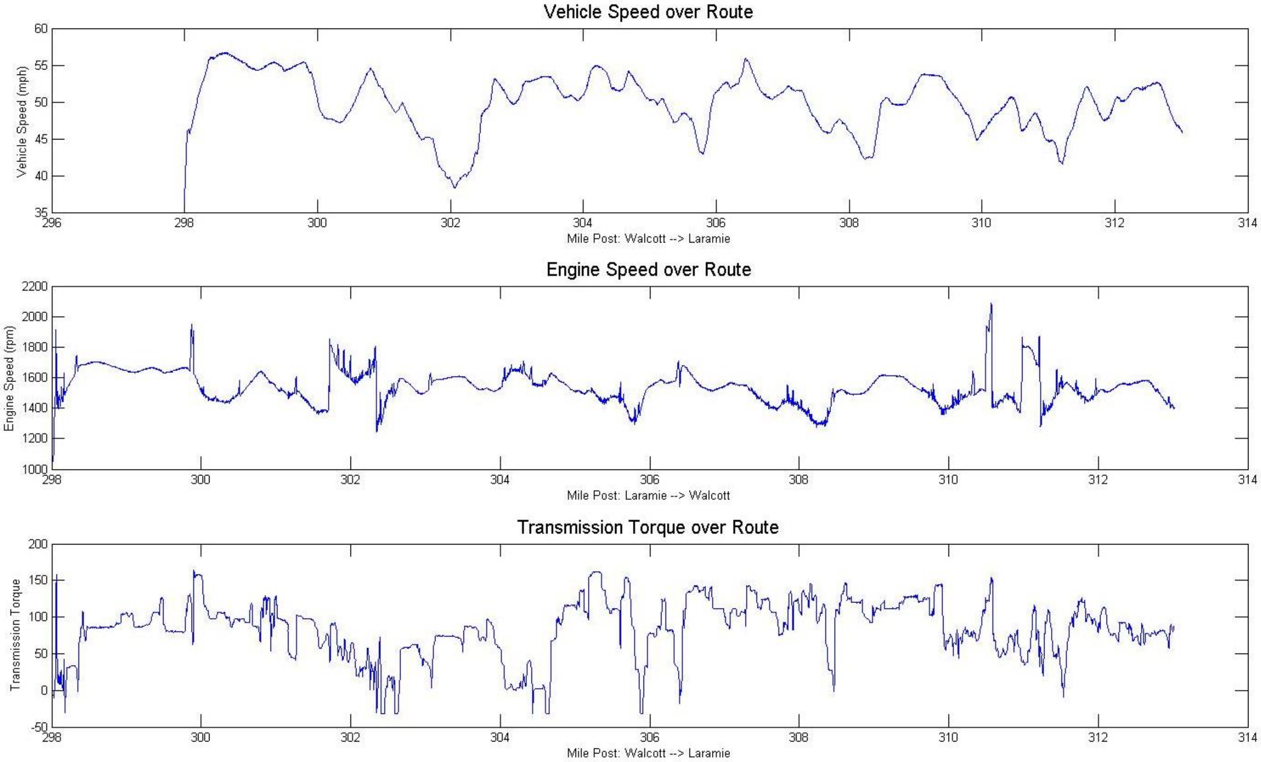


Figure D.40 CC11 Vehicle Speed, Engine Speed, and Transmission Torque

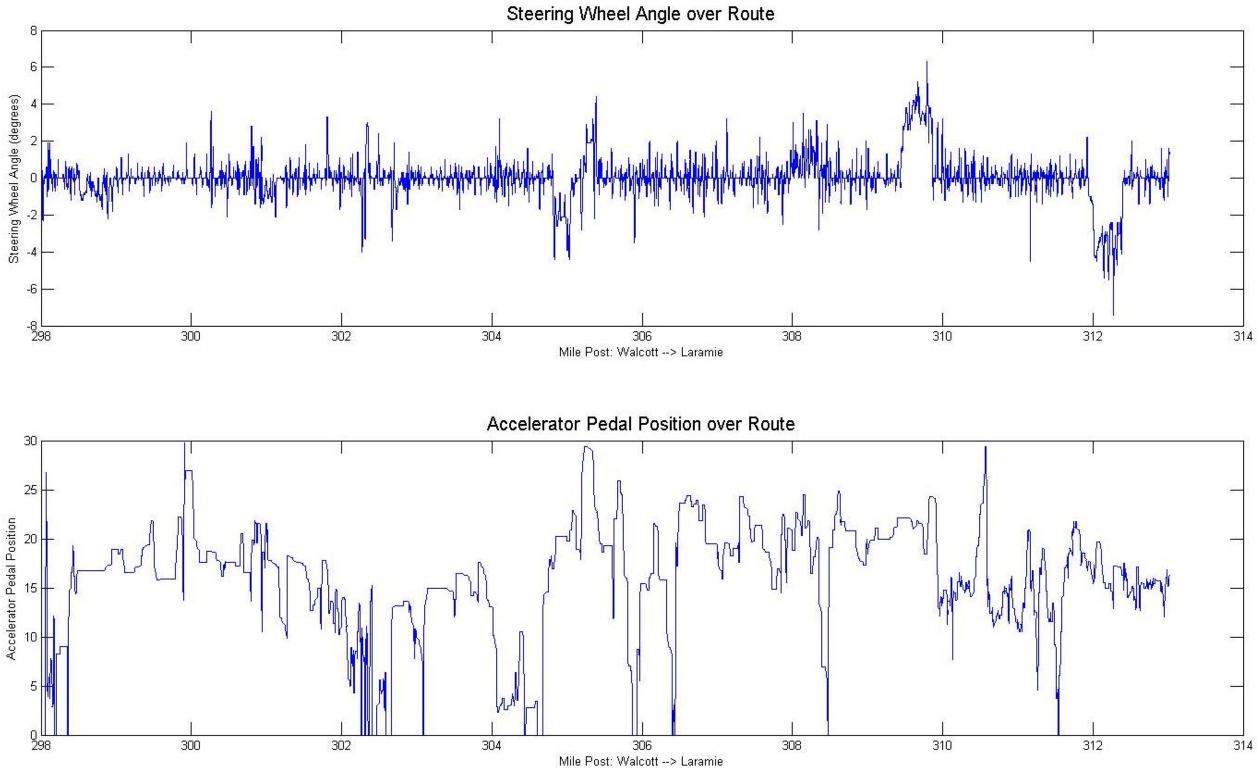


Figure D.41 CC11 Steering Wheel Angle and Accelerator Pedal Position

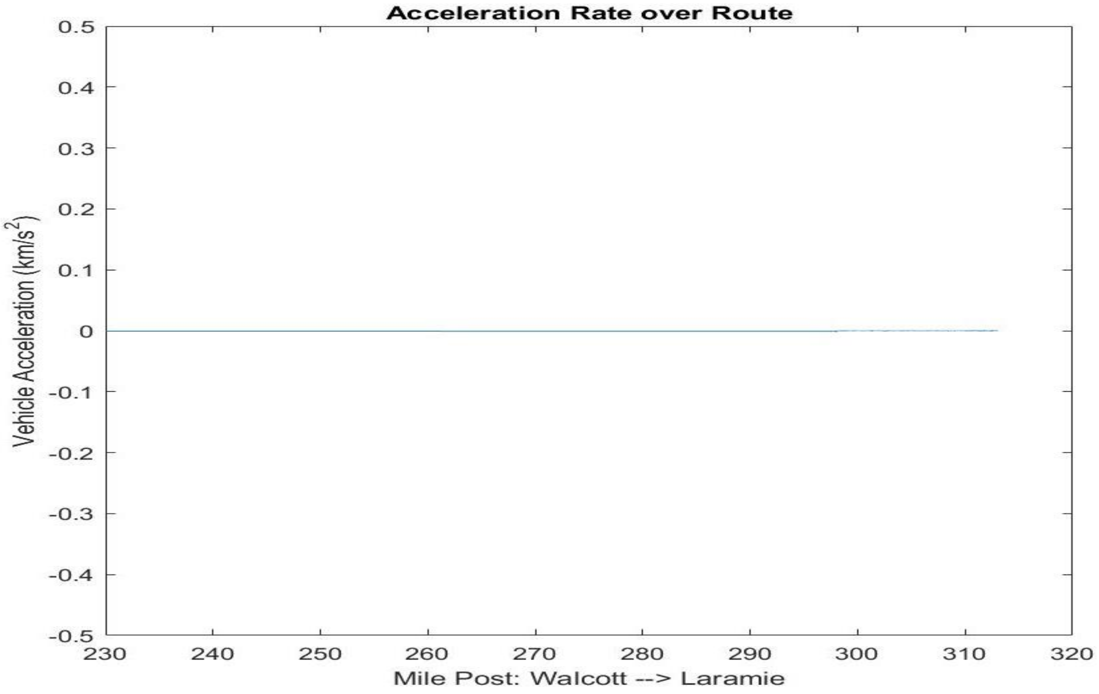


Figure D.42 CC11 Acceleration/Deceleration Rate

Trip CC13

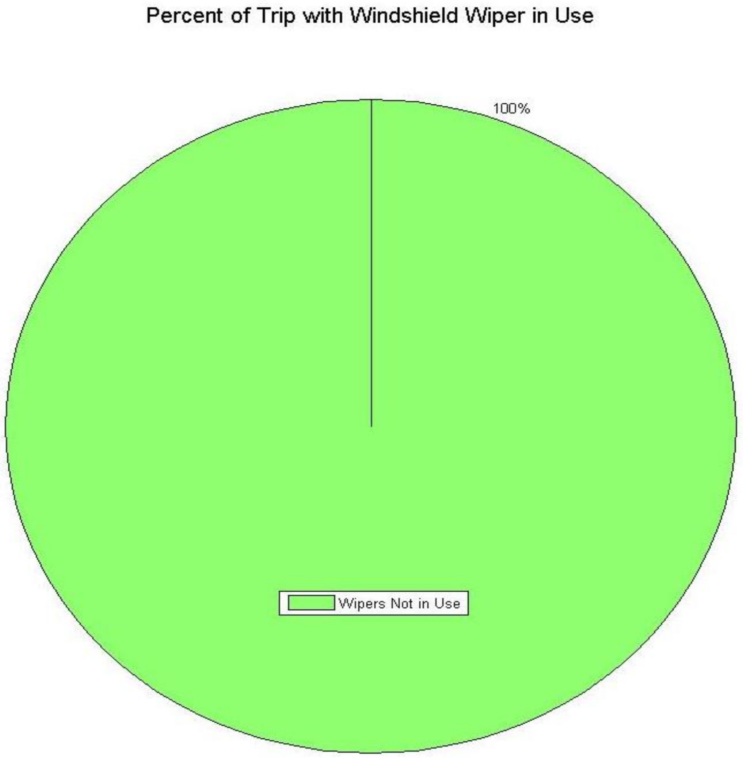


Figure D.43 CC13 Percent Windshield Wiper Use

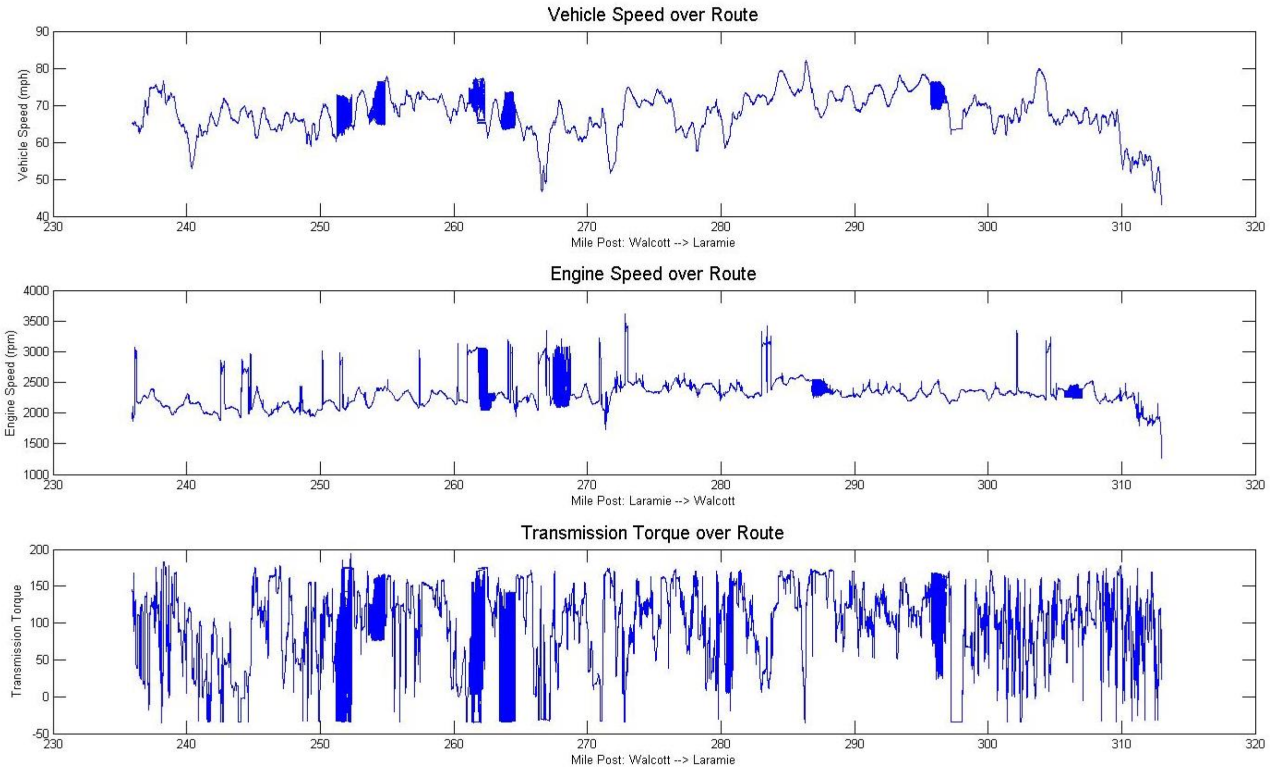


Figure D.44 CC13 Vehicle Speed, Engine Speed, and Transmission Torque

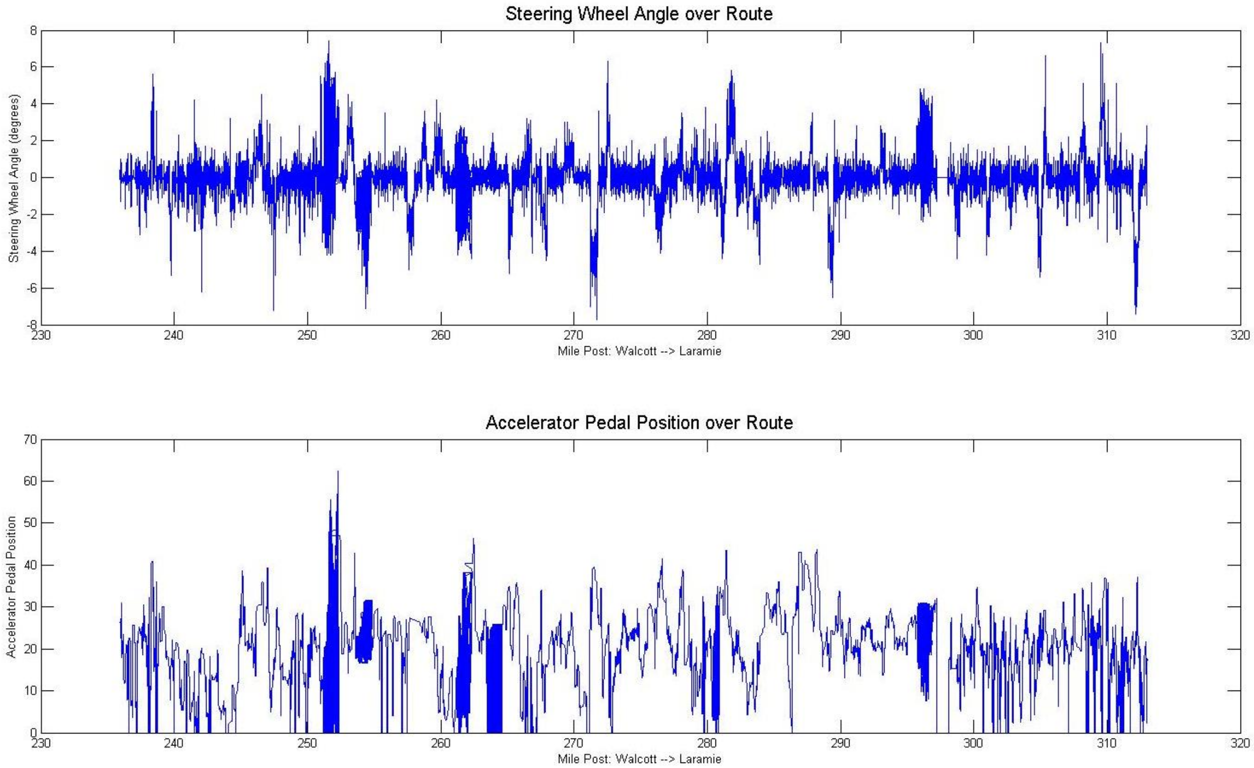


Figure D.45 CC13 Steering Wheel Angle and Accelerator Pedal Position

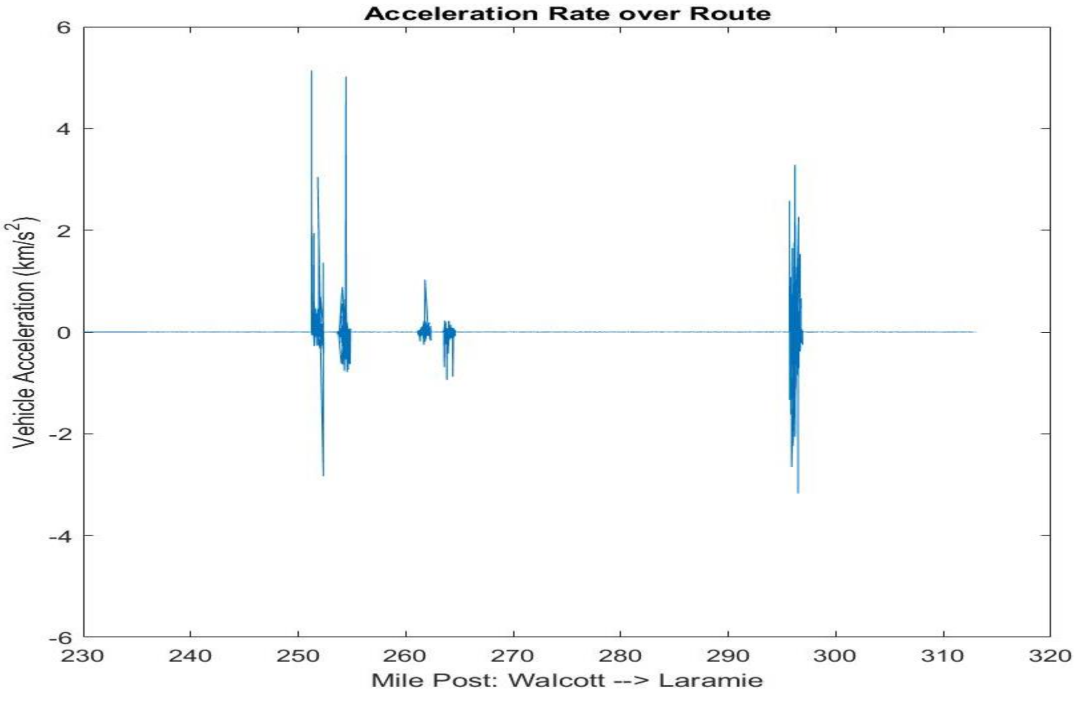


Figure D.46 CC13 Acceleration/Deceleration Rate

Trip CC14

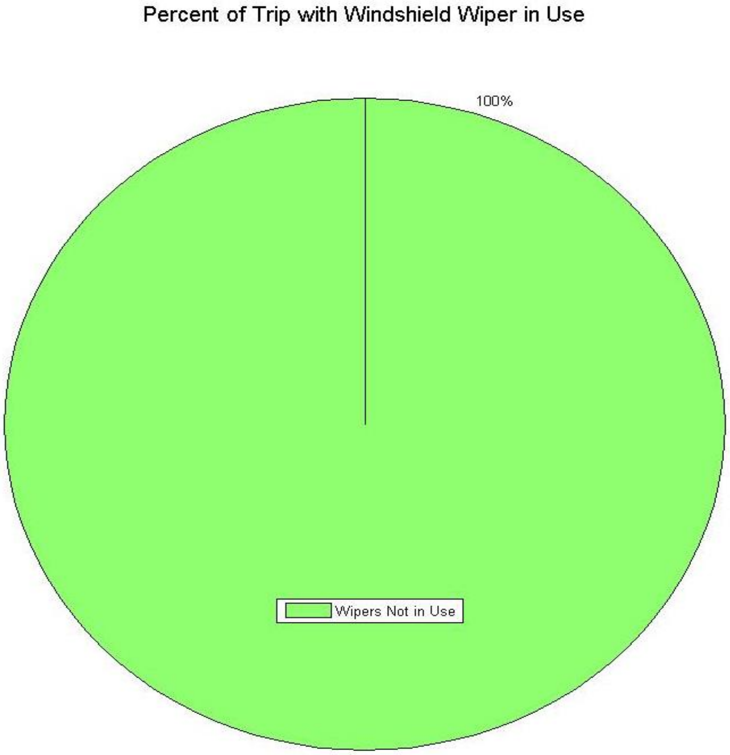


Figure D.47 CC14 Windshield Wiper Use

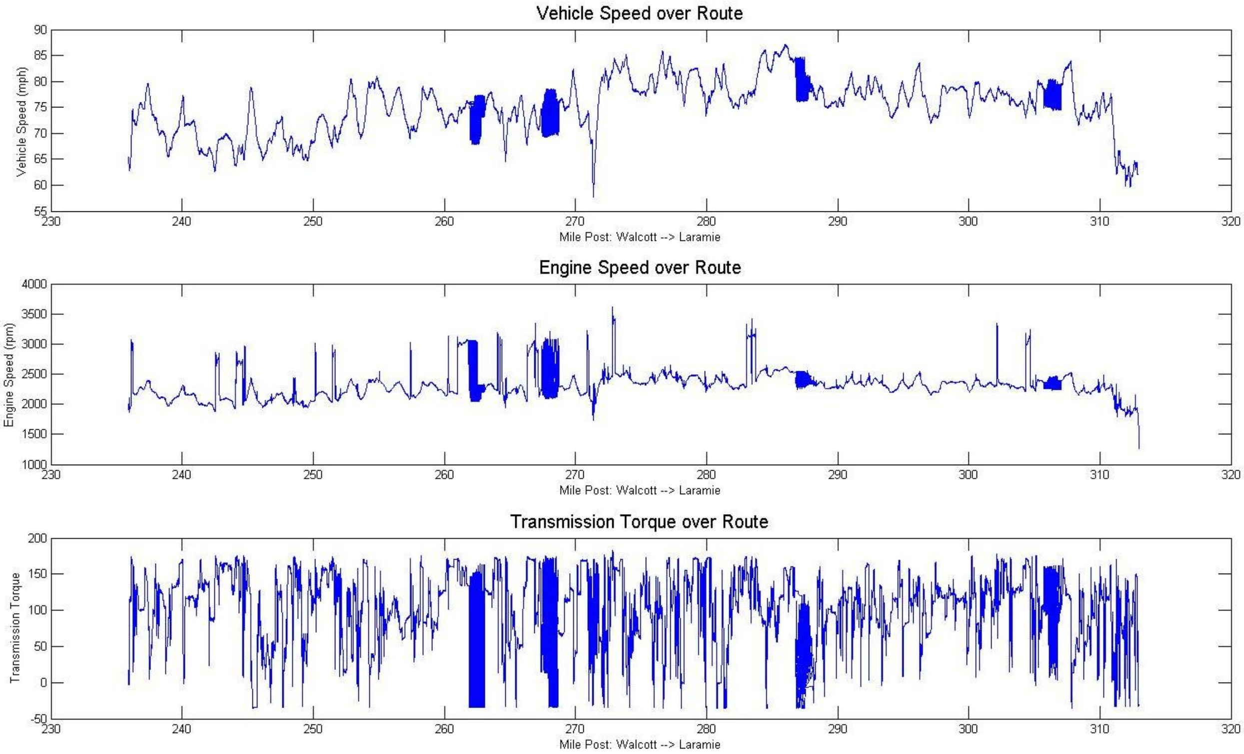


Figure D.48 CC14 Vehicle Speed, Engine Speed, and Transmission Torque

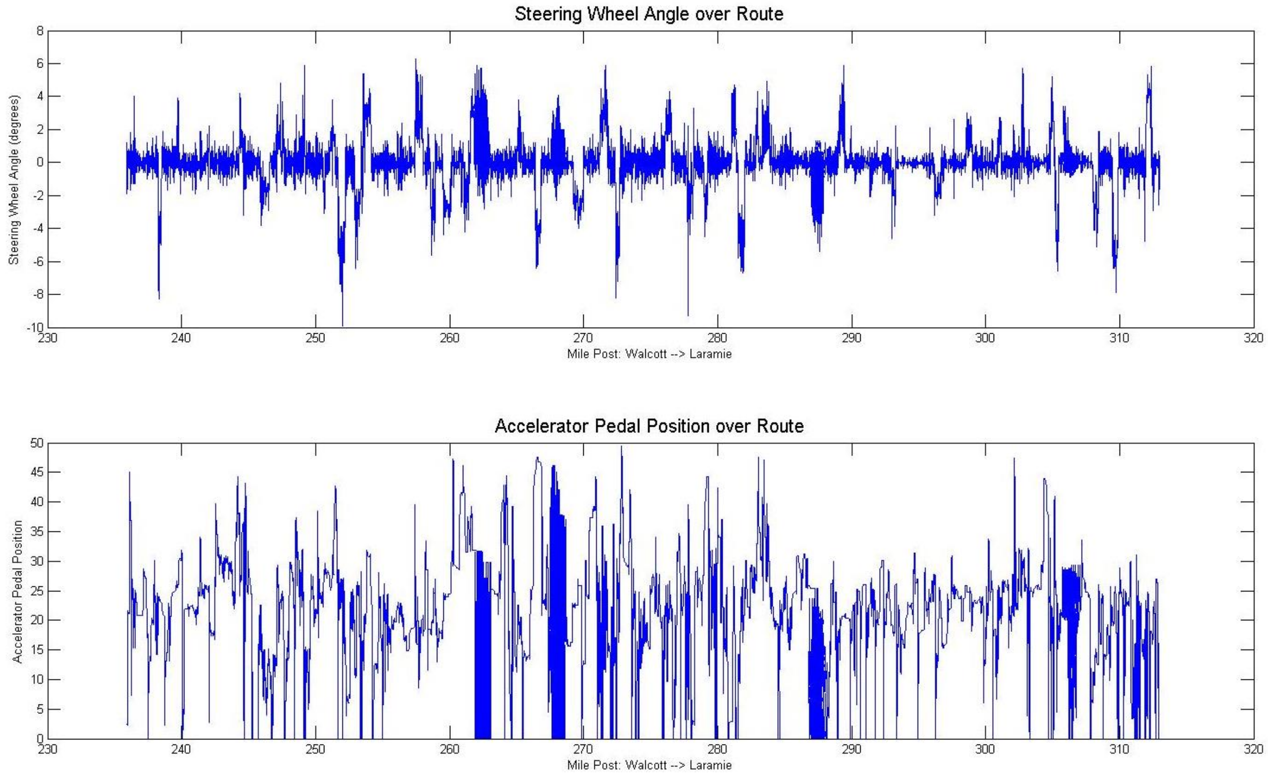


Figure D.49 CC14 Steering Wheel Angle and Accelerator Pedal Position

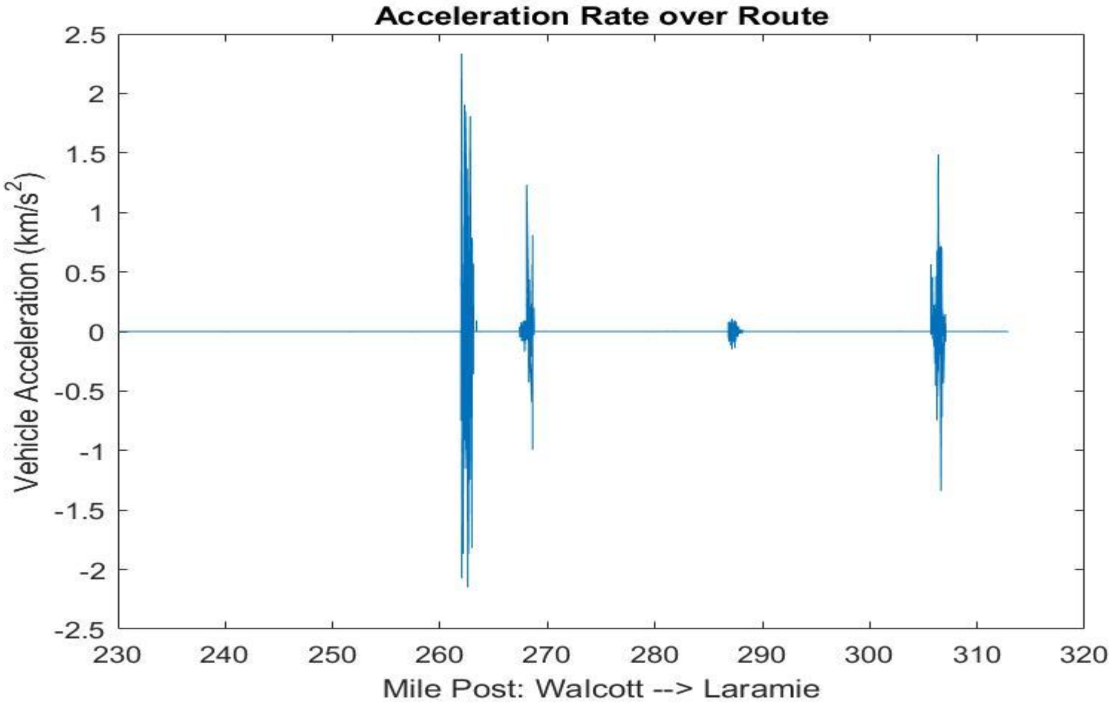


Figure D.50 CC14 Acceleration/Deceleration Rate

Trip CC15

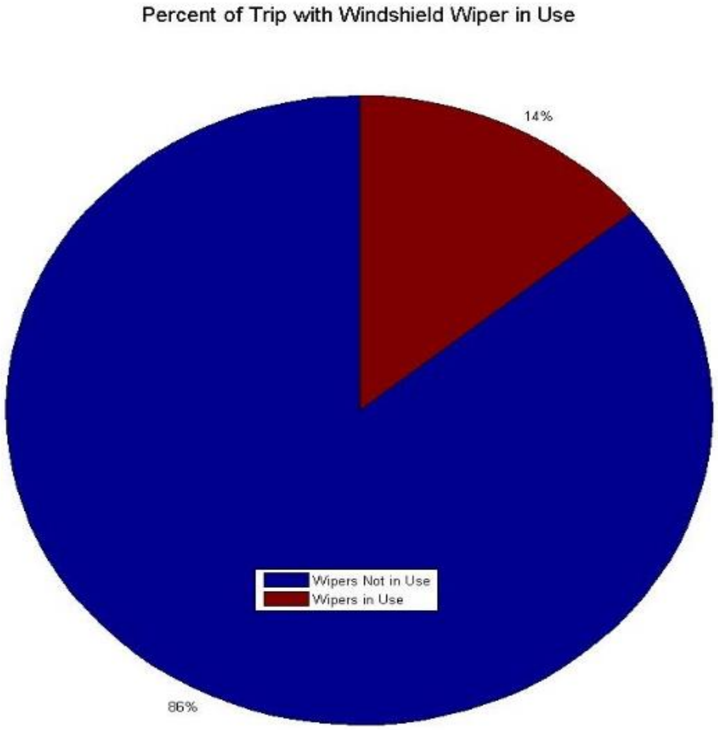


Figure D.51 CC15 Percent Windshield Wiper Use

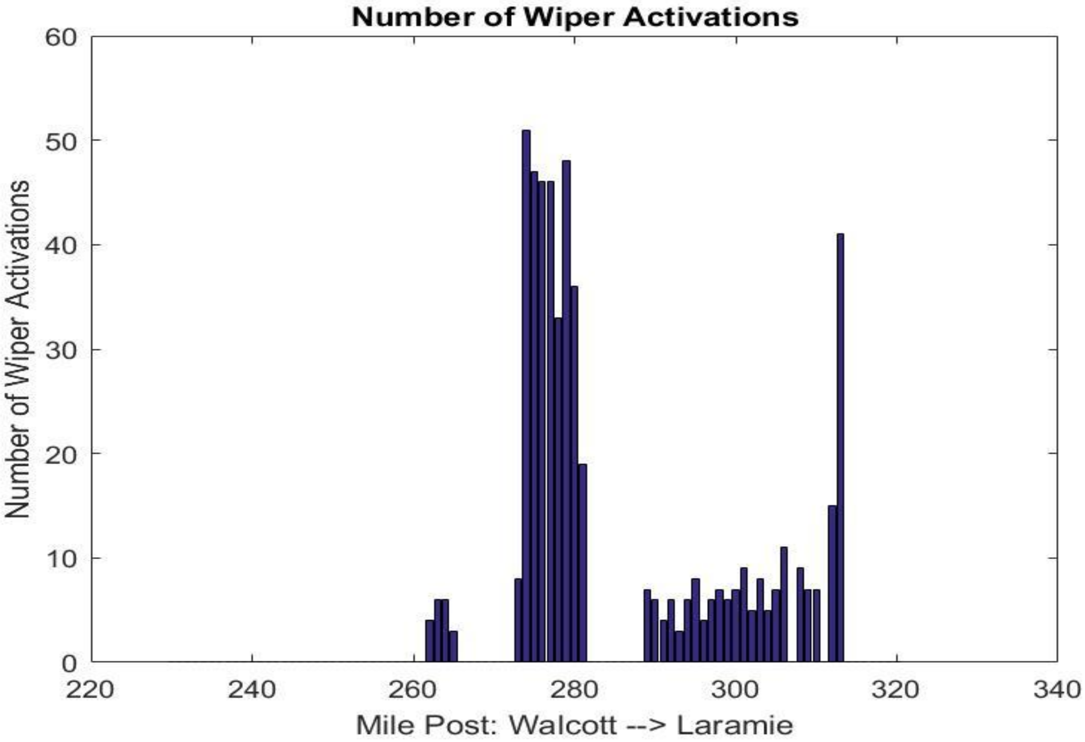


Figure D.52 CC15 Wiper Activation Frequency

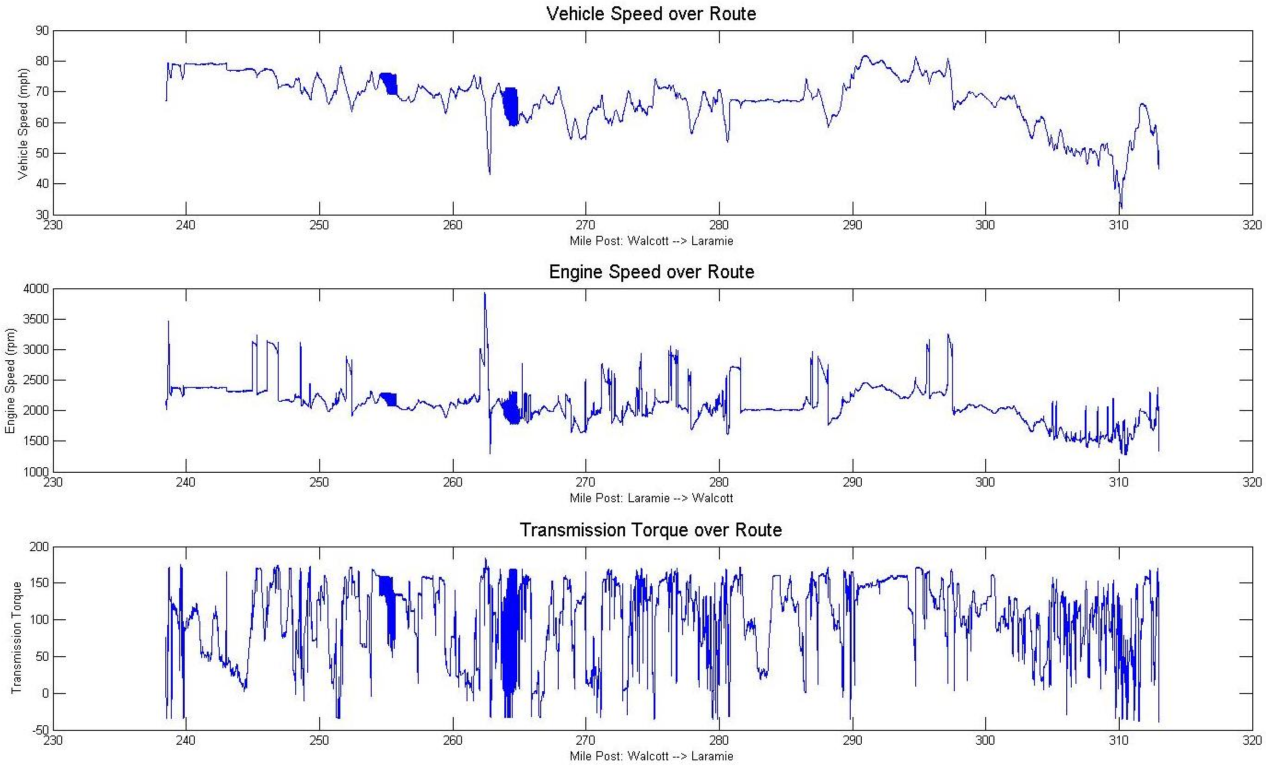


Figure D.53 CC15 Vehicle Speed, Engine Speed, and Transmission Torque

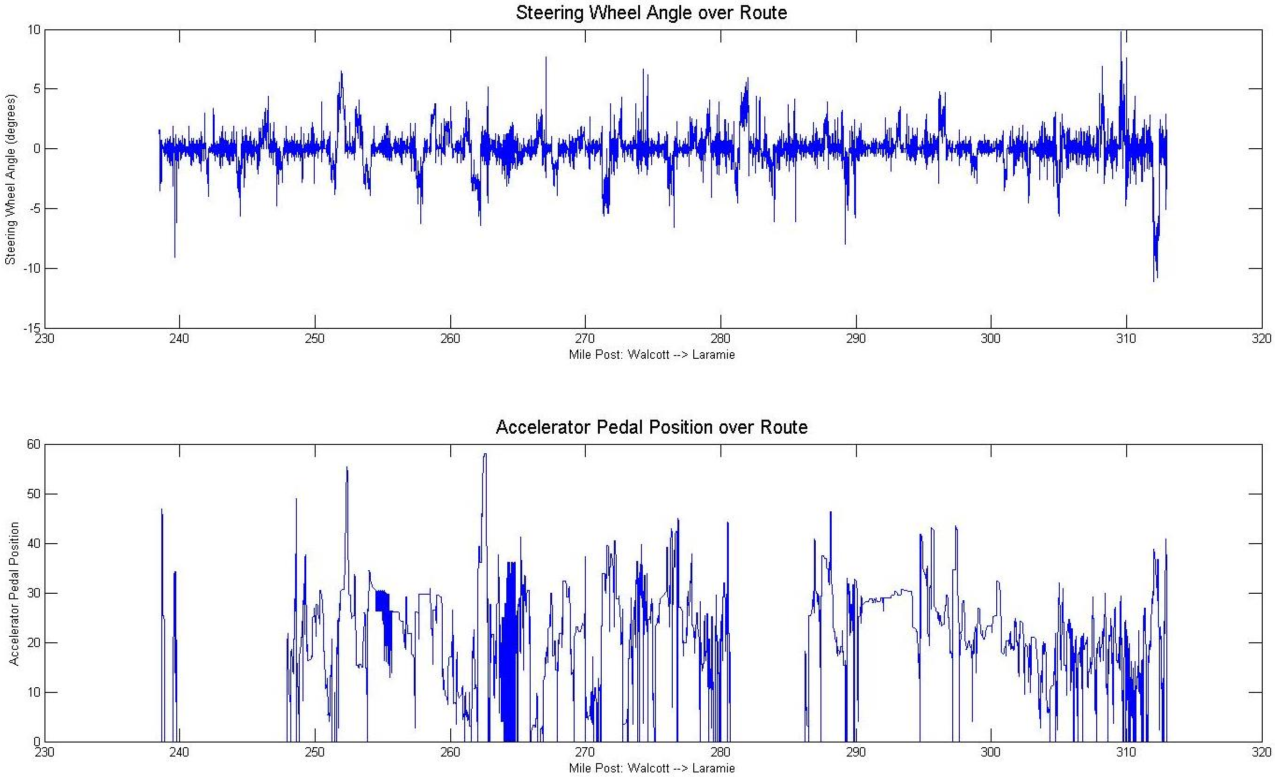


Figure D.54 CC15 Steering Wheel Angle and Accelerator Pedal Position

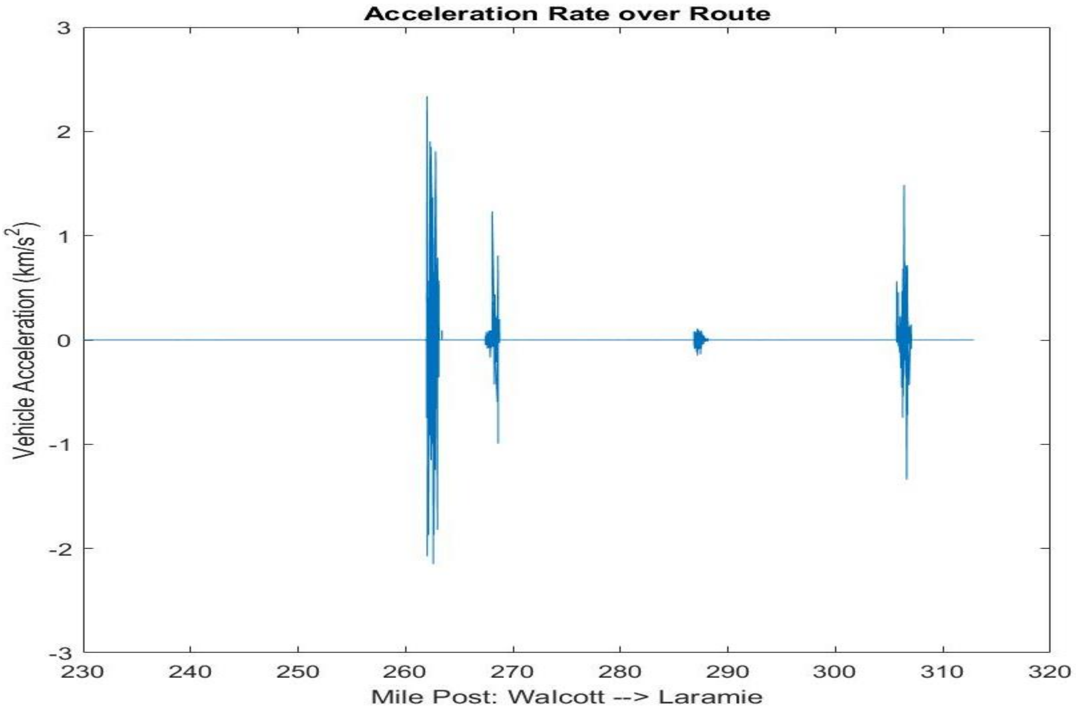


Figure D.55 CC15 Acceleration/Deceleration Rate

Trip CC16

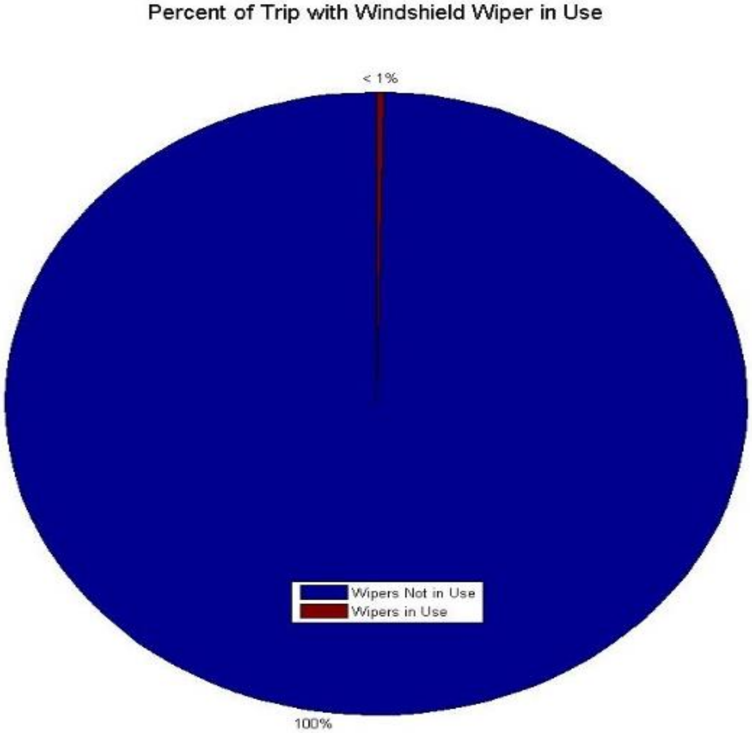


Figure D.56 CC16 Percent Windshield Wiper Use

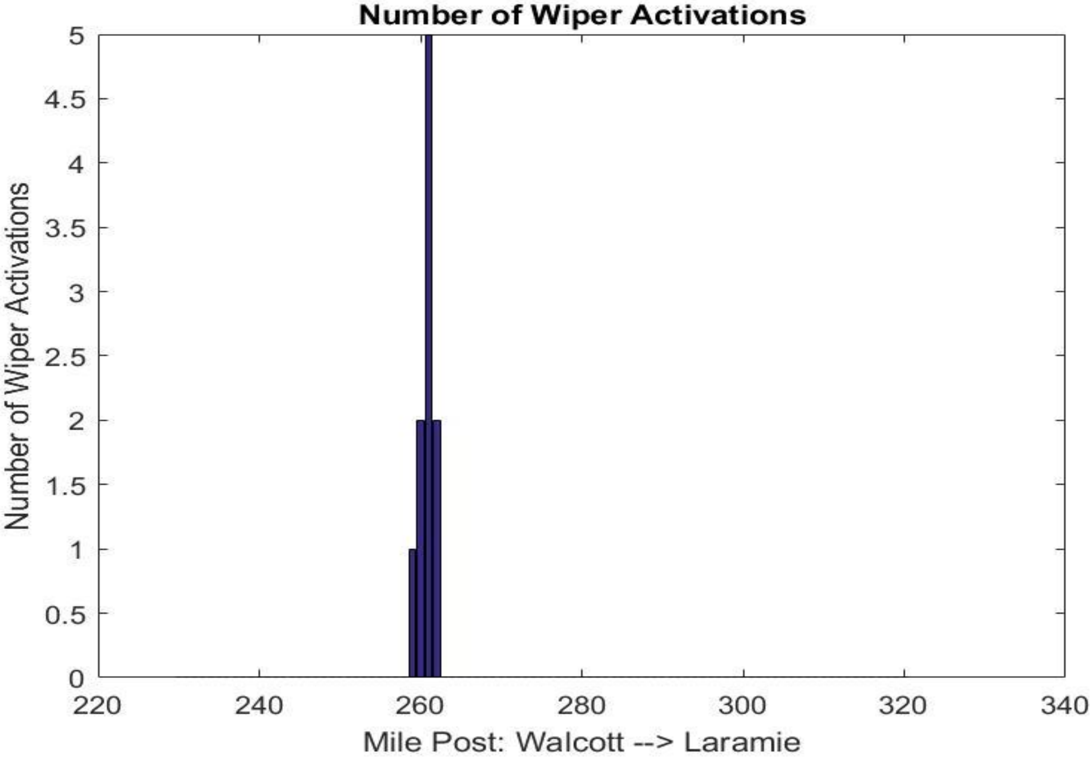


Figure D.57 CC16 Wiper Activation Frequency

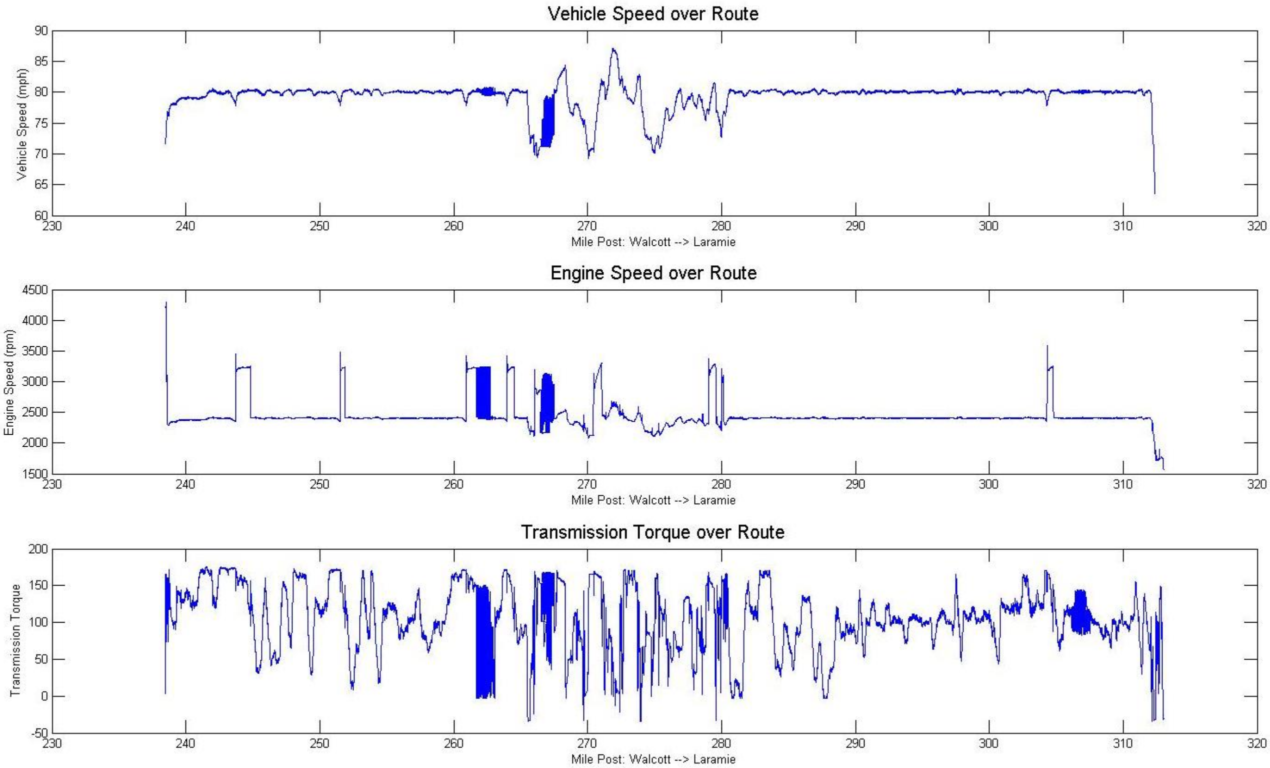


Figure D.58 CC16 Vehicle Speed, Engine Speed, and Transmission Torque

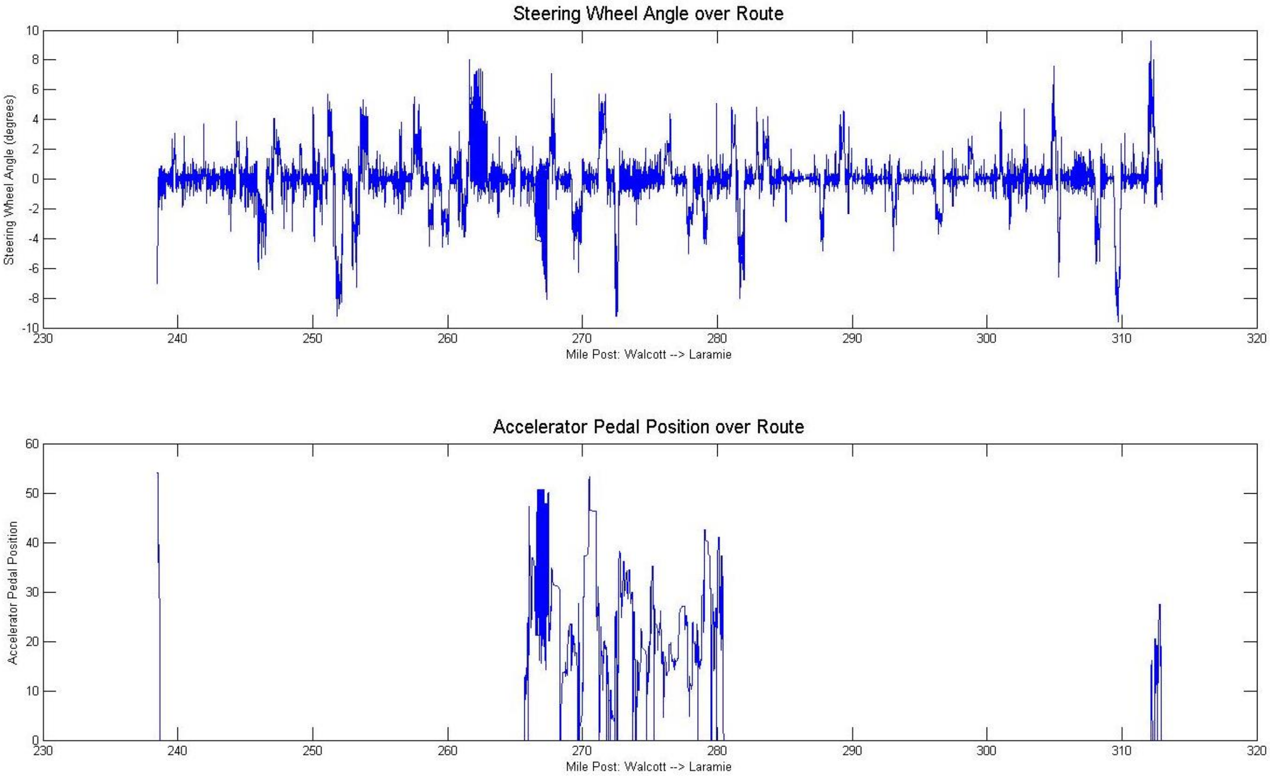


Figure D.59 CC16 Steering Wheel Angle and Accelerator Pedal Position

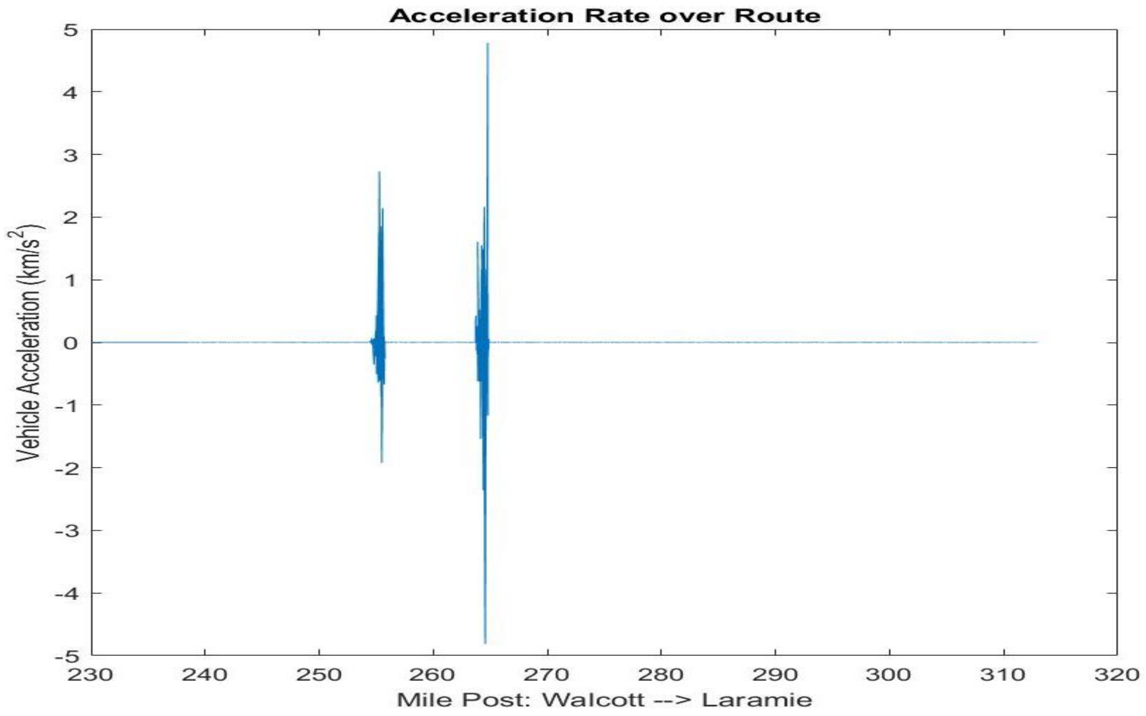


Figure D.60 CC16 Acceleration/Deceleration Rate

APPENDIX E: GIS VEHICLE DATA REPRESENTATION

Trip CC1

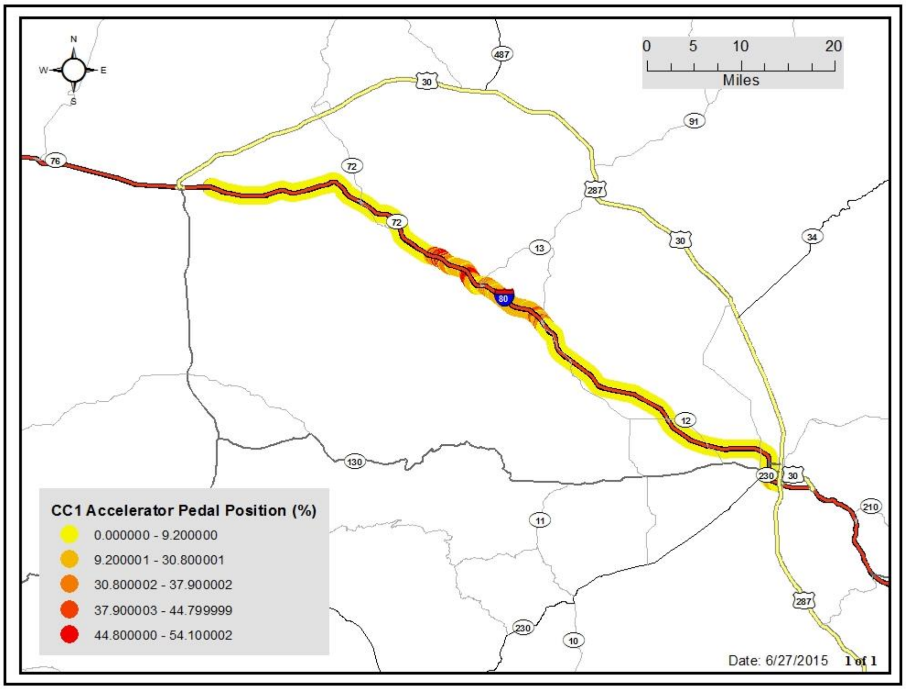


Figure E.1 CC1 Accelerator Pedal Position Data

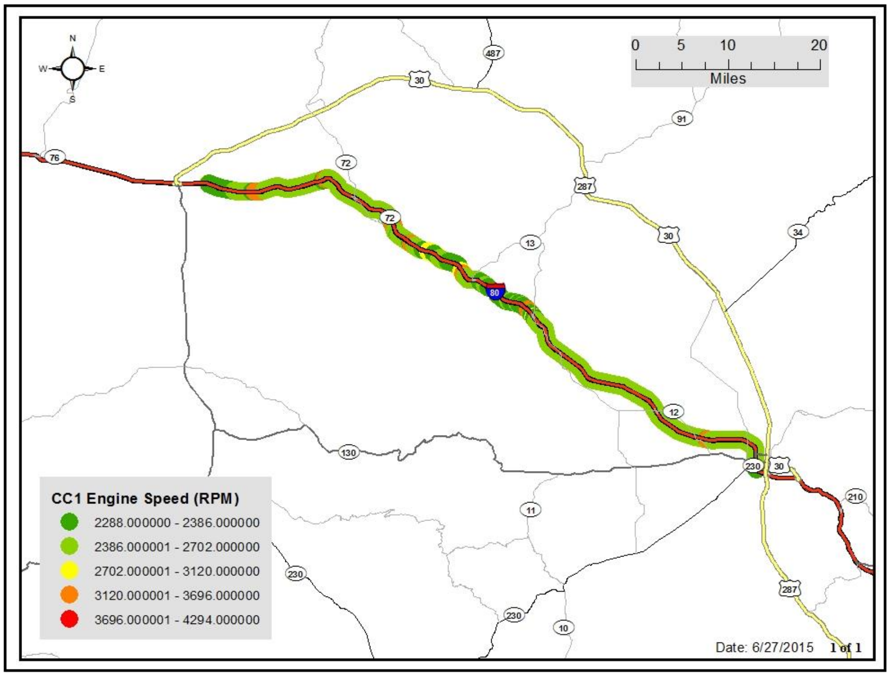


Figure E.2 CC1 Engine Speed Data

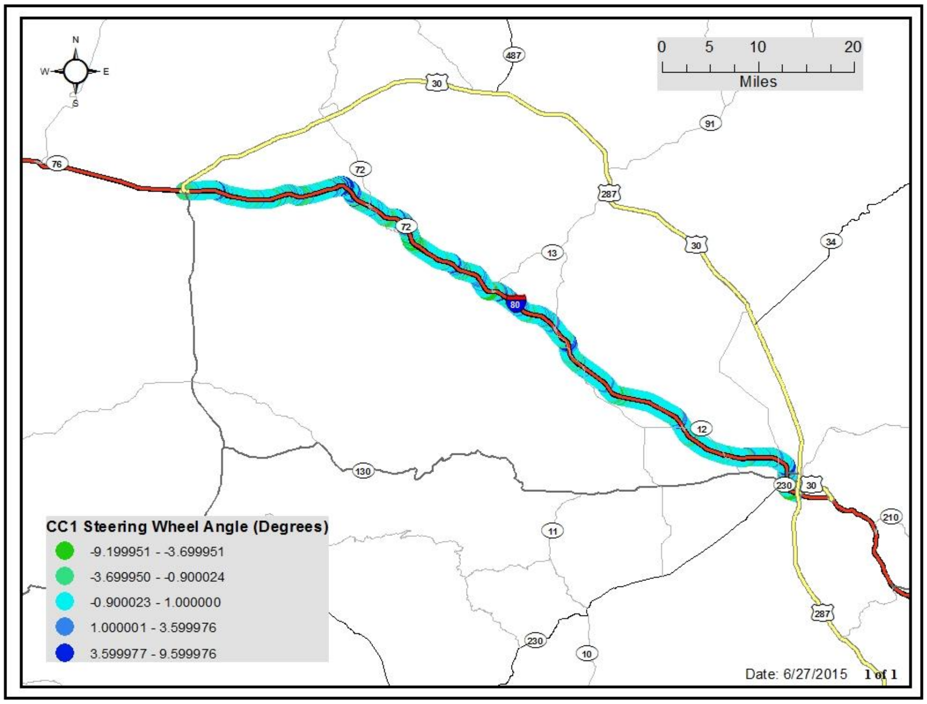


Figure E.3 CC1 Steering Wheel Angle Data

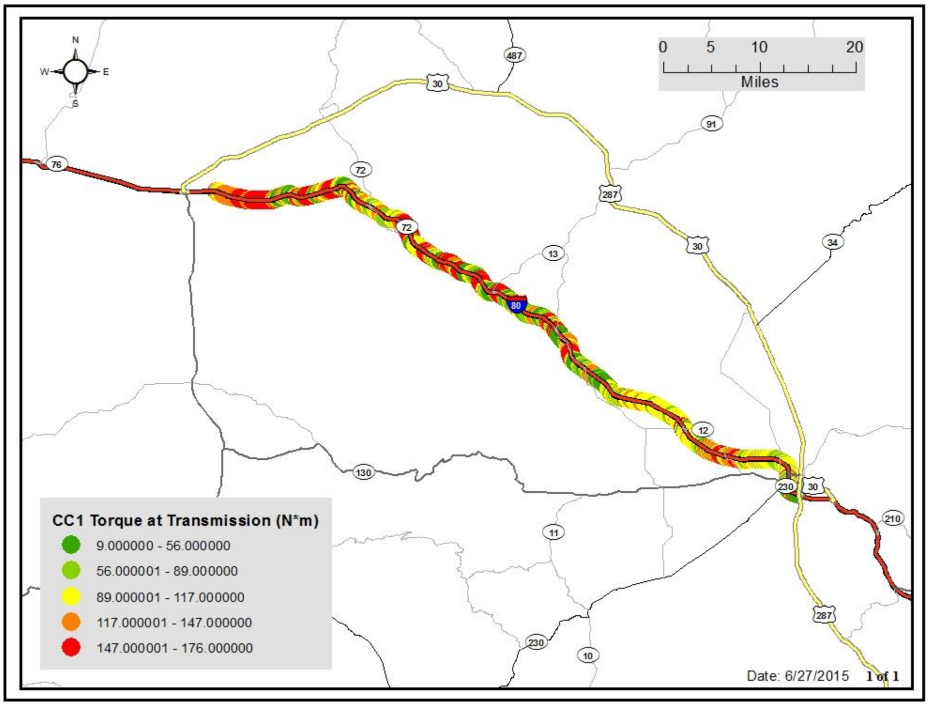


Figure E.4 CC1 Torque at Transmission Data

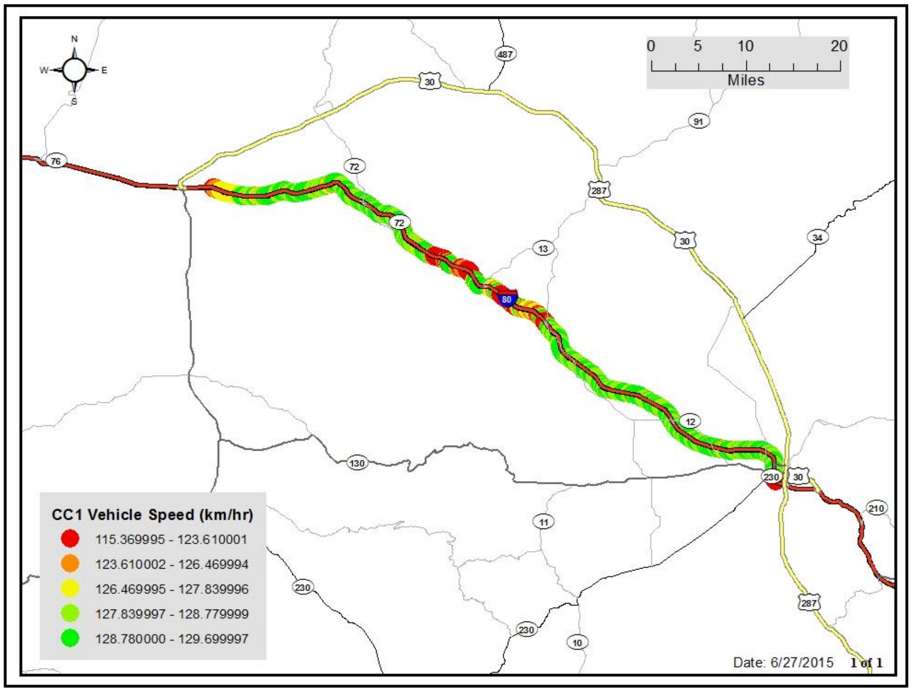


Figure E.5 CC1 Vehicle Speed Data

Trip CC2

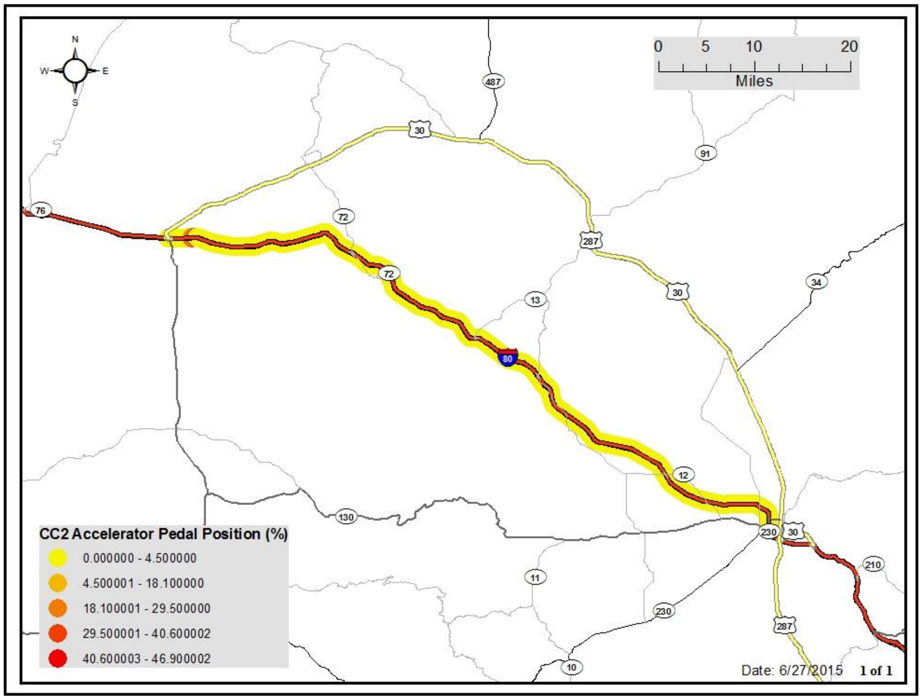


Figure E.6 CC2 Accelerator Pedal Position Data

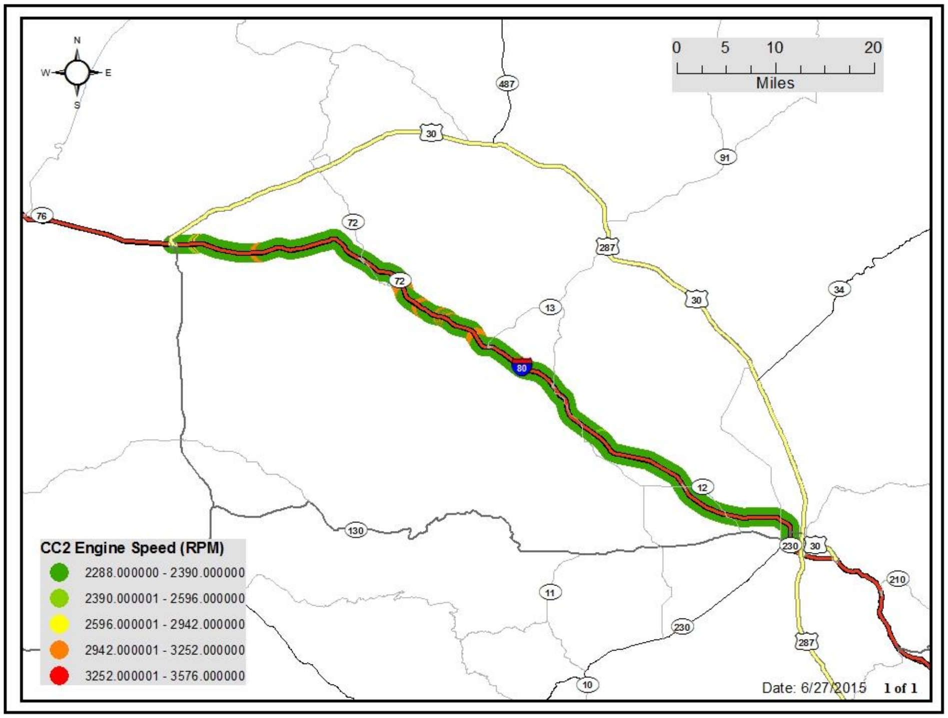


Figure E.7 CC2 Engine Speed Data

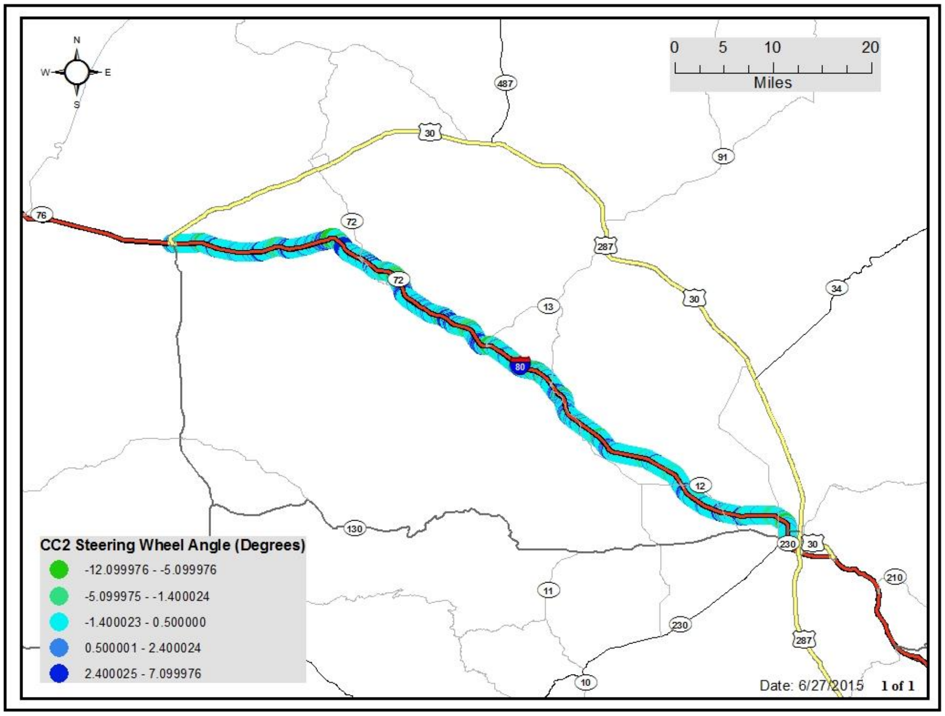


Figure E.8 CC2 Steering Wheel Angle Data

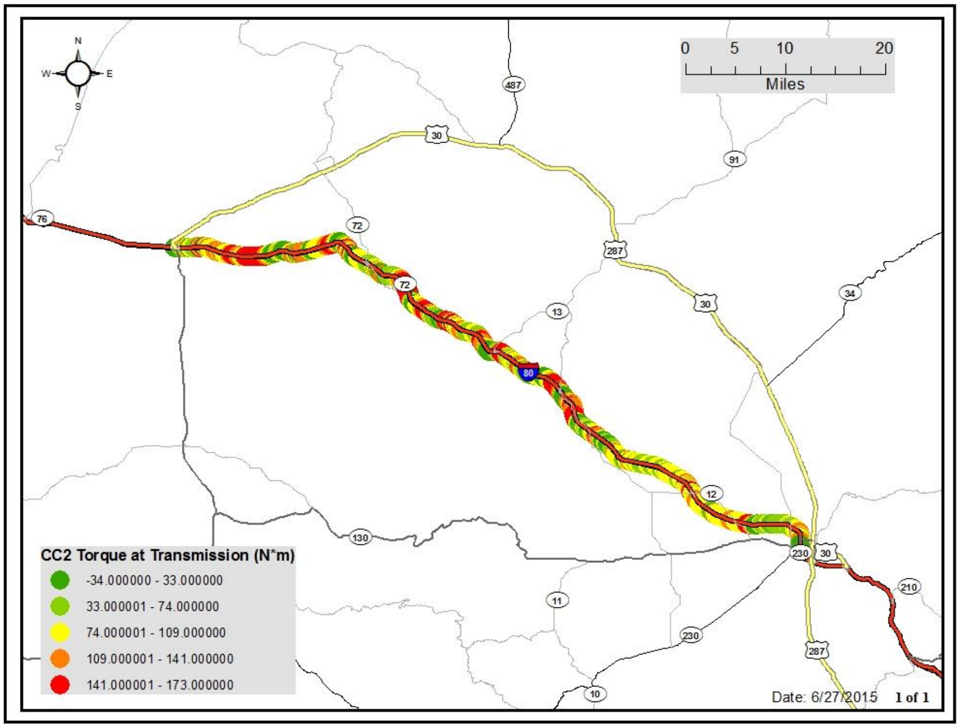


Figure E.9 CC2 Torque at Transmission Data

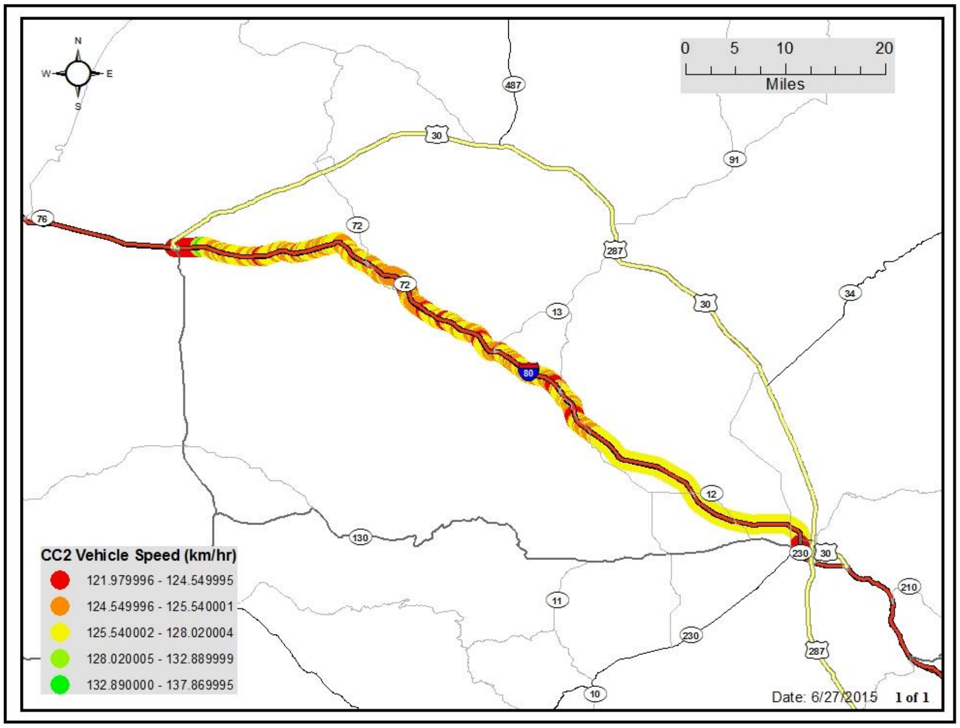


Figure E.10 CC2 Vehicle Speed Data

Trip CC3

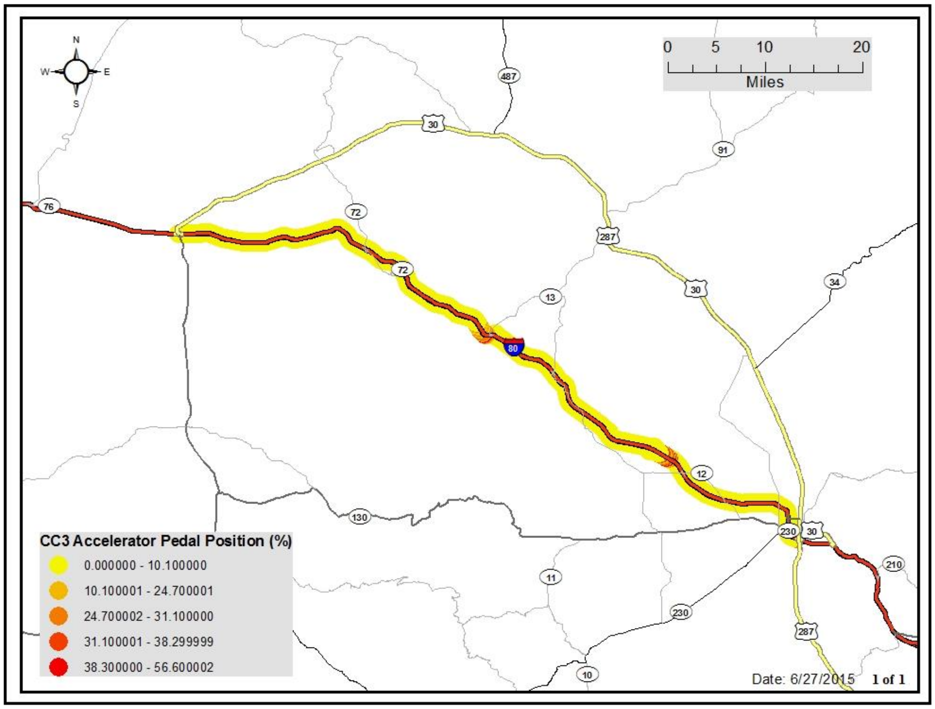


Figure E.11 CC3 Accelerator Pedal Position Data

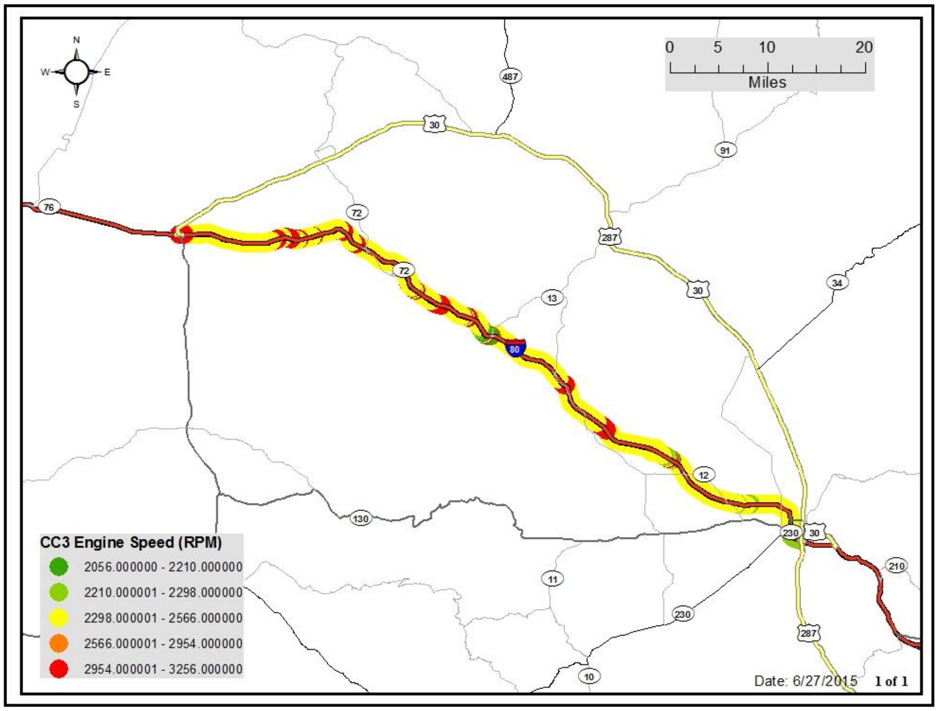


Figure E.12 CC3 Engine Speed Data

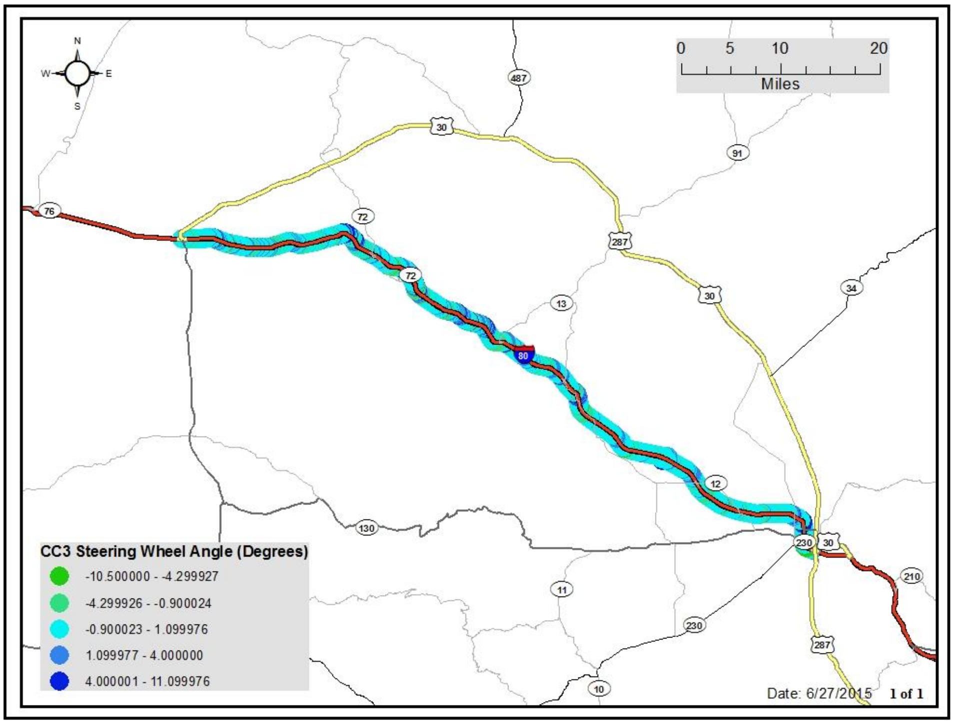


Figure E.13 CC3 Steering Wheel Angle Data

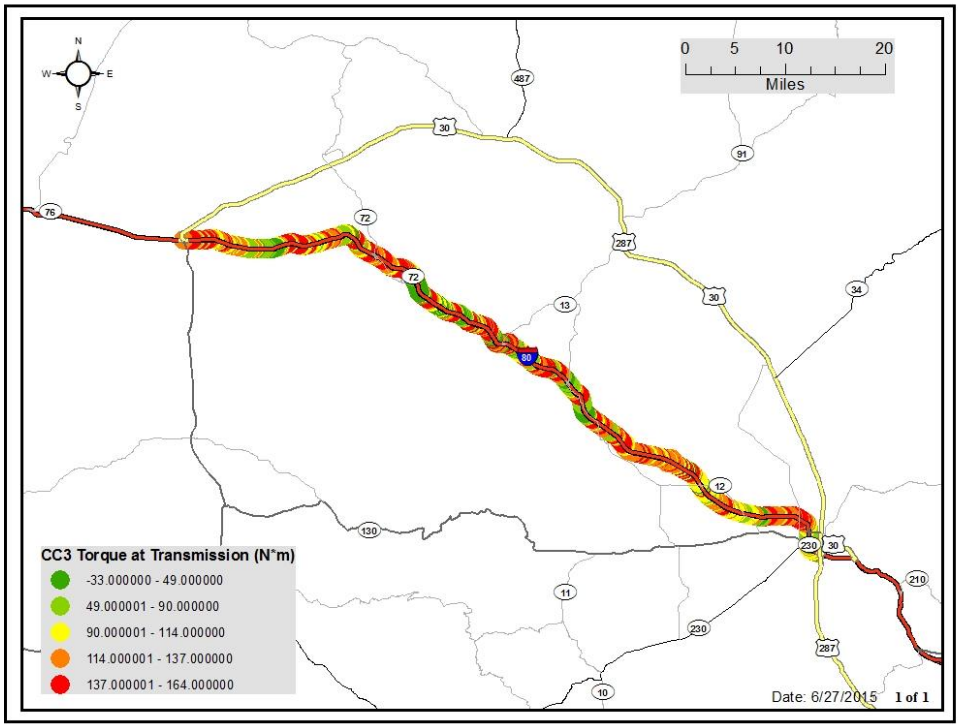


Figure E.14 CC3 Torque at Transmission Data

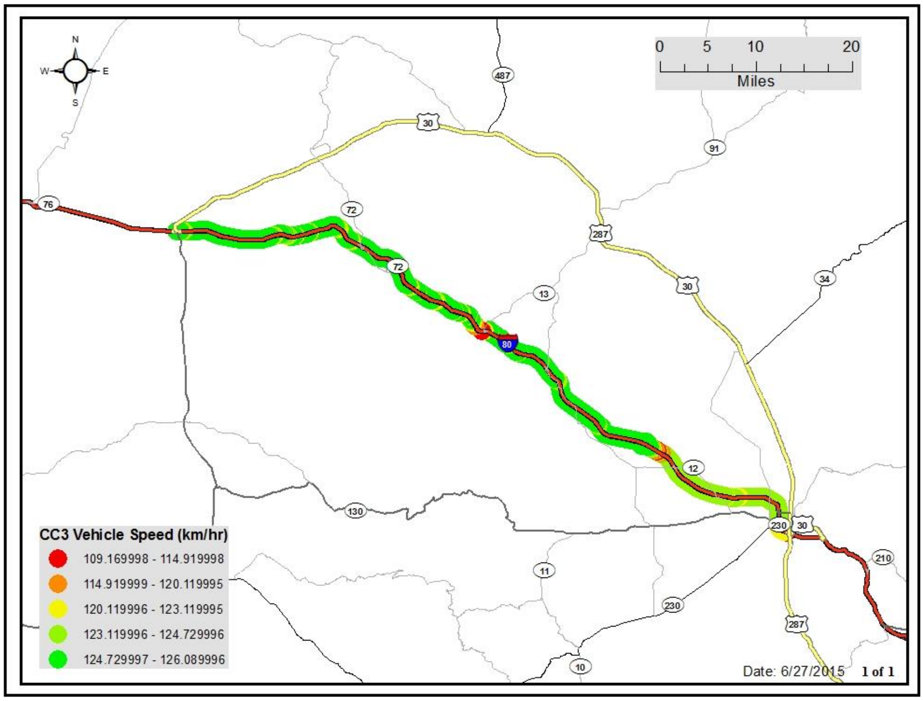


Figure E.15 CC3 Vehicle Speed Data

Trip CC4

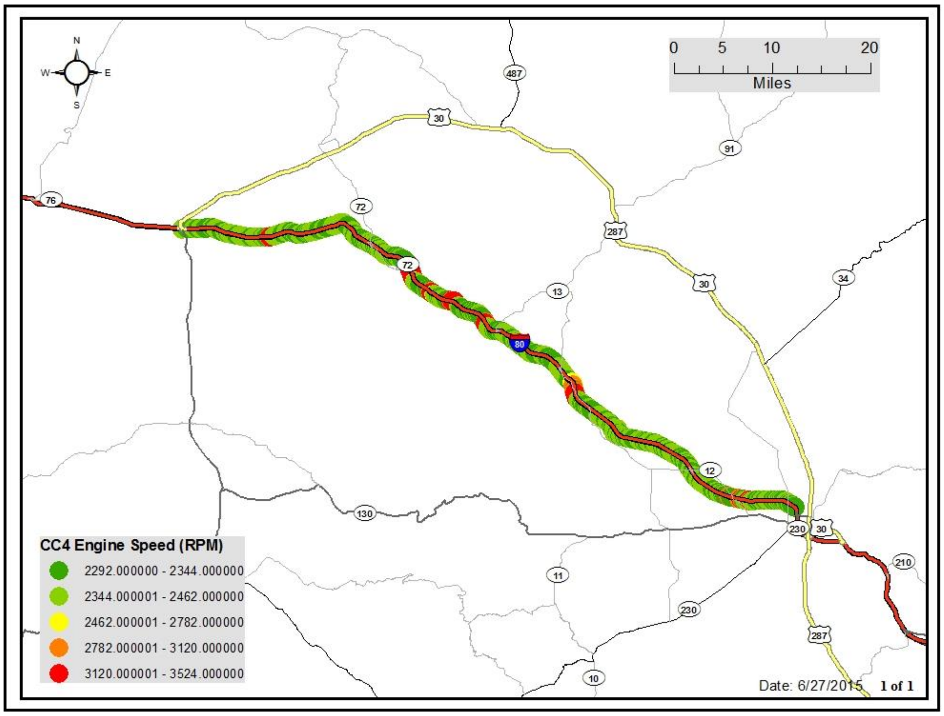


Figure E.16 CC4 Engine Speed Data

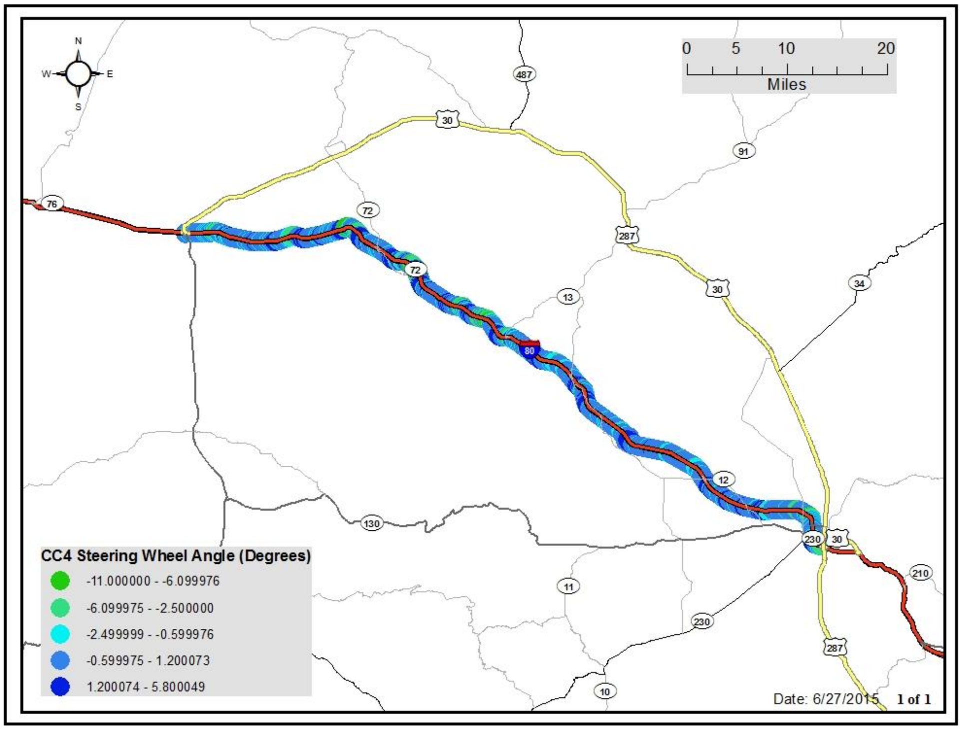


Figure E.17 CC4 Steering Wheel Angle Data

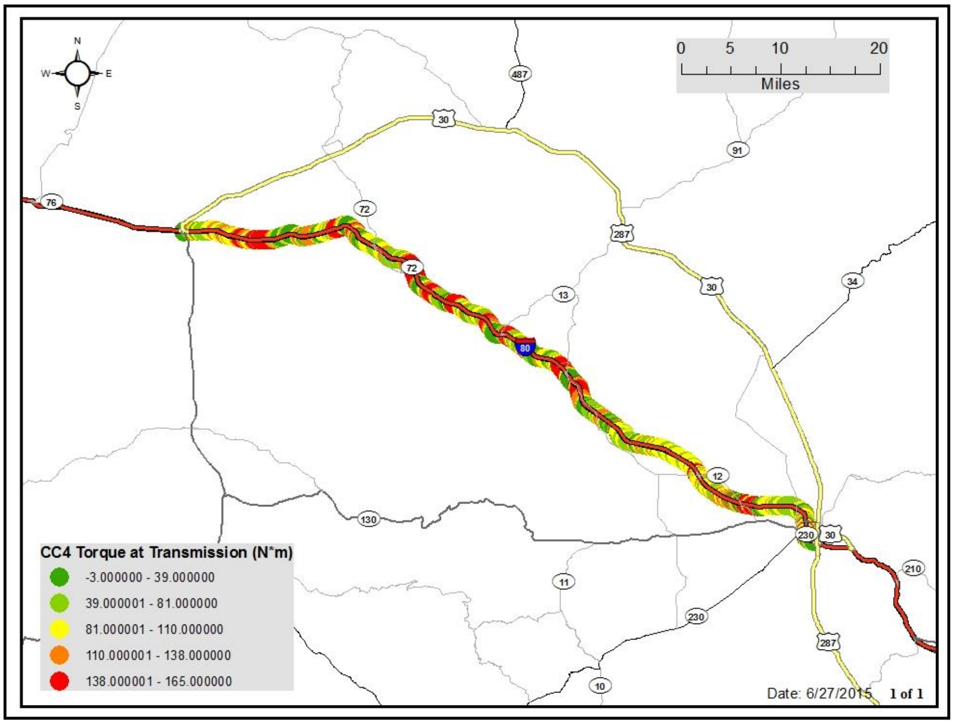


Figure E.18 CC4 Torque at Transmission Data

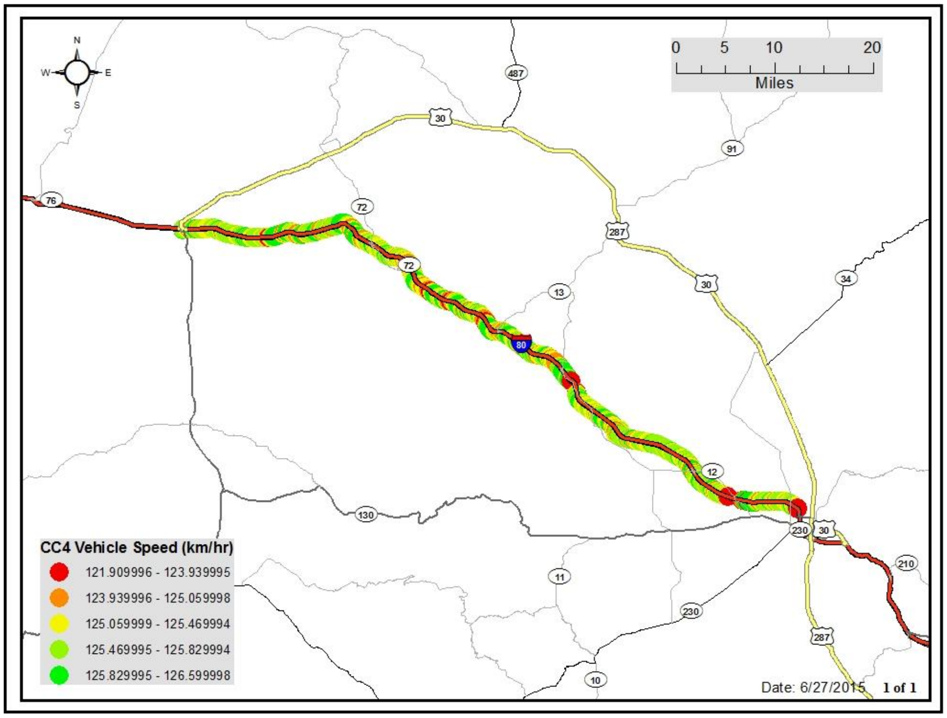


Figure E.19 CC4 Vehicle Speed Data

Trip CC5

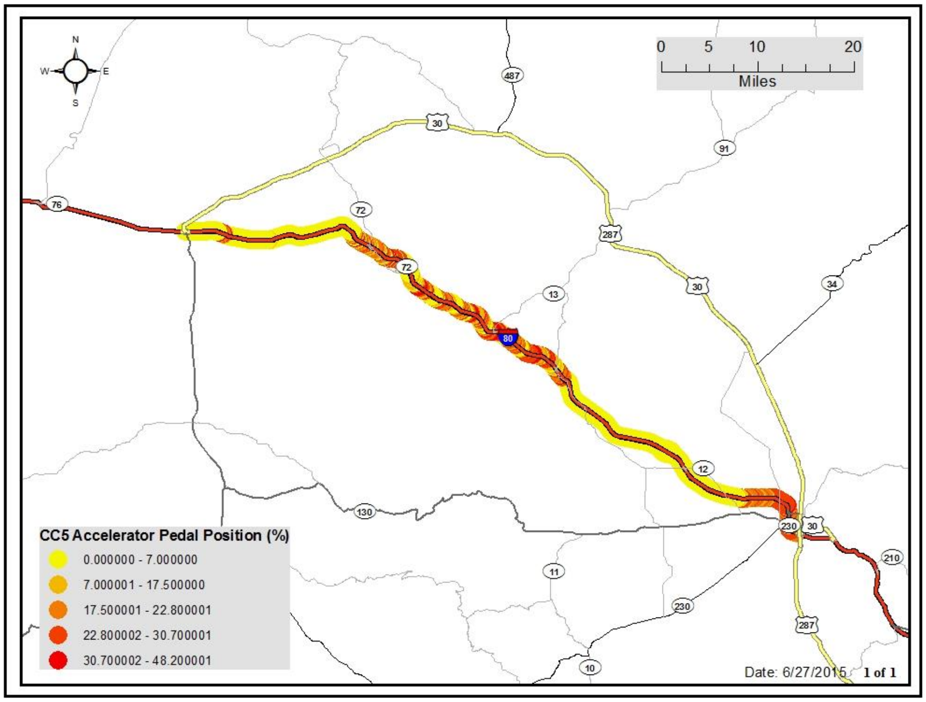


Figure E.20 CC5 Accelerator Pedal Position Data

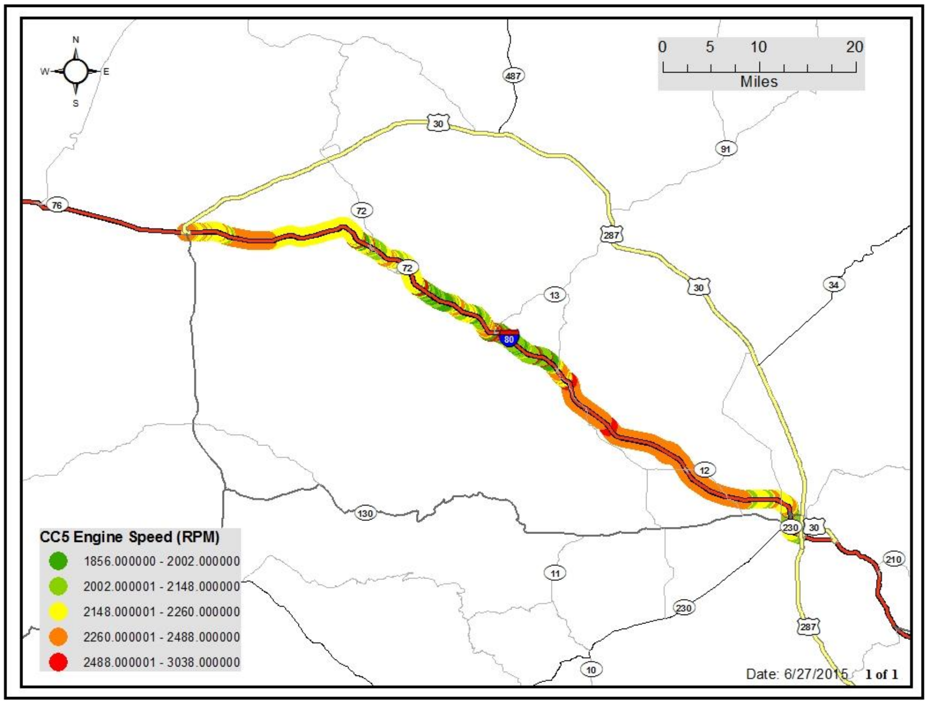


Figure E.21 CC5 Engine Speed Data

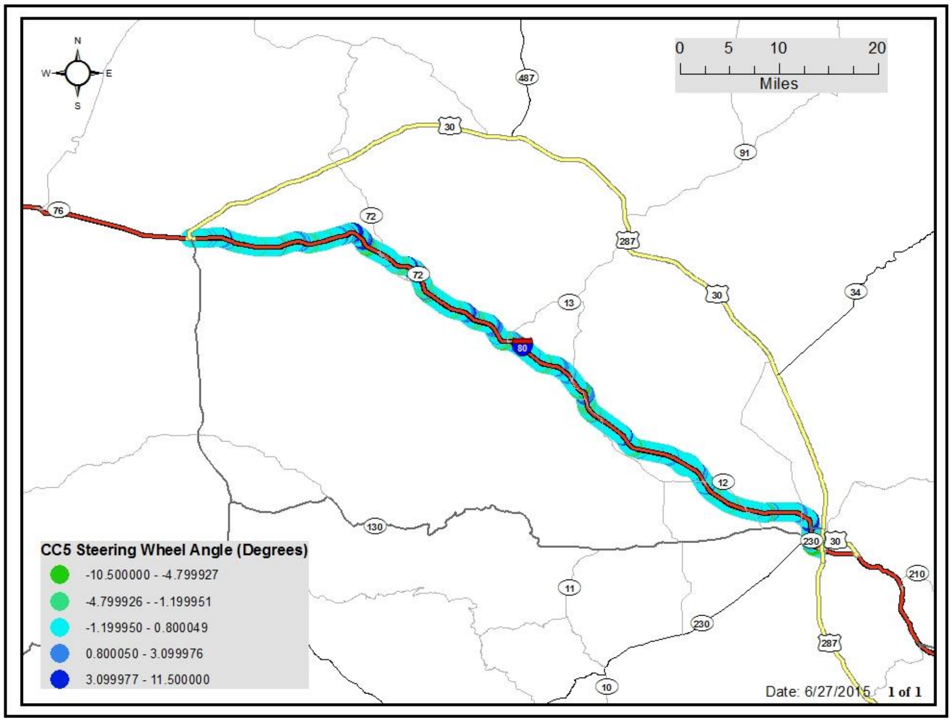


Figure E.22 CC5 Steering Wheel Angle Data

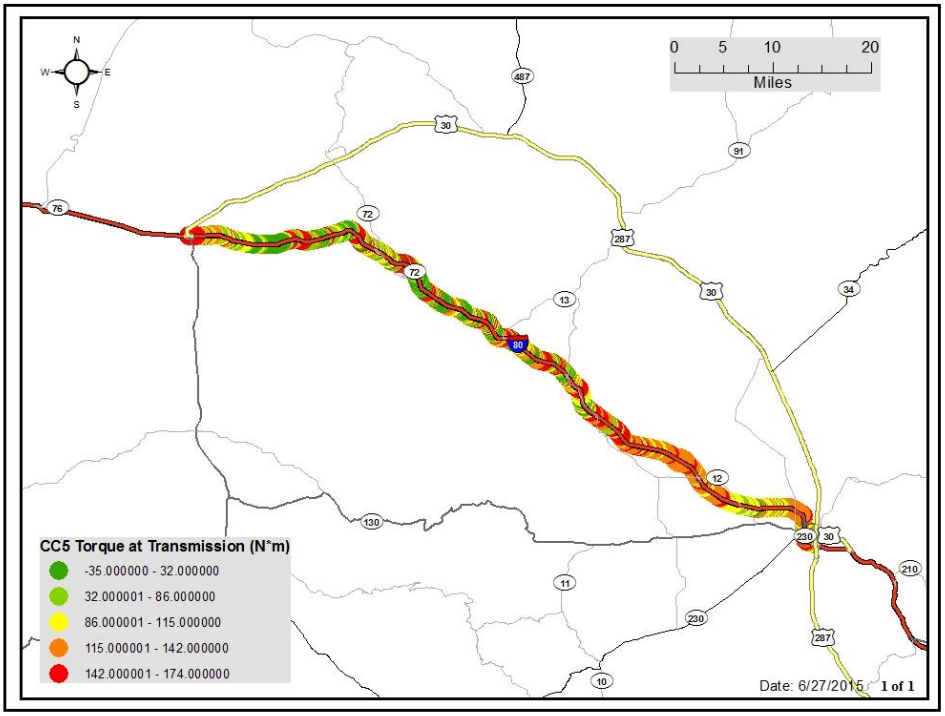


Figure E.23 CC5 Torque at Transmission Data

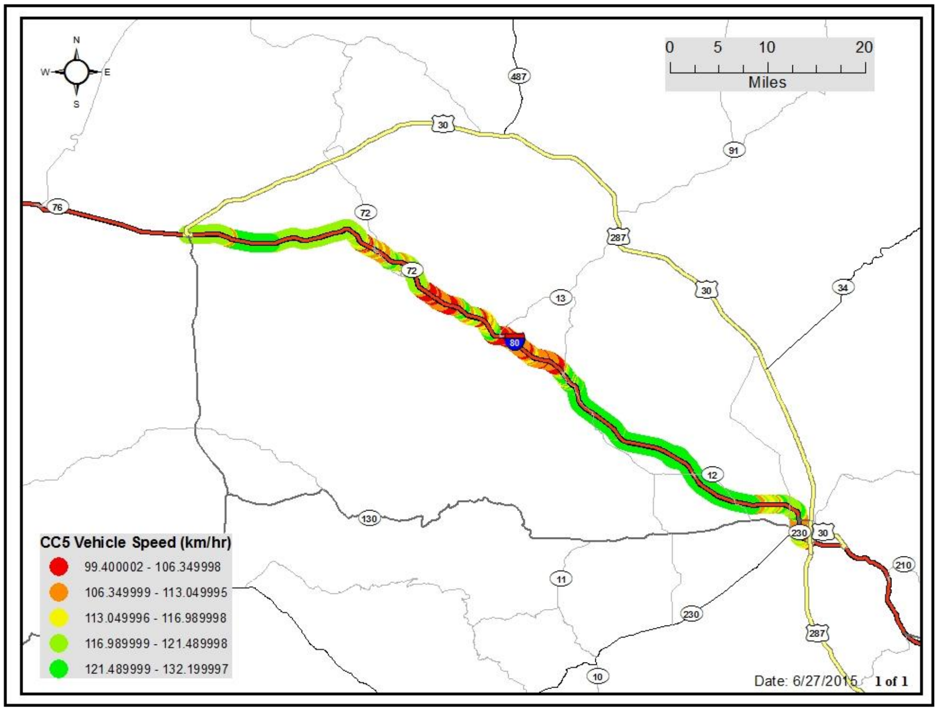


Figure E.24 CC5 Vehicle Speed Data

Trip CC6

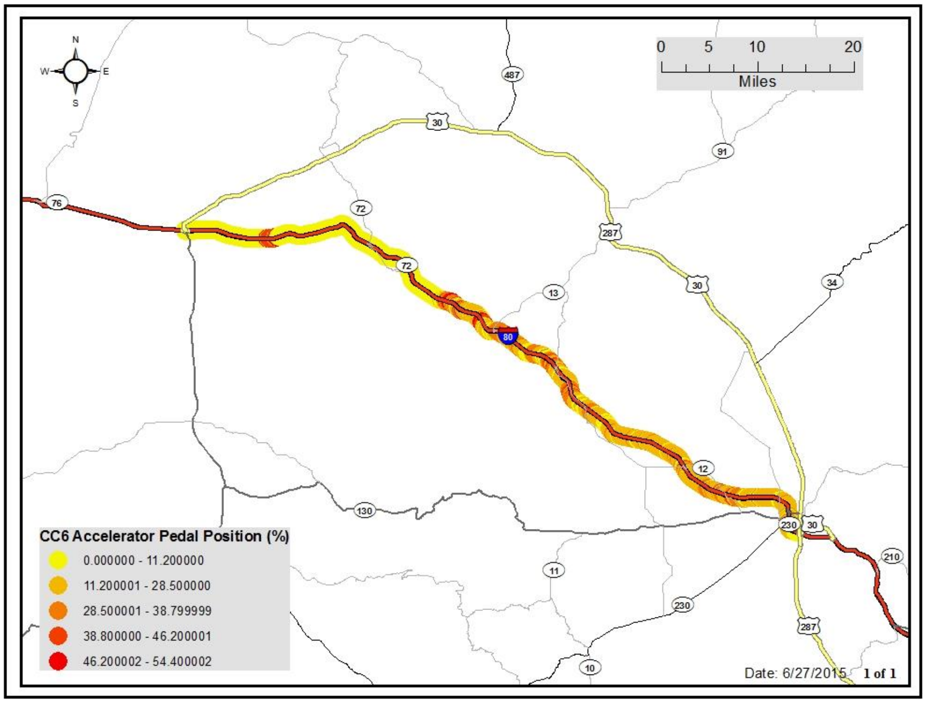


Figure E.25 CC6 Accelerator Pedal Position

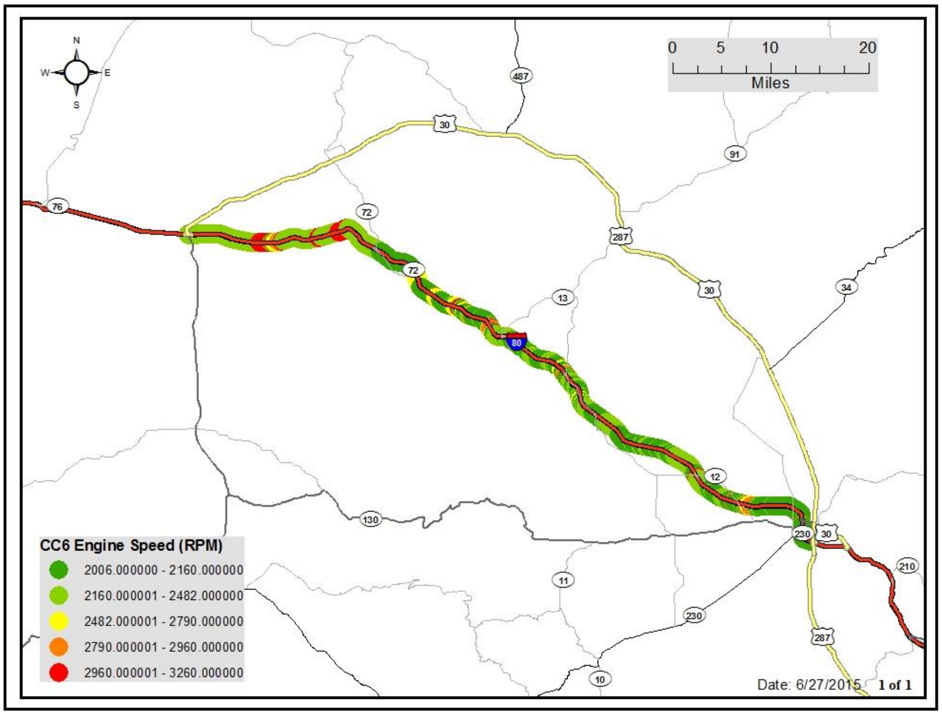


Figure E.26 CC6 Engine Speed Data

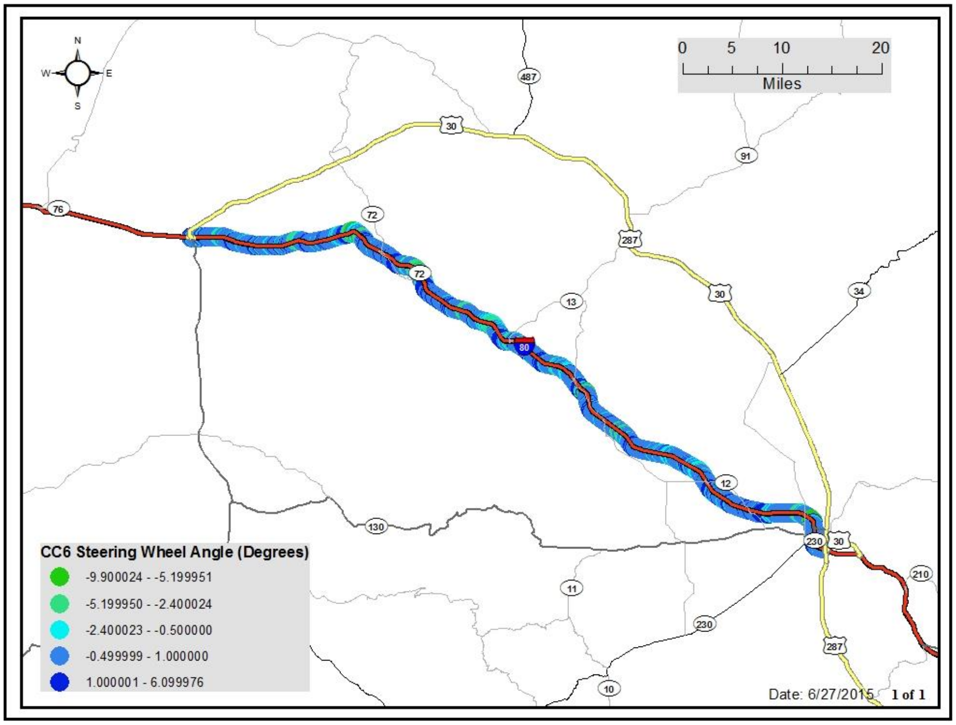


Figure E.27 CC6 Steering Wheel Angle Data

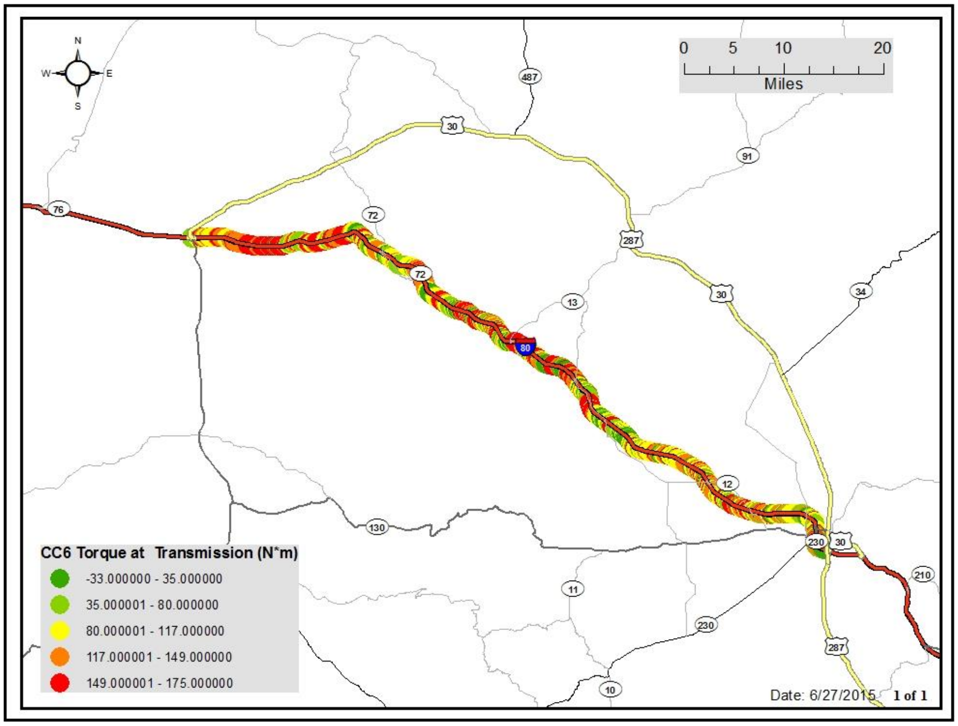


Figure E.28 CC6 Torque at Transmission Data

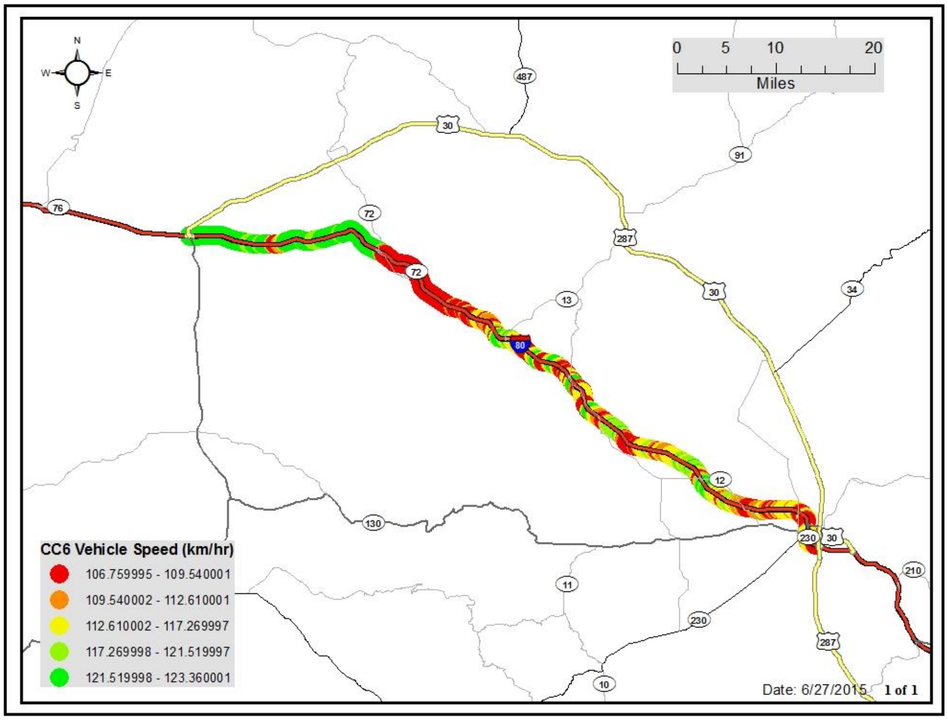


Figure E.29 CC6 Vehicle Speed Data

Trip CC7

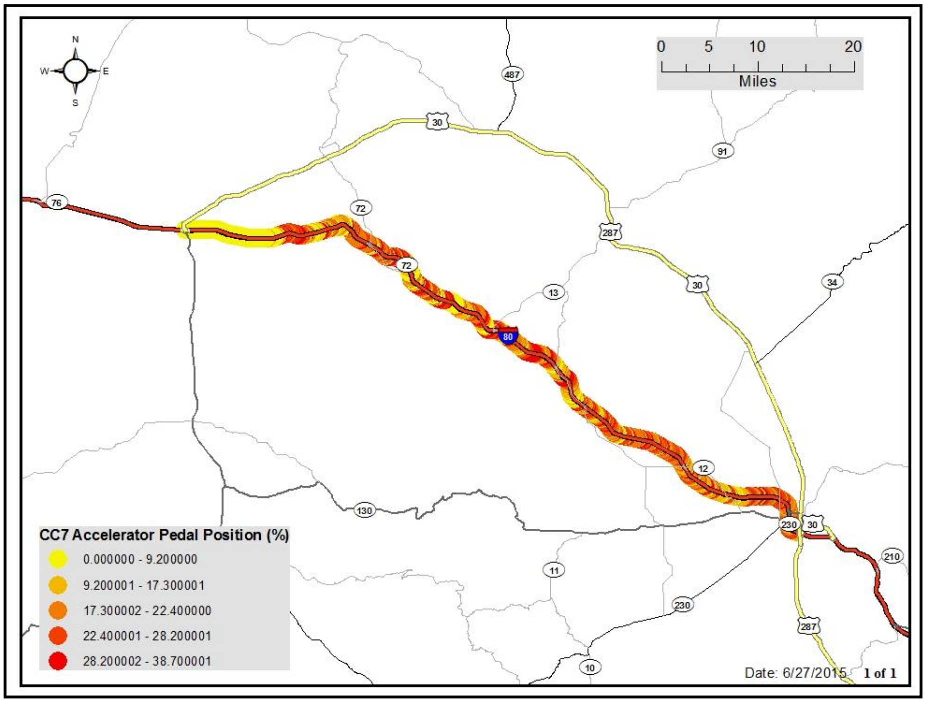


Figure E.30 CC7 Accelerator Pedal Position Data

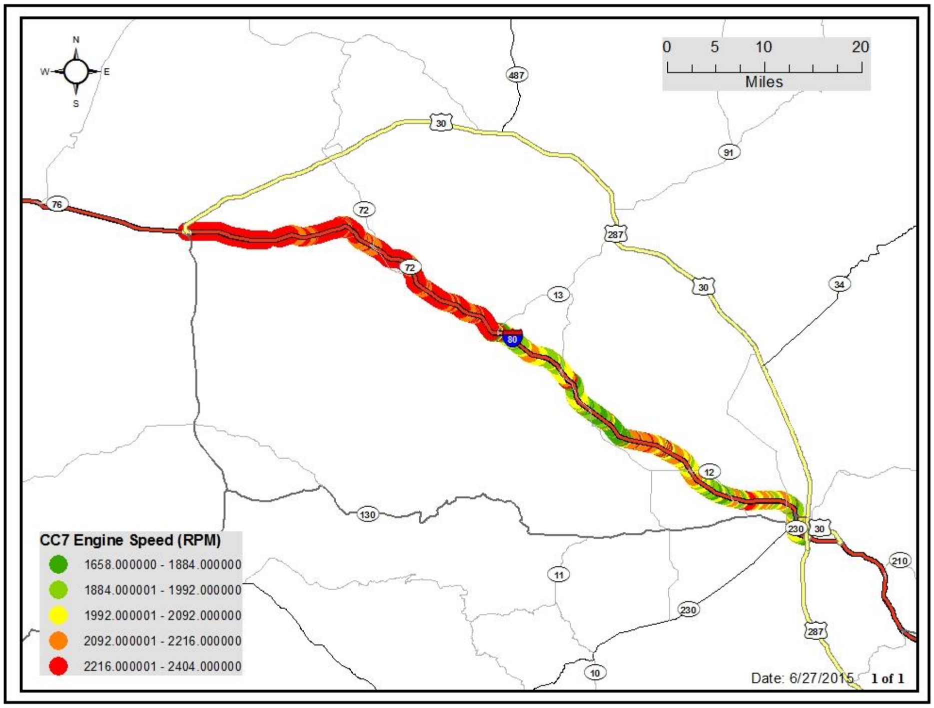


Figure E.31 CC7 Engine Speed Data

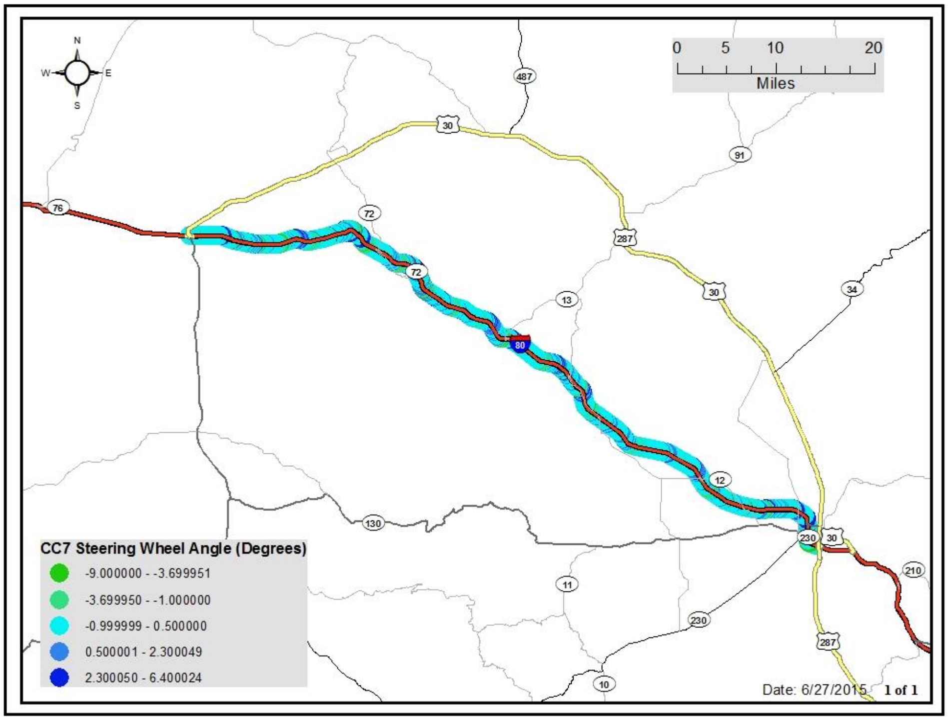


Figure E.32 CC7 Steering Wheel Angle Data

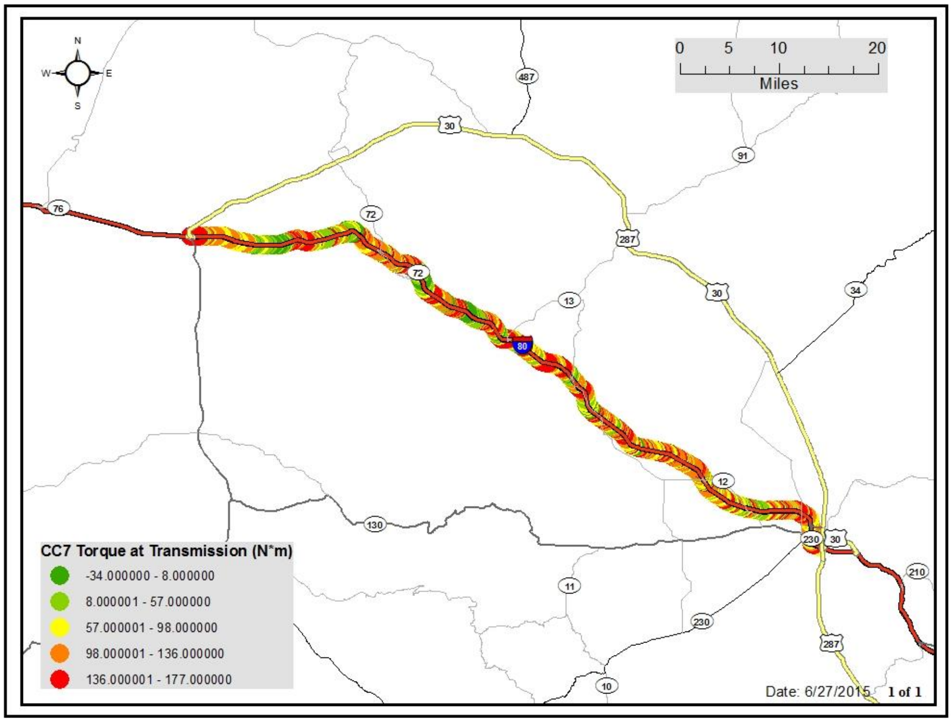


Figure E.33 CC7 Torque at Transmission Data

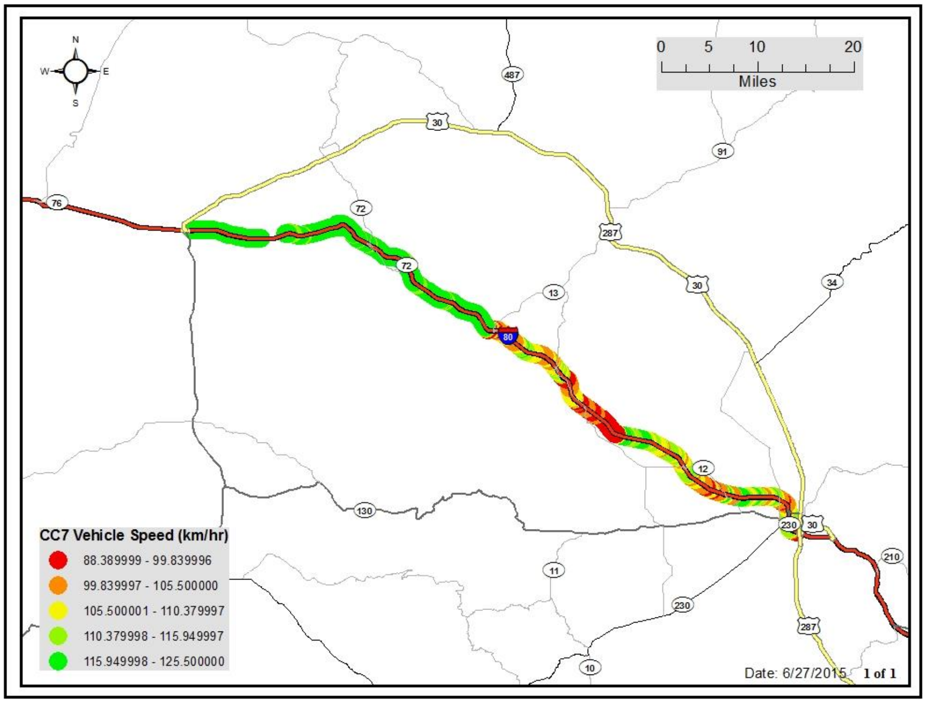


Figure E.34 CC7 Vehicle Speed Data

Trip CC8

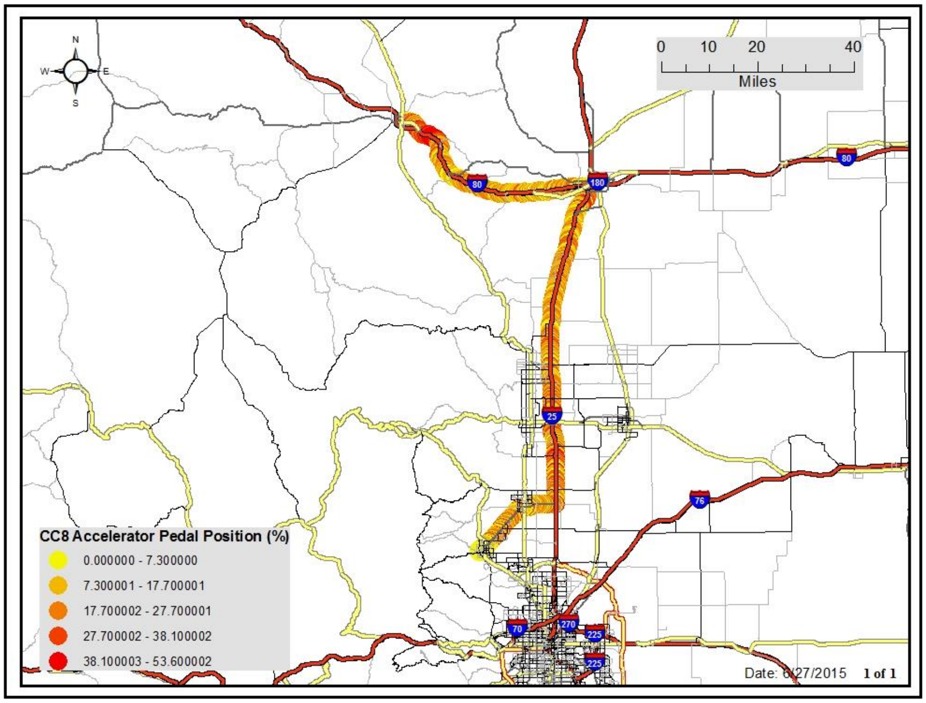


Figure E.35 CC8 Accelerator Pedal Position

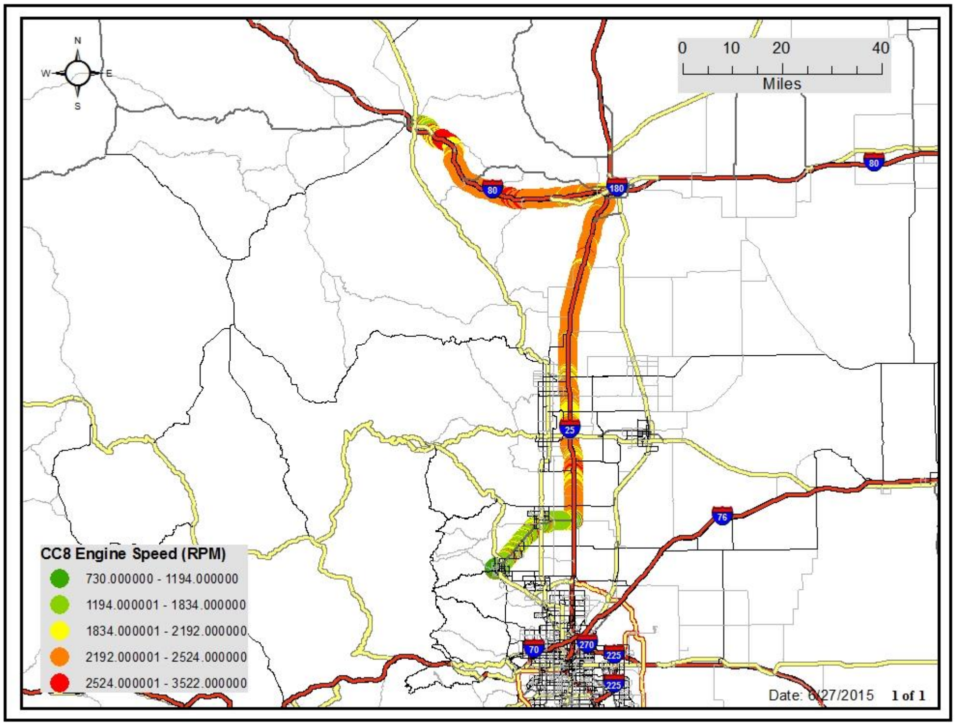


Figure E.36 CC8 Engine Speed Data

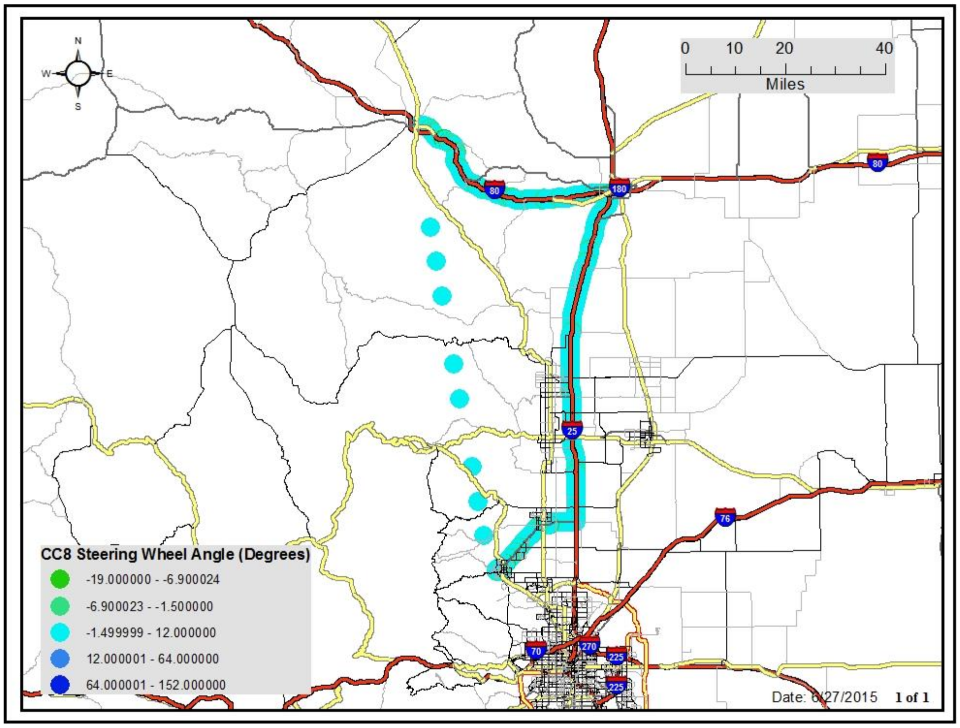


Figure E.37 CC8 Steering Wheel Angle Data

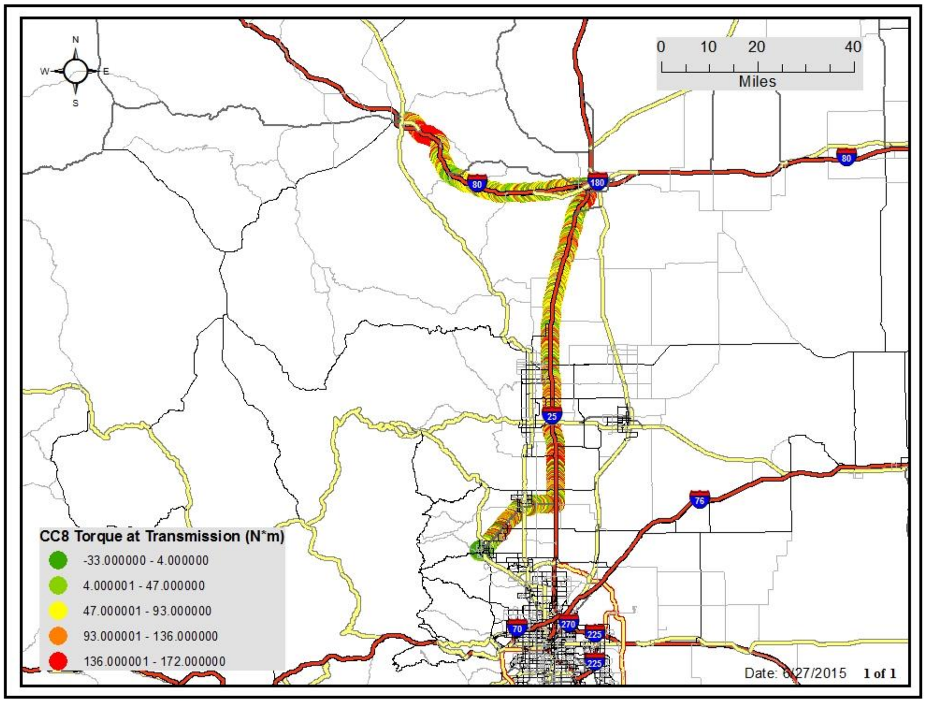


Figure E.38 CC8 Torque at Transmission Data

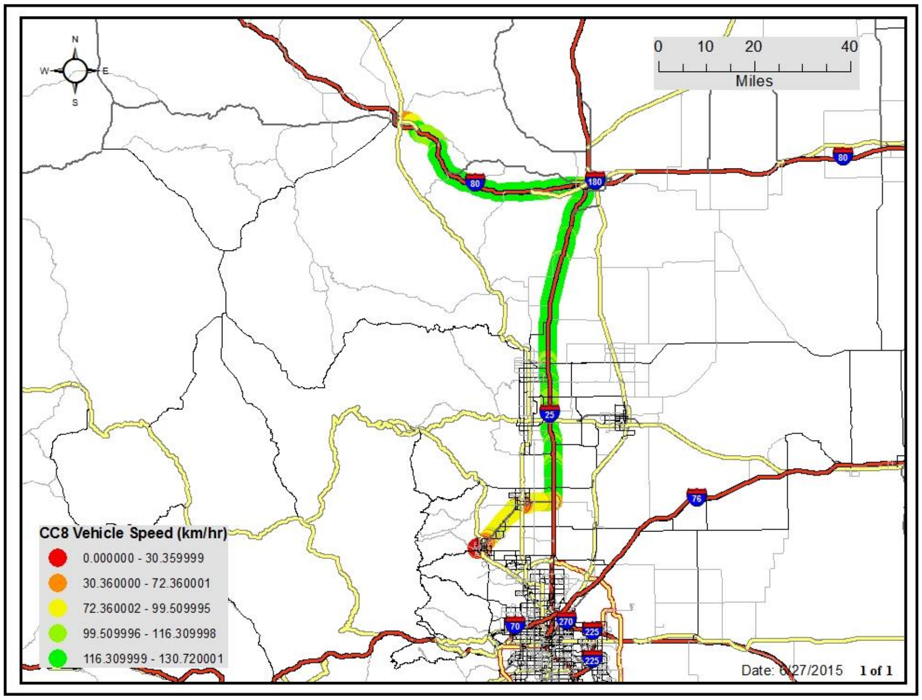


Figure E.39 CC8 Vehicle Speed Data

Trip CC9

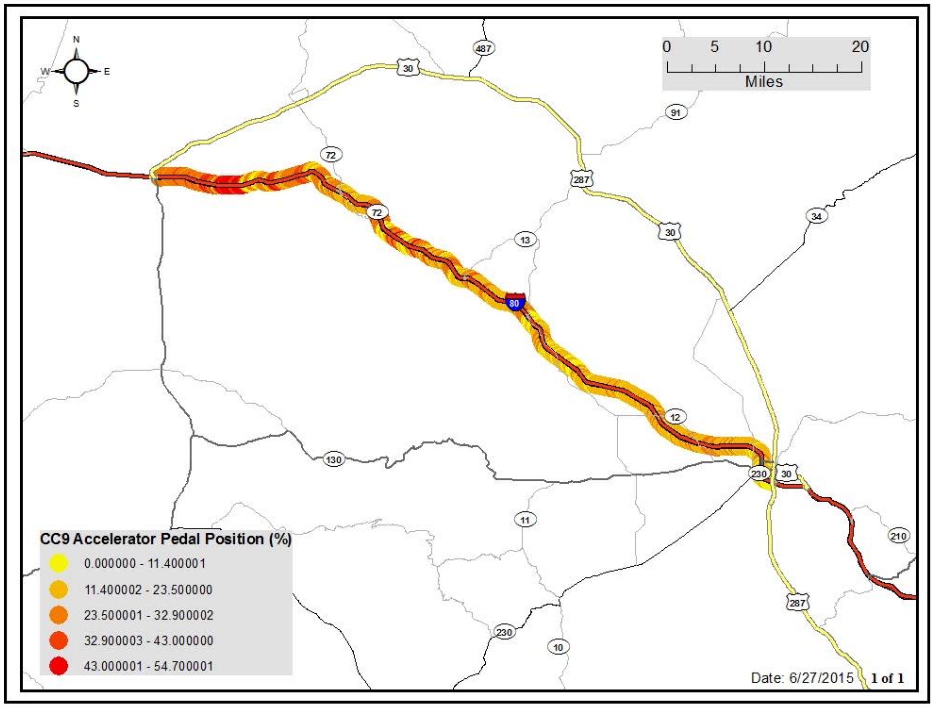


Figure E.40 CC9 Accelerator Pedal Position Data

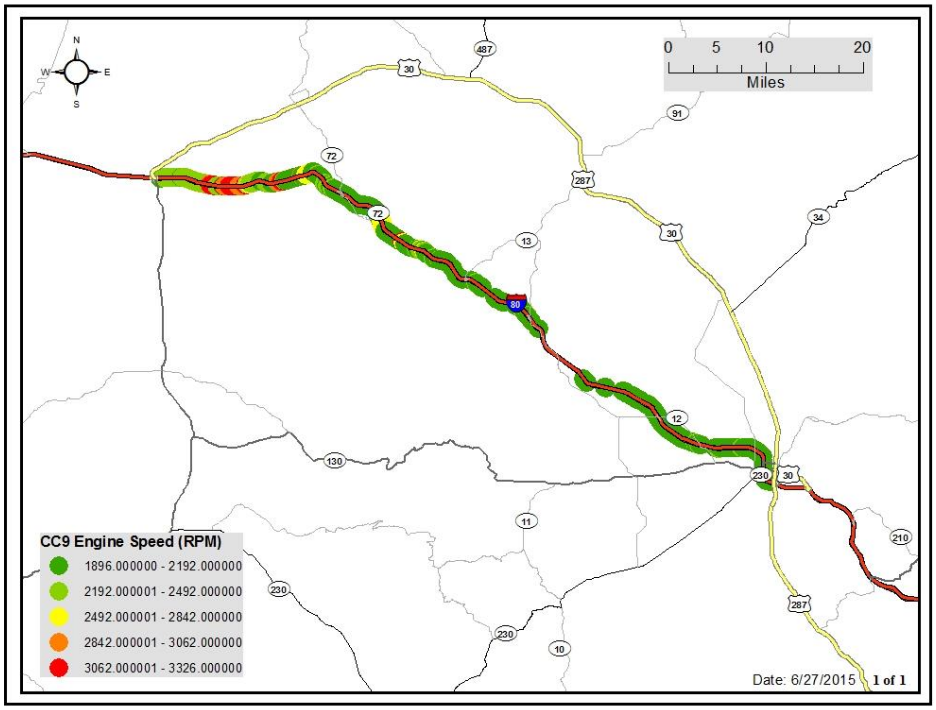


Figure E.41 CC9 Engine Speed Data

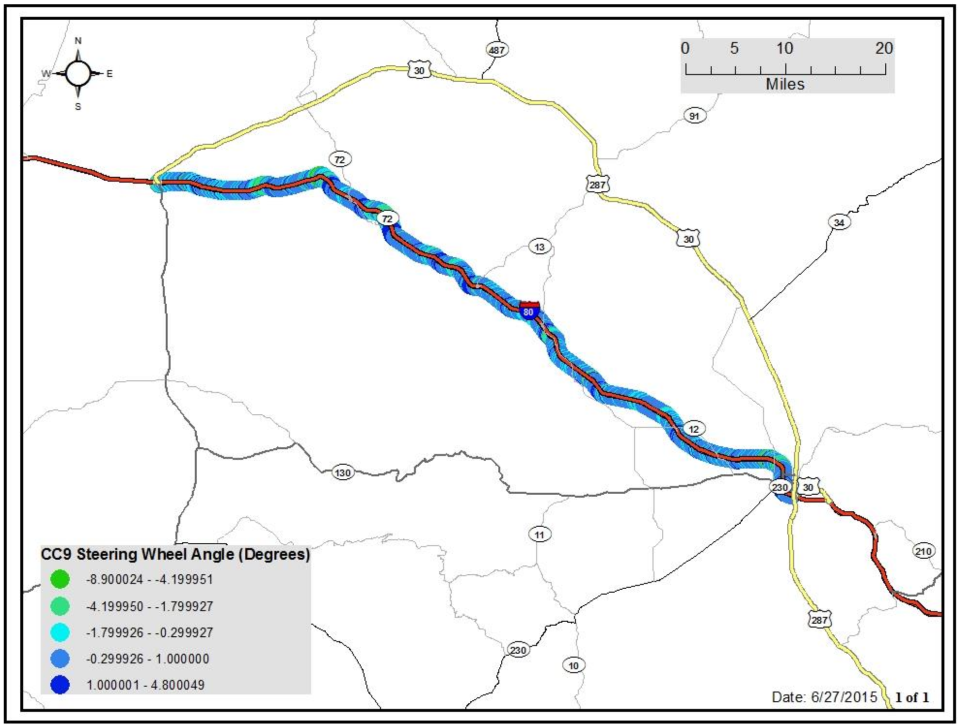


Figure E.42 CC9 Steering Wheel Angle Data

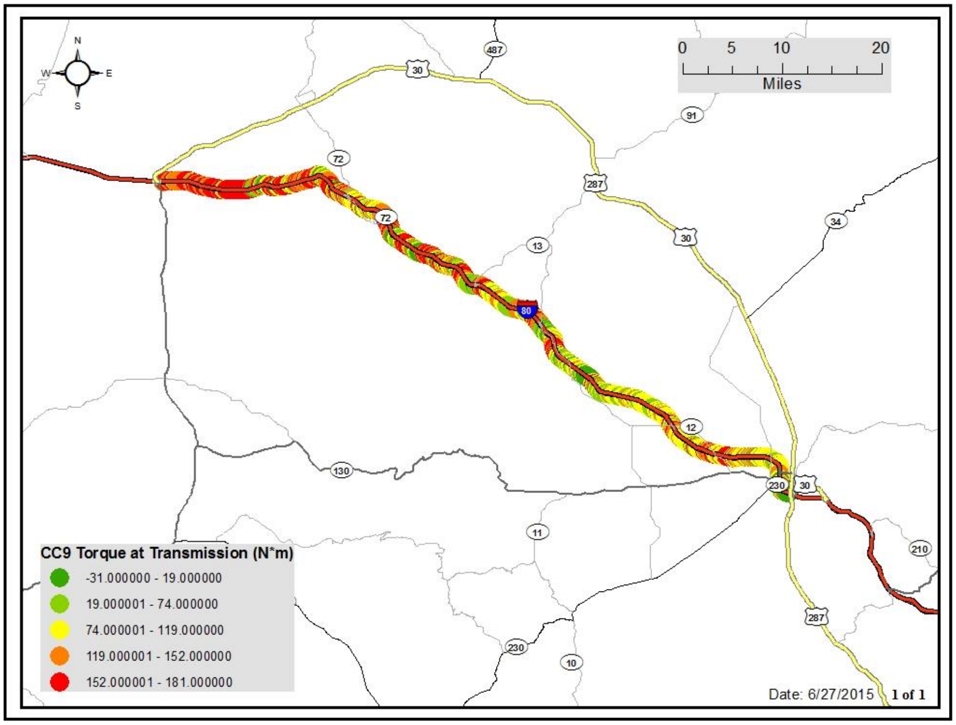


Figure E.43 CC9 Torque at Transmission Data

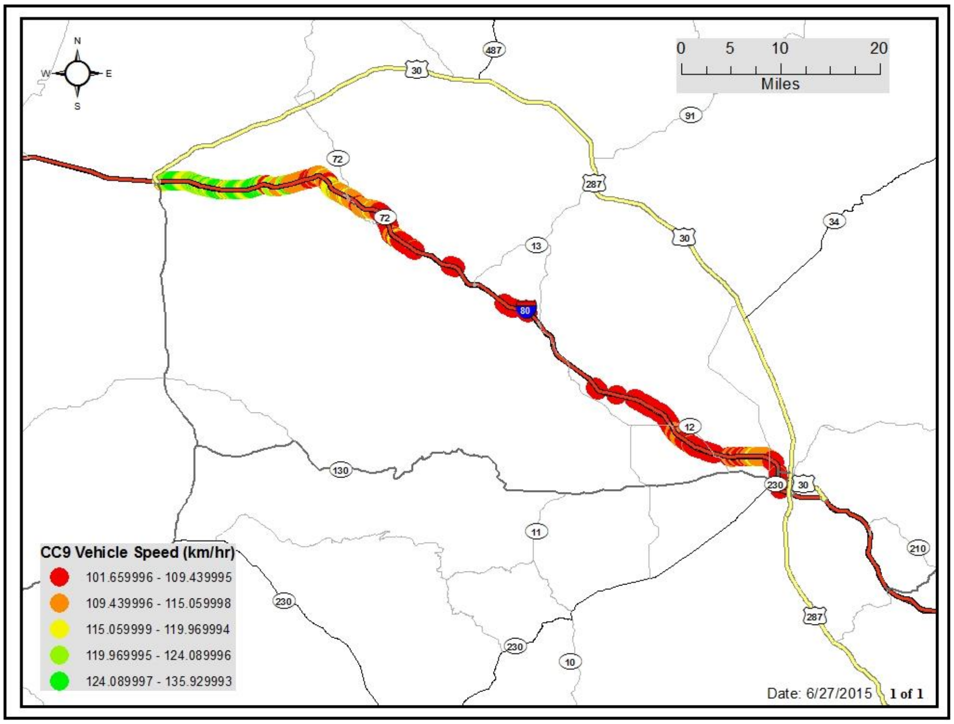


Figure E.44 CC9 Vehicle Speed Data

Trip CC11

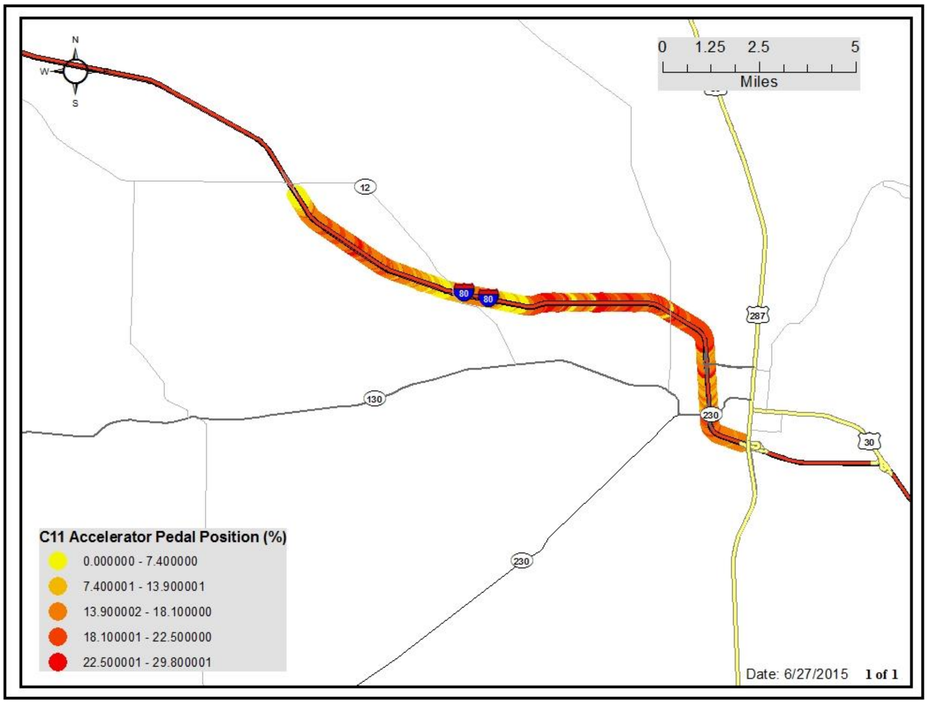


Figure E.45 CC11 Accelerator Pedal Position Data

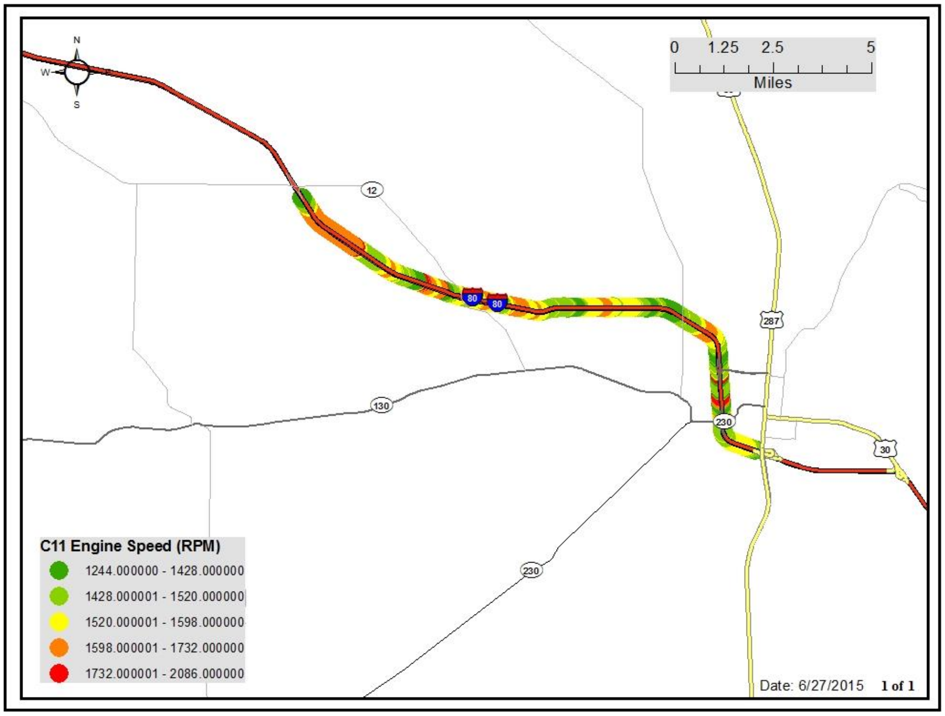


Figure E.46 CC11 Engine Speed Data

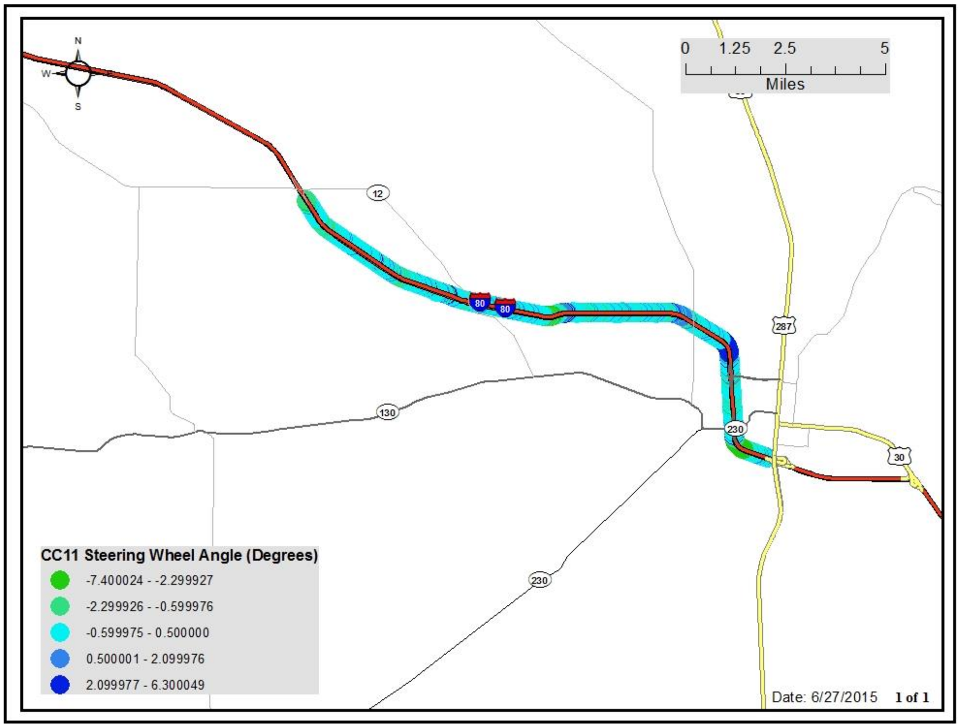


Figure E.47 CC11 Steering Wheel Angle Data

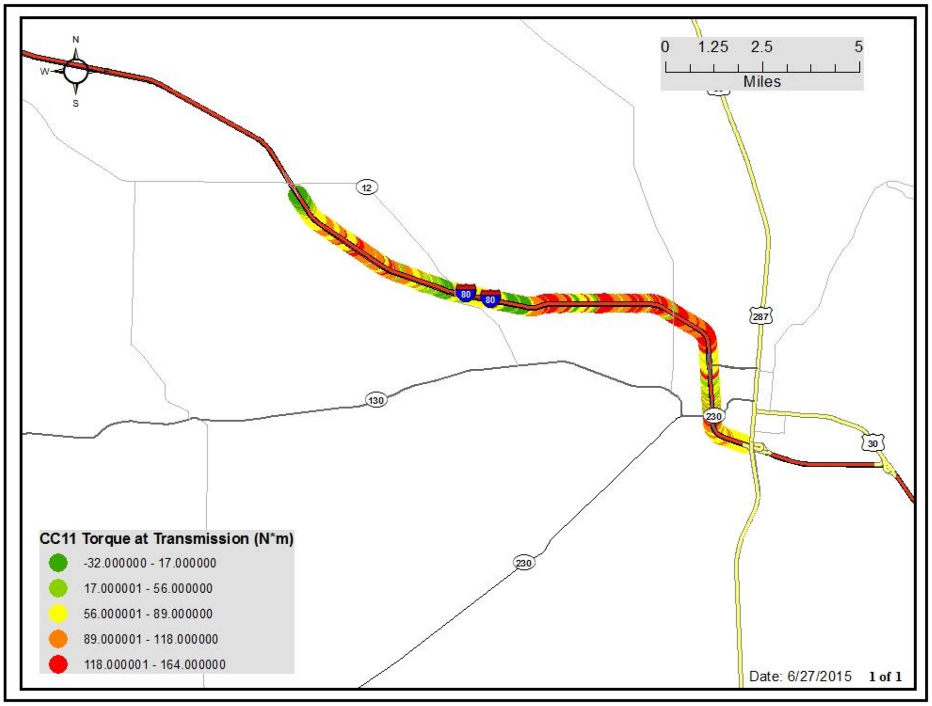


Figure E.48 CC11 Torque at Transmission Data

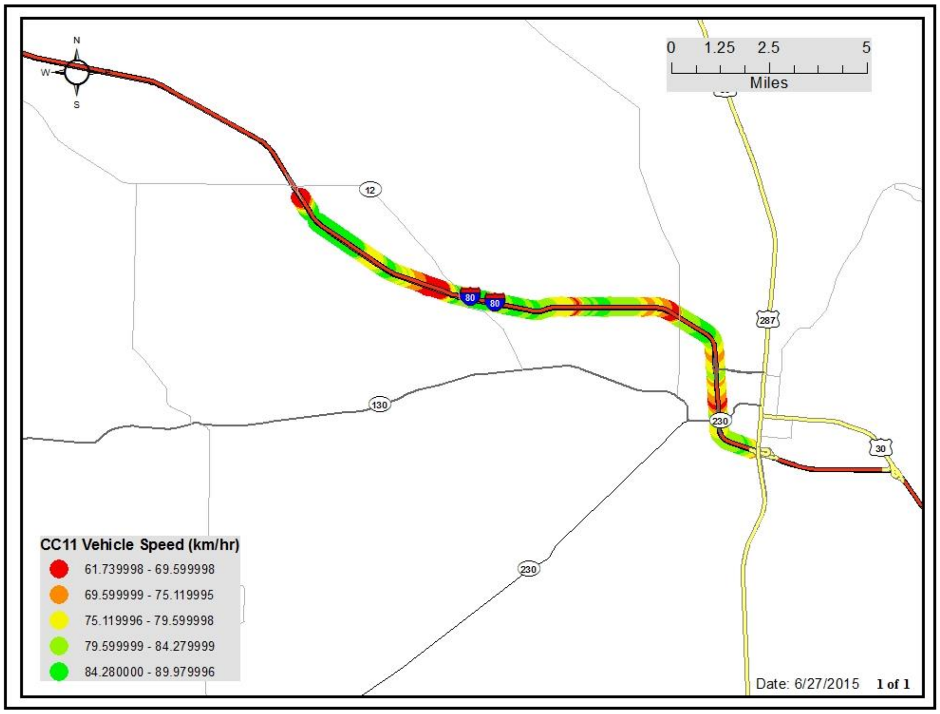


Figure E.49 CC11 Vehicle Speed Data

Trip CC13

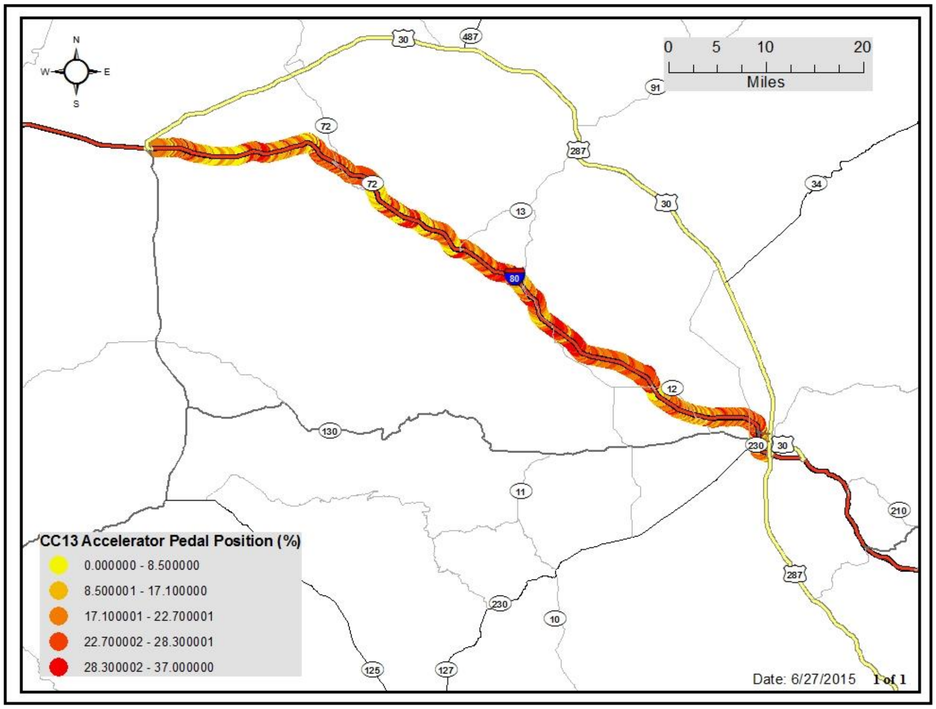


Figure E.50 CC13 Accelerator Pedal Position Data

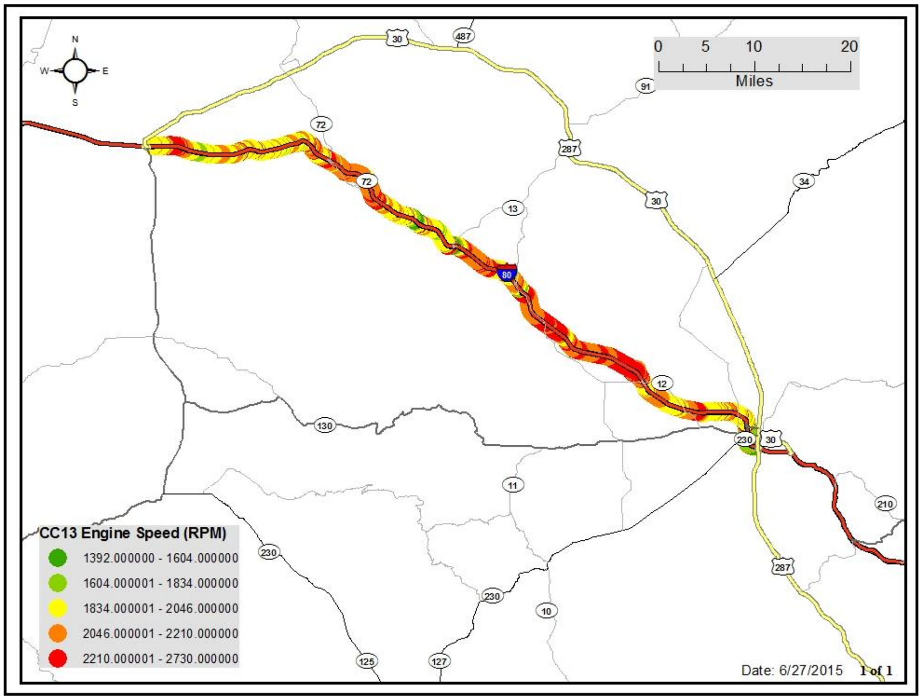


Figure E.51 CC13 Engine Speed Data

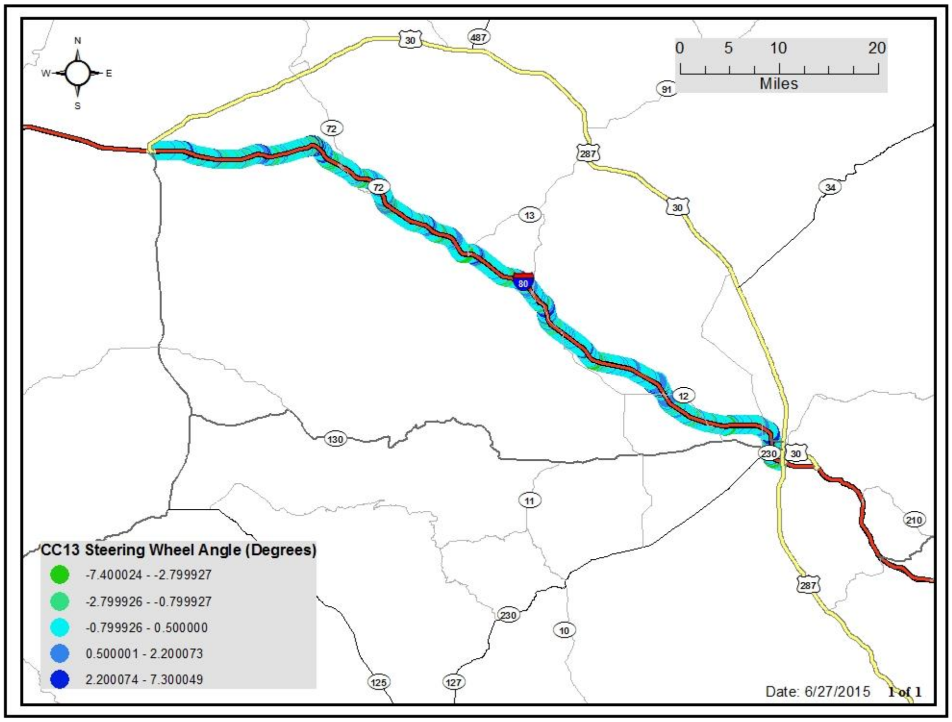


Figure E.52 CC13 Steering Wheel Angle Data

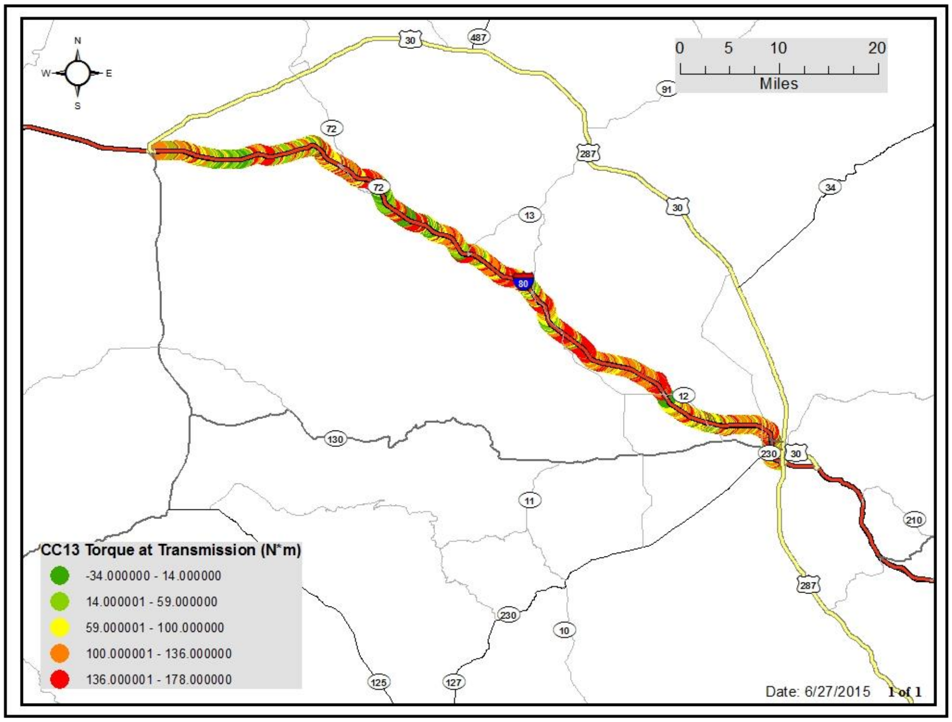


Figure E.53 CC13 Torque at Transmission Data

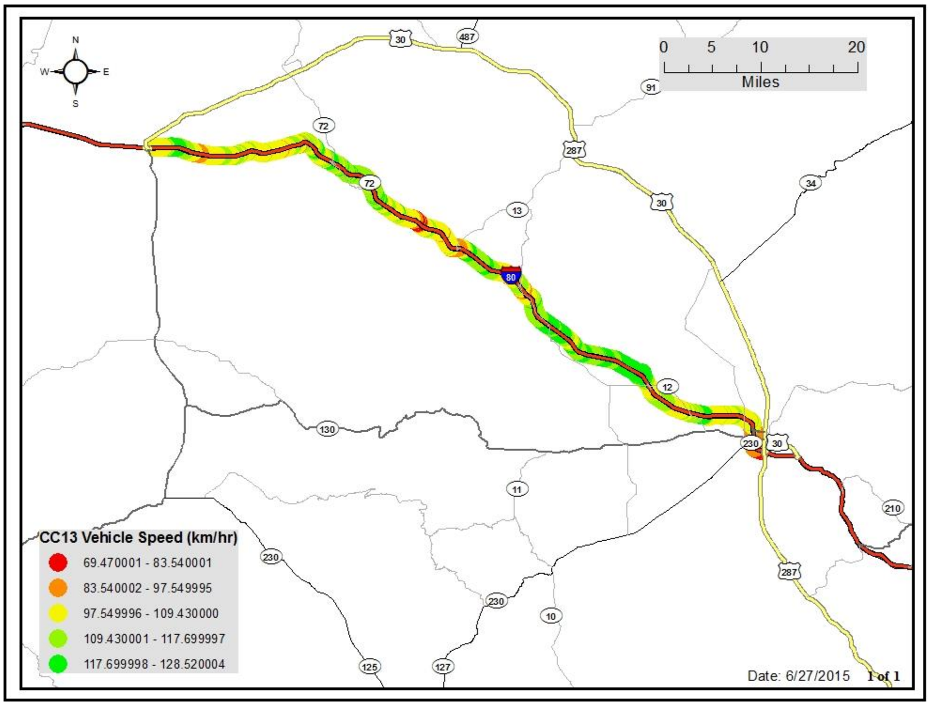


Figure E.54 CC13 Vehicle Speed Data

Trip CC14

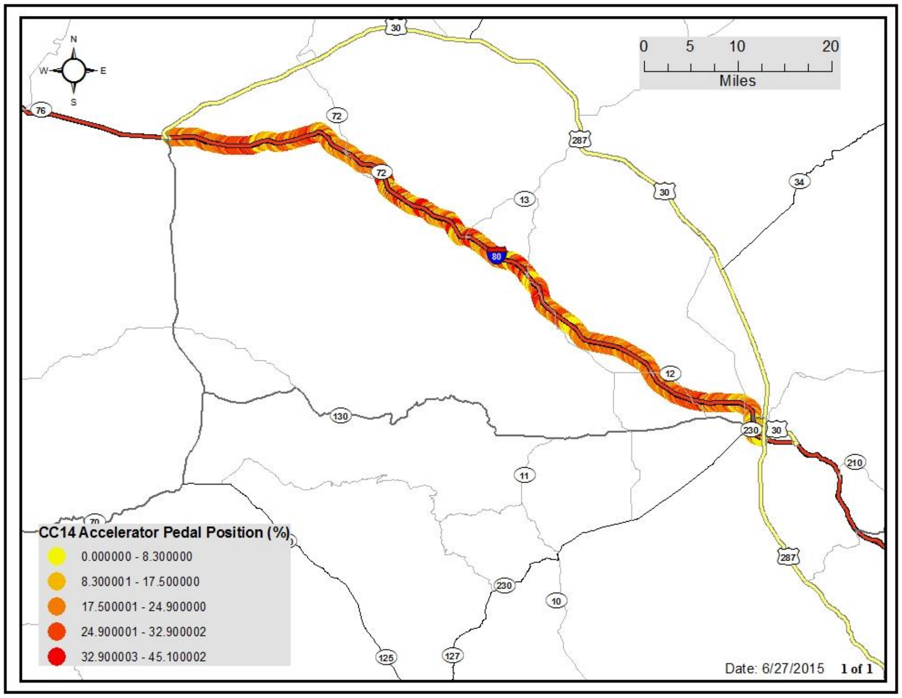


Figure E.55 CC14 Accelerator Pedal Position Data

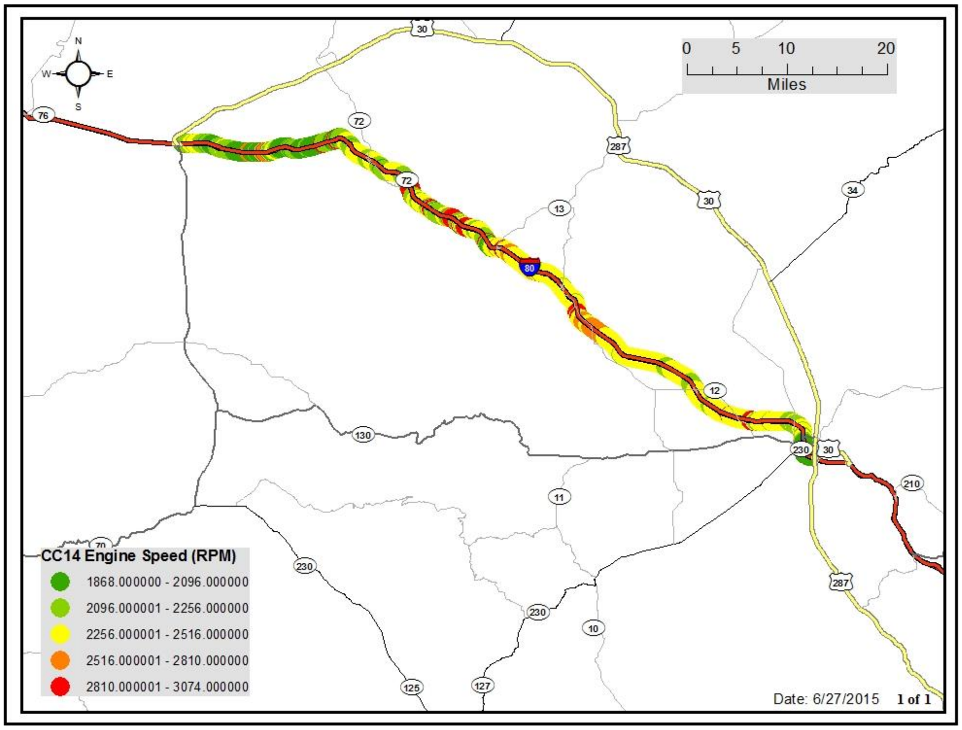


Figure E.56 CC14 Engine Speed Data

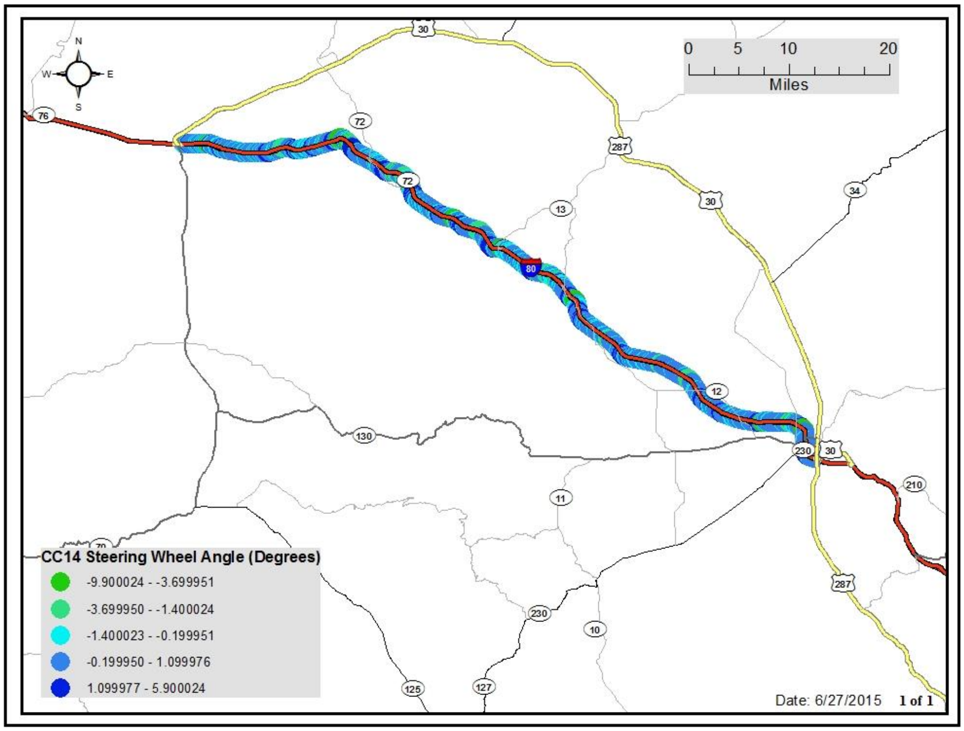


Figure E.57 CC14 Steering Wheel Angle Data

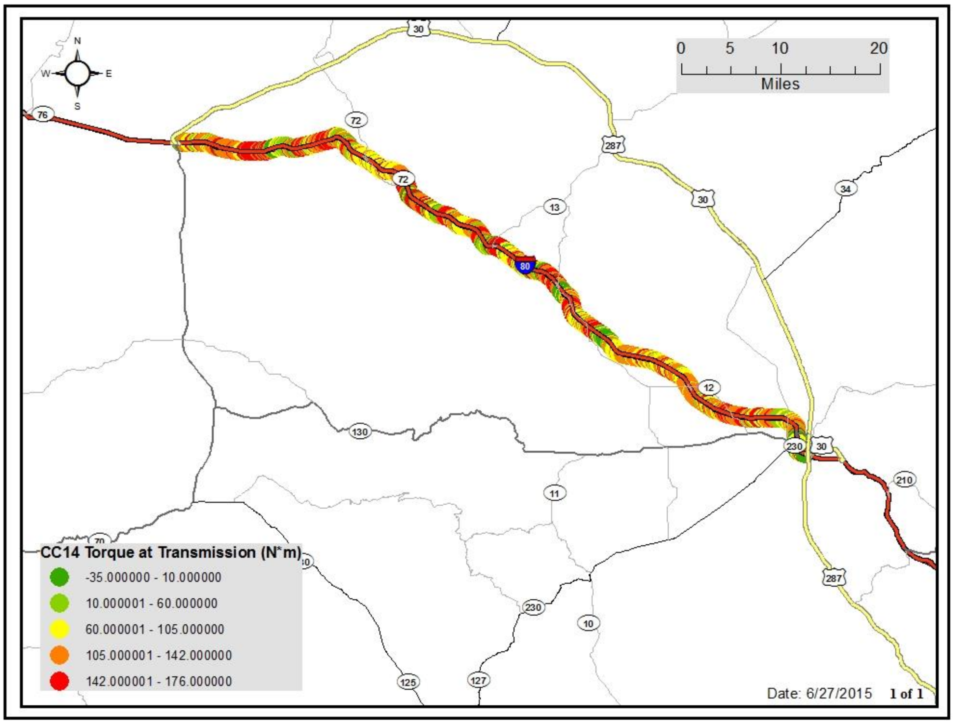


Figure E.58 CC14 Torque at Transmission Data

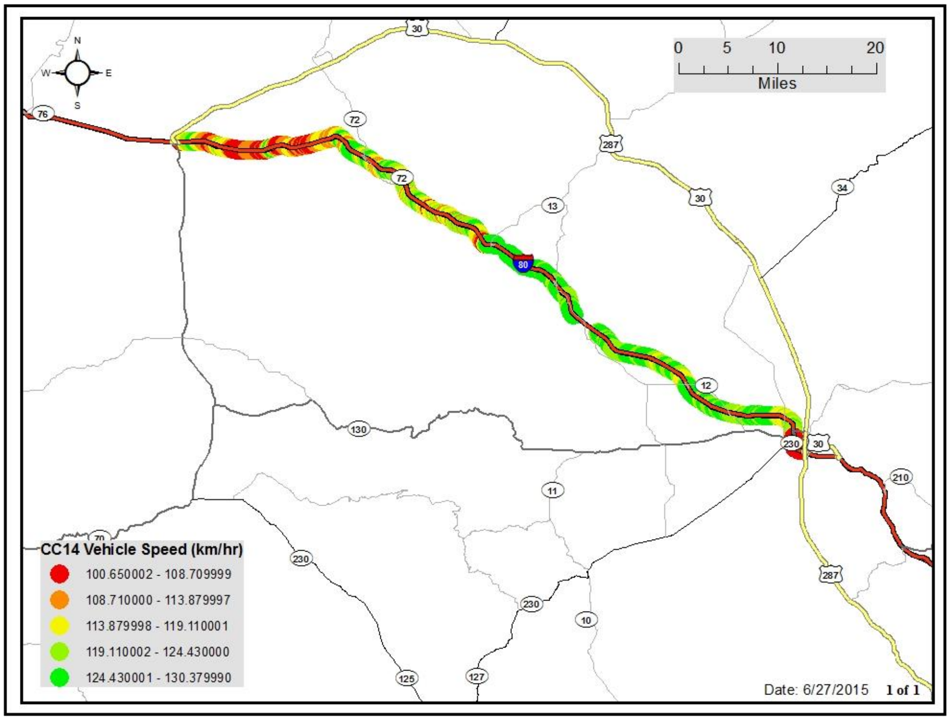


Figure E.59 CC14 Vehicle Speed Data

Trip CC15

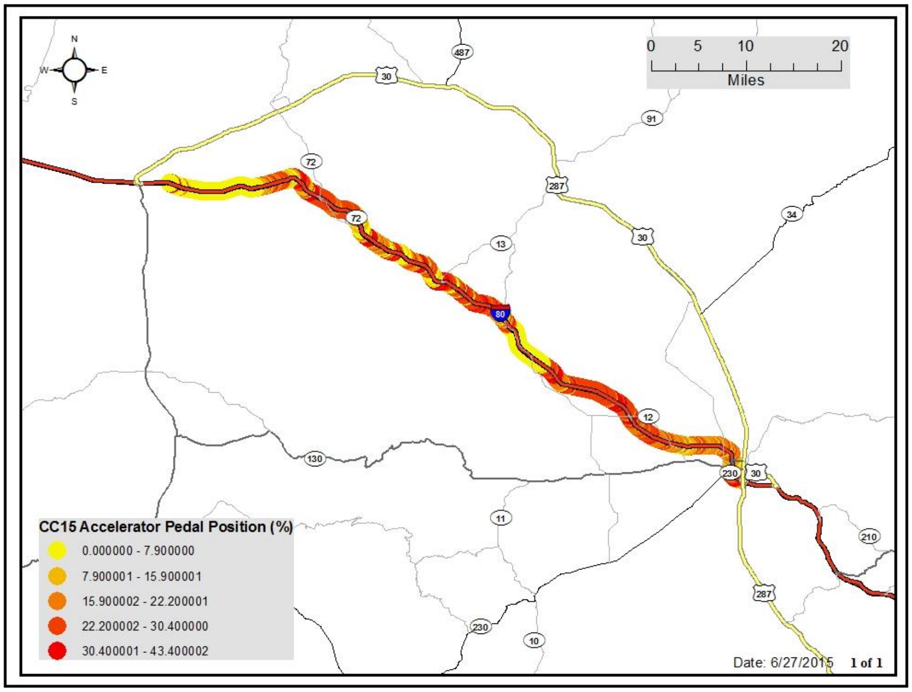


Figure E.60 CC15 Accelerator Pedal Position Data

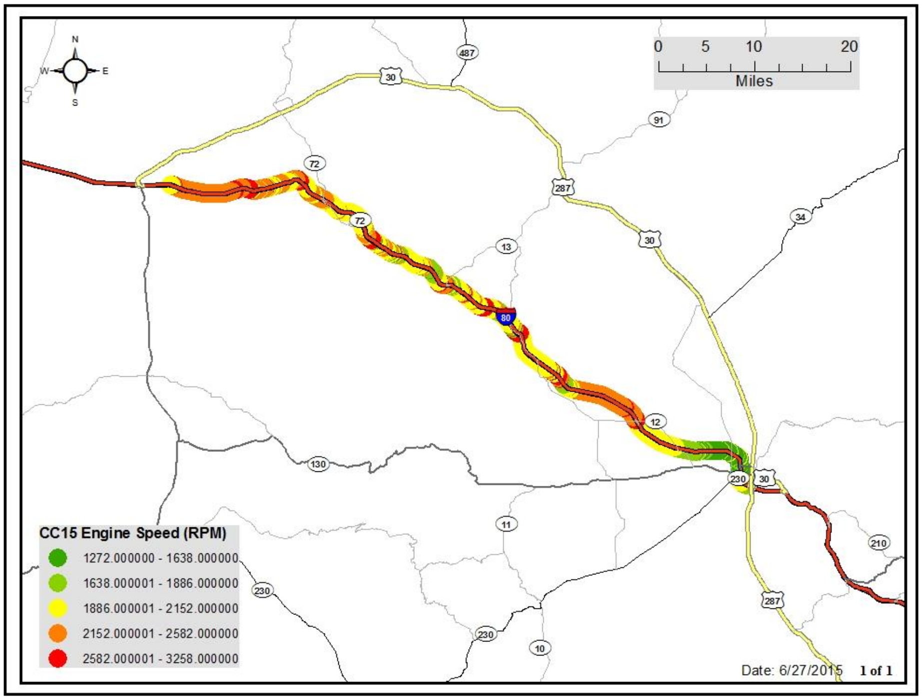


Figure E.61 CC15 Engine Speed Data

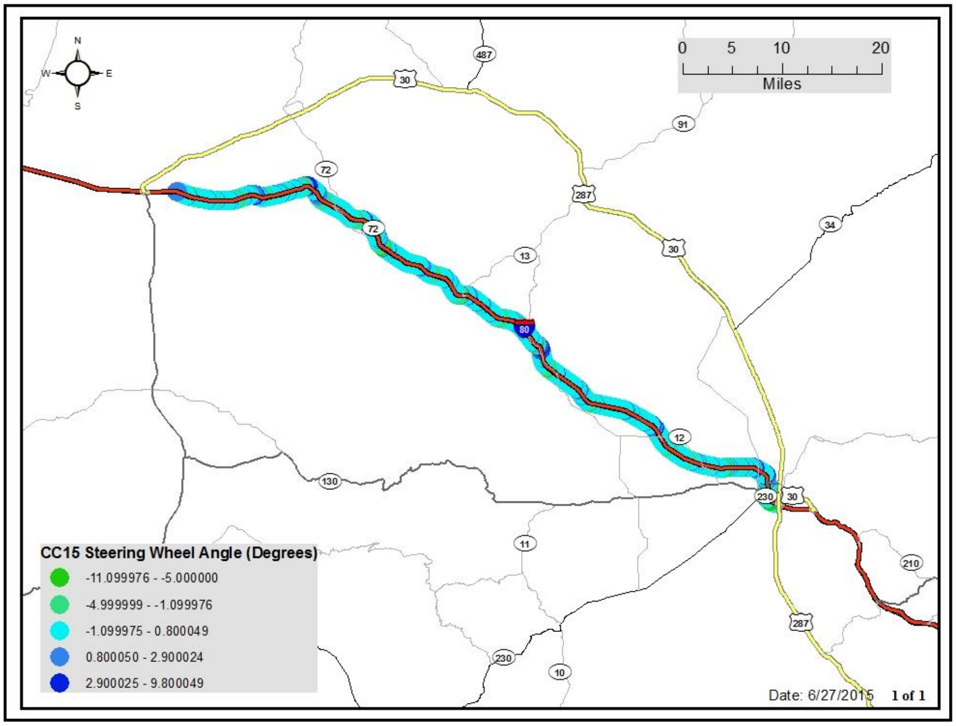


Figure E.62 CC15 Steering Wheel Angle Data

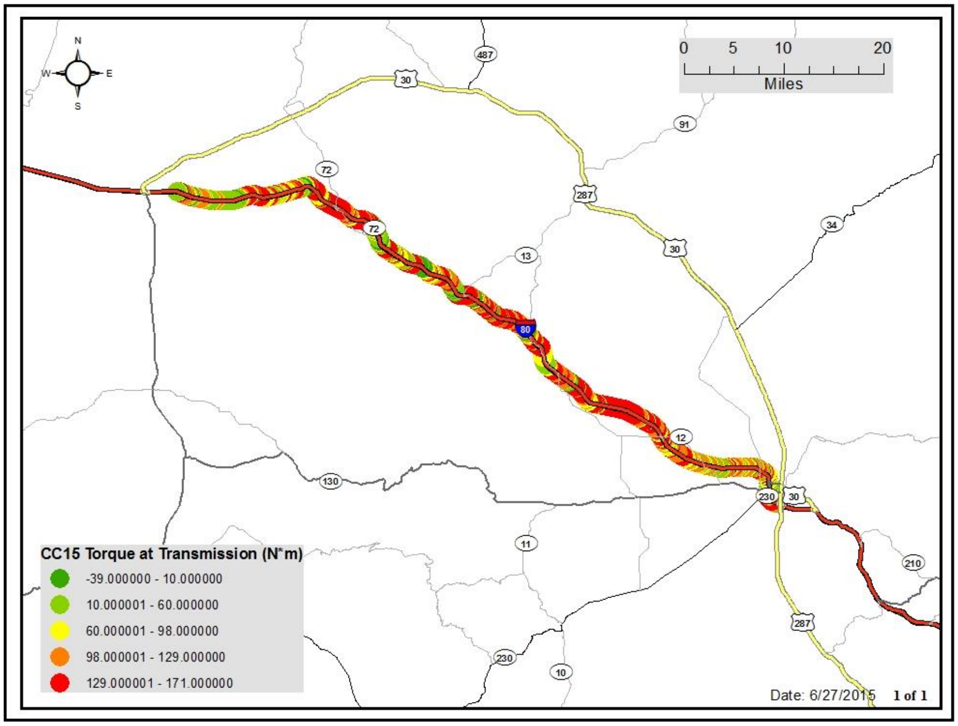


Figure E.63 CC15 Torque at Transmission Data

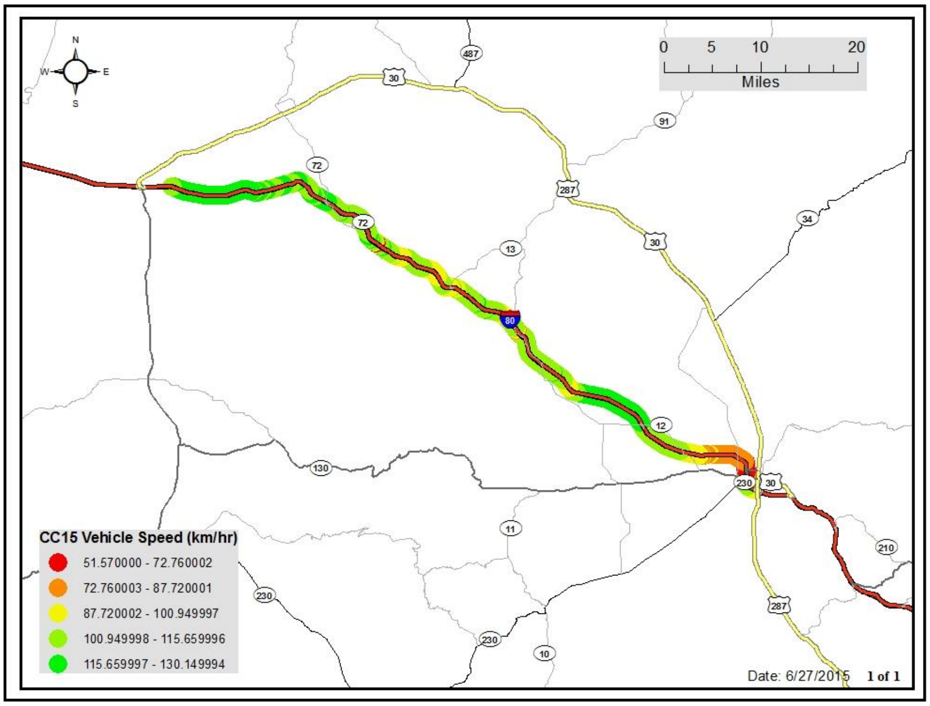


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Figure E.64 CC15 Vehicle Speed Data

Trip CC16

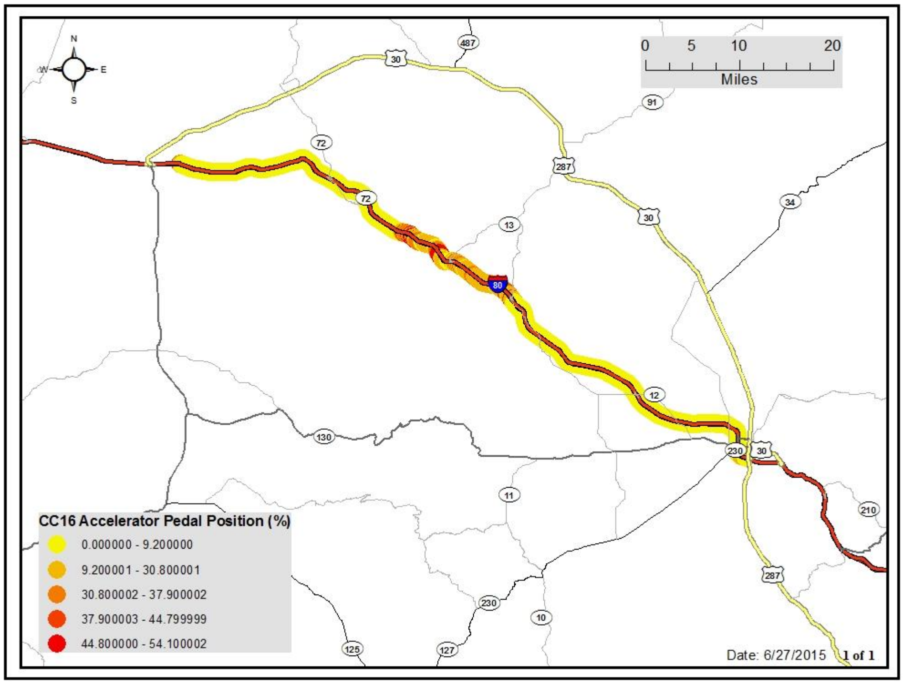

Figure E.65 CC16 Accelerator Pedal Position Data

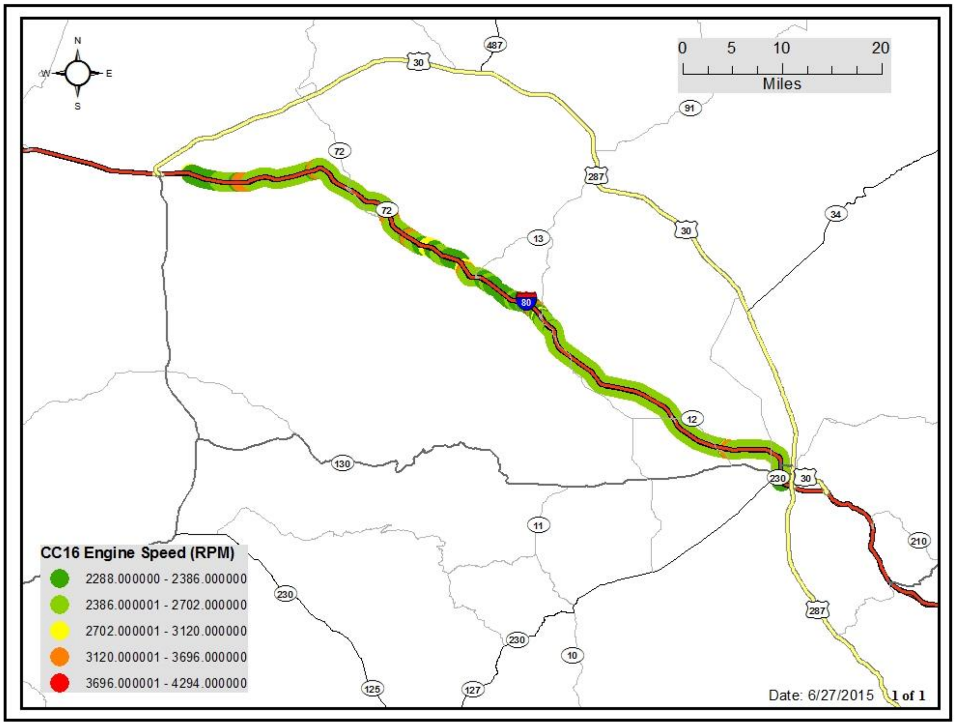

Figure E.66 CC16 Engine Speed Data

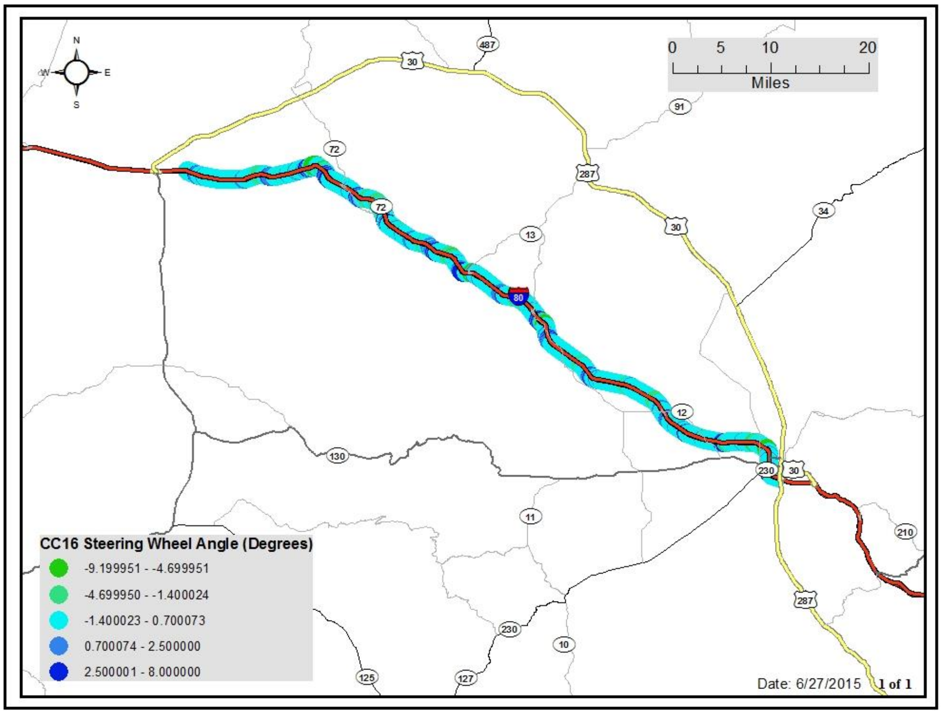

Figure E.67 CC16 Steering Wheel Angle Data

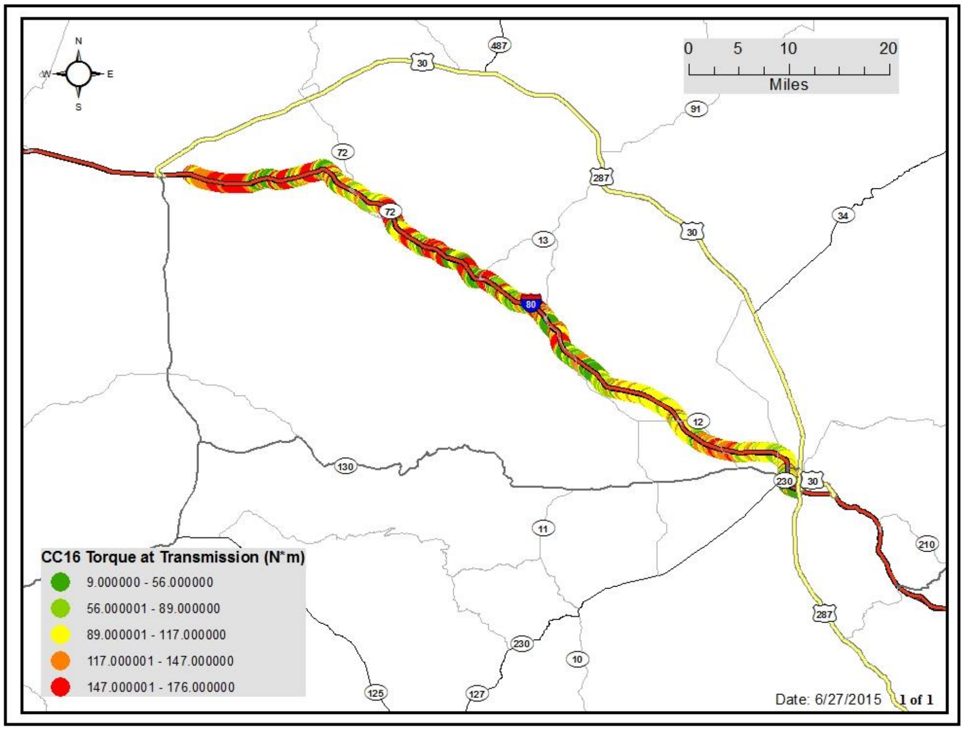

Figure E.68 CC16 Torque at Transmission Data

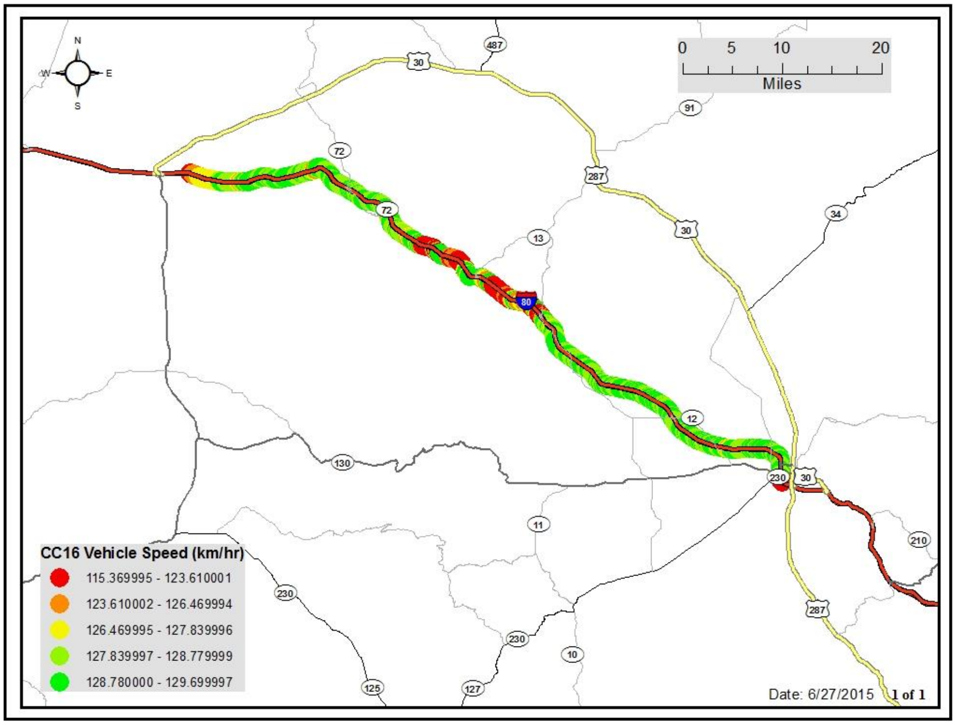

Figure E.69 CC16 Vehicle Speed Data