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Project Title

Assessing the Effectiveness of the Wyoming Connected Vehicle Pilot Program: New Traffic Safety Research Perspectives

University

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Research Needs

Wyoming is one of the first wave of Connected Vehicle Pilot sites selected to showcase the value of and spur the adoption of CV technology in the United States (WYDOT, 2018). As one of the three selected pilot sites, the Wyoming Department of Transportation (WYDOT) is focusing on improving safety and mobility by creating new ways to communicate road and travel information to commercial truck drivers and fleet managers along the 402 miles of Interstate 80 (I-80 henceforth) in the State. I-80 is a major corridor for east/west freight in the northwest part of the country, supporting the movement of over 32 million tons of freight per year (at 16 tons per truck). Truck volume ranges from 30 to 55% of the total traffic stream on an annual basis, with seasonal surges that can make up as much as 70% of the traffic volume. Furthermore, its elevation is all above 6,000 feet, with the highest point reaching 8,640 feet (2,633 m) above sea level at Sherman Summit. The corridor is also characterized by severe weather conditions; i.e., strong winds, heavy snow and fog, and severe blowing snow and low visibility. The problems along I-80 in Wyoming are not new issues. Starting the year I-80 was opened for traffic, WYDOT recognized severe weather issues and has worked to improve safety, using technological solutions when appropriate and by installing miles and miles of snow fences to mitigate the blowing snow conditions. The corridor is one of the most heavily instrumented rural corridors in the United States. WYDOT installed four regulatory variable speed limit sections on the route with a total of 136 variable speed limit signs supported by 94 speed sensors. Moreover, 54 electronic message signs, 44 weather stations and 52 web-cameras were installed along the route to make the route safer for travelers. The Connected Vehicle pilot is just the progression of WYDOT looking for innovative ways to improve safety and mobility. It is anticipated that systems and applications developed within the CV pilot will enable drivers of connected vehicles and other road users to have improved awareness of potential hazards and of situations they cannot see. This project consisted of three phases; where phase 1 was for planning, phase 2 was for deployment, and phase 3 is for real-world demonstration. Figure 1 illustrates the existing communication and traffic control devices along Wyoming I-80 corridor, and the DSRC locations that will be deployed on the corridor.

Figure 1. Wyoming CV Pilot Deployment Study Area *(WYDOT, 2018)*

The Wyoming Connected Vehicle systems and applications developed are expected to enable CV drivers to have improved awareness of potential hazards when driving on I-80, help fleet managers to better manage their freight operations, and support WYDOT Traffic Management Center staff to implement more effective traffic control strategies. An evaluation of the impacts of the CV Pilot is vital to the USDOT's strategic goals.

Background

Real-Time Risk Assessment

Real-time crash risk assessment studies investigate the dynamic factors that could affect the crash probability. This modeling technique focuses on individual incidents and their precursors to predict the probability of crash risks. These statistical techniques require a high resolution speed, traffic, and weather data. This technique would be among the most appropriate approaches that could be used to identify the effectiveness of the CV and its effect on enhancing the traffic safety.

Ahmed et al. investigated the effect of roadway geometry, real-time weather, and traffic data on crash probability on mountainous freeway sections (Ahmed et al., 2012a). Bayesian logistic regression technique was used to analyze space mean speed, real-time weather conditions, and roadway geometry. The study utilized Automatic Vehicle Identification (AVI) systems to measure space mean speed. Speed profiles were aggregated to a 6 minutes time slices, where two time slices before the crash time were included in the analysis. Additionally, a verification process was developed to verify the crash time, in which 30 minutes of speed profiles before and after the incident were extracted and compared to normal speed profiles in regular operations with matched characteristics. The results showed that steep grades and adverse weather are among the factors that increased the crash risk for mountainous roadways. Additionally, the study concluded that weather and roadway geometry should be among the investigated factors for conducting real-time risk analysis. Another study explored the benefits of using Bayesian approaches with real-time safety evaluation (Ahmed et al., 2012b). The results of the study depicted that utilizing Bayesian techniques increased the overall accuracy of the developed models by nearly 3.5%. The study recommended using Bayesian approach as a robust technique to reduce uncertainty in the parameters and increase the accuracy of the model fit. Reduction in visibility is one of the major factors contributing to increasing crash risk. Several studies investigated the impact of reduced visibility due to foggy conditions on the probability of crash occurrence. Ahmed et al. examined the viability of using airport weather stations in assessing the real-time crash risk (Ahmed et al., 2014). The study utilized Bayesian logistic models to analyze historical fog-related crashes occurred within the buffer zones for the airport weather stations, in which real-time weather information was linked to each extracted crash. Additionally, the study investigated the influence of visibility on crash occurrence. Different visibility thresholds were tested and modelled. The results showed that the coefficients of the visibility parameter decrease significantly as the visibility threshold increases. In addition, weather stations could be used as a reliable source to determine roadways visibility conditions within 5 nautical miles radius around airports. Another study utilized Bayesian logistic model with a matched case control approach to predict real-time visibility related crashes (Abdel-Aty et al., 2012). The study succeeded in identifying up to 73% of the visibility-related crashes correctly. The study utilized two sources to collect traffic data, Loop Detectors (LD), and Automatic Vehicle Identification (AVI) systems. A comparison between the two data sources were conducted using statistical models. The results showed that model accuracy that utilized data from LDs was performing slightly better that AVIs. However, data obtained for AVIs provided a comparable models to the LD that could be utilized in certain cases. Peng et al. used microscopic data and Surrogate Measures of Safety (SMoS) to assess the impact of reduced visibility on traffic crash risk (Peng et al., 2017). Traffic and weather data were collected using remote traffic microwave sensors and a mobile fog monitoring system. Time to collision (TTC), speed variance and headway variance were considered as the main SMoS used in the study. Analysis of Variance (ANOVA) was adopted to compare the SMoS among different visibility conditions (i.e. good moderate, and low). The results showed that the TTC reduced and the standard deviation of headway increased significantly as the visibility reduced, which is an indicator of higher crash risk. Furthermore the study investigated the effect of reduced visibility on different vehicles types. The results showed that trucks are the most vehicle class affected by reduction in visibility.

Microsimulation of Safety

The safety benefits of CV technology are mostly gained from the change in driving behavior and the assistance from the real-time CV warnings provided. Using microsimulation for safety evaluation, the most commonly used method is the Surrogate Safety Assessment Model (SSAM), which was first introduced by Gettman et al. (Gettman & Head, 2003; Gettman, et al., 2008). After the conception of Surrogate Measure of Safety (SMoS) was proposed, several research were conducted to validate the simulation traffic conflicts using SMoS. Among various surrogate measures of safety used in the literature, time-to-collision (TTC) was found to be an efficient surrogate safety measure. Ozbay et al. (2008) developed and validated an analytically derived Crash Index (CI) and Modified Time-to-Collision (MTTC) as new safety indicators based on the extension of the traditional TTC safety index. Preliminary results indicate that there was a strong relationship between the proposed surrogate safety measures and real crash data. Huang et al. (2013) compared the conflicts generated by the VISSIM simulation model and identified by SSAM to the traffic conflicts measured at ten signalized intersections in China. Similarly, Essa and Sayed (2015) investigated the relationship between field-measured and simulated conflicts at an urban signalized intersection in Canada. Results from both research showed that there was a reasonable goodness-of-fit between the simulated and the observed conflicts, and both research highlighted the importance of the calibration of VISSIM model to match the existing traffic conditions and the actual driver behavior parameters. Young et al. (2014) summarized the developments of road safety simulation models, and proposed new research areas to direct the further work of simulating safety. The suggested developments mainly includes: using crash as the measure of performance, investigate the theory behind driver behavior in crashes, present a more detailed representation of the vehicle and conflict situations, and a generalization of the models to look at more crash and vehicle types.

To date, there has been a number of studies that adopted SMoS and SSAM for traffic safety assessment in a Connected Vehicle environment. Olia et al. (2013) attempted to quantify potential safety benefits of deploying a Connected Vehicle system through microscopic traffic simulation modelling. PARAMICS was used to model Connected Vehicles, construction zones and incidents associated with work zones. The result of this research clearly demonstrates the effectiveness of Connected Vehicle systems to improve network safety. The percentage of Connected Vehicles within the network is the most significant factor to increase network safety and can be explained by re-routing to alternate routes and increased driver awareness with improvements of up to 50% in network safety. Another study evaluated the impact of Connected Vehicles on work zone safety (Genders et al., 2014). A dynamic route guidance system based on decaying average-travel-time and shortest path routing was developed and tested in a microscopic traffic simulation environment to avoid routes with work zones. To account for the unpredictable behavior and psychology of driver's response to information, three behavior models, in the form of multinomial distributions, are proposed and studied in their study. The surrogate safety measure "improved Time to Collision" was used to gauge network safety at various market penetrations of Connected Vehicles. Results show that higher market penetrations of connected vehicles decrease network safety due to increased average travel distance, while the safest conditions, 5%-10% reduction in critical Time to Collision events, were observed at market penetrations of 20%-40% connected vehicle, with network safety strongly influenced by behavior model. Genders and Raviza (2016) evaluated the potential safety benefits of deploying a connected vehicle system on a traffic network in the presence of a work zone. The modeled connected vehicle system in the study uses vehicle-to-vehicle (V2V) communication to share information about work zone links and link travel times. Vehicles which receive work zone information will also modify their driving behavior by increasing awareness and decreasing aggressiveness. Traffic microsimulation software was used to model the network and a C plugin was developed to implement connected vehicle in the simulation. The surrogate safety measure "improved time to collision (TTC)" was used to assess the safety of the network. Various market penetrations of connected vehicles were utilized along with three different behavior models to account for the uncertainty in driver response to connected vehicle information. The results show that network safety is strongly correlated with the behavior model used; conservative models yield conservative changes in network safety. The results also show that market penetrations of connected vehicles under 40% contribute to a safer traffic network, while market penetrations above 40% decrease network safety. The decrease in safety when rerouting more than 40% of traffic on a work zone is attributed to longer average trip distances (Genders & Razavi, 2016). This also could be explained by the fact that more traffic will be diverted to other alternate routes resulting in more exposure to higher traffic volumes and increased crash risks. Fyfe and Sayed (2017) combined VISSIM and SSAM with the application of the cumulative travel time (CTT) algorithm to evaluate the safety under CV environment. The study showed a 40% reduction of rear-end conflict frequency at a signalized intersection with the application of CV. Li et al. (2017) developed a microsimulation testbed to assess the safety benefits of an integrated system of cooperative adaptive cruise control (CACC) and variable speed limit (VSL); surrogate safety measures of the time exposed time-to-collision (TET) and time integrated time-to-collision (TIT) were used. The simulation results showed that the proposed integration system with 100% CACC penetration rate can reduce the rear-end collision risks effectively, with the TIT and TET declined by 98%. Rahman et al. (2018) employed the standard deviation of speed, the standard deviation of headway, and rear-end crash risk index (RCRI) as surrogate measures of safety in a microsimulation environment to assess the safety effectiveness of CV technologies. Simulation results indicated that CV improved traffic safety significantly in fog conditions as market penetration rates of CV increase.

Research Objectives

The main research objectives of this study are as follows:

- Evaluate the safety effectiveness of the Wyoming Connected Vehicle Pilot Deployment Program.
- Identify suitable methodologies to assess the efficacy of CV.
- Develop new tools in microsimulation to assess the Safety of Emerging Technologies.
- Understand the effect of other traditional safety countermeasures; snow fences, horizontal curves, roadway safety features, and new ITS measures on safety.

Research Methods

The Wyoming CV Pilot team developed a Performance Measurement and Evaluation Support Plan (Kitchener, et al., 2018), which includes 21 performance measures incorporated within 8 performance categories, as listed in Table 1.

Table 1. Summary of Performance Measures (PMs) and their Categories (Kitchener, et al., 2018)

PM #	Wyoming CV Pilot PM	PM Category
1	Number of road weather condition reports per road section/day pre and post CV Pilot (quantity)	Improved Road Weather Condition Reports Received into the TMC
2	Number of road sections with at least one reported road condition per hour pre and post CV Pilot (coverage)	
3	Average refresh time of road condition reports in each section pre and post CV Pilot (latency)	
4	Pikalert™ generated motorist alert warnings (MAWs) that were accepted by TMC operators	Improved Ability of the TMC to Generate Alerts and Advisories
5	Number of messages sent from the TMC that are received by the RSU	

6	Number of messages sent and received between the RSU and WYDOT fleet vehicle's OBU (when vehicles are in the vicinity of a RSU)	Effectively Disseminate and Receive I2V and V2I Messages
7	Connected vehicles that likely took action following receipt of an alert. “Parked, Reduced speed, Came to a stop safely, Exited”	
8	Commercial vehicle managers are satisfied with information provided by the TMC (compare before and after CV Pilot). “Road conditions, Road weather forecasts, Parking information)	Improved Information to Commercial Vehicle Fleets
9	Number of operational changes made by fleet managers due to information from TMC (compare before and after CV Pilot). “Routing, Timing, Parking availability, Cancelled trips”	
10	Commercial vehicle drivers' benefits experienced due to CV technology during major incidents and events on I-80	
11	Number of V2V messages properly received in surrounding vehicles from sending vehicle (WYDOT fleet vehicles in vicinity of each other)	Effectively Transmitted V2V Messages
12	Connected vehicles that likely took action following receipt of a V2V alert. “Parked, Reduced speed, Came to a stop safely, Exited”	
13	Number of emergency notifications that are first received in the TMC from connected vehicles (compared to alternate traditional methods, such as 911 caller)	Automated Emergency Notification of a Crash
14	Total vehicles traveling at no more than 5 mph over the posted speed (compare before and after CV Pilot)	Improved Speed Adherence and Reduced Speed Variation
15	Total vehicles traveling within +/- 10 mph of 85th percentile speed (compare before and after CV Pilot)	
16	Speed of applicable connected vehicles are closer to posted speed when compared to non-connected vehicles	
17	Number of connected vehicles involved in a crash. “Initial crashes, and Secondary crashes”	Reduced Vehicle Crashes
18	Reduction of the number of vehicles involved in a crash (compare a multi-year average before and after CV Pilot)	
19	Reduction of total and truck crash rates within a work zone area (compare a multi-year average before and after CV Pilot)	
20	Reduction of total and truck crash rates along the corridor (compare a multi-year average before and after CV Pilot)	

21	Reduction of critical (fatal or incapacitating) total and truck crash rates in the corridor (compare a multi-year average before and after CV Pilot)	

The major performance categories represent the primary activities and outcomes of the Wyoming CV pilot system. These categories focus on improvements to efficiency, safety and mobility. Quantitative and qualitative measures were proposed to evaluate the Wyoming CV project with a focus on understanding the extent and impact of the benefits described above. This research proposal mainly focuses on evaluating the effectiveness of the CV on enhancing the last two categories: 1) improved speed adherence and reduced speed variation, and 2) reduced vehicle crashes. The first performance category focuses on speed behavior in the corridor as measured by better adherence to posted speed limits as well as decreasing the variation of speeds among vehicles on the corridor. Data for the performance measures will be collected from the Variable Speed Limit (VSL) and non-VSL corridors within the 402-mile I-80, as illustrated in Figure 2. The speed performance measures involve the analysis of observed speeds of both connected and non-connected vehicles.

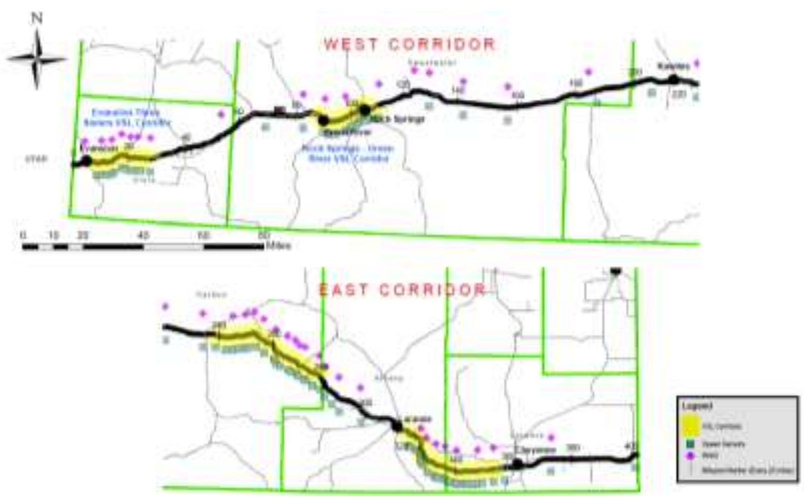

Figure 2. Location of speed sensor, RWIS, and VSL corridors on Wyoming I-80 (*Kitchener, et al., 2018*)

Nevertheless, the traditional safety evaluation methodologies presented in the Highway Safety Manual (HSM) (AASHTO 2011) might not be the most appropriate approaches to evaluate CV technology due to several limitations. Mainly, statistical analysis performed utilizing historical data is the core of the approaches presented in the HSM. Being in an early development phase of CAV, assessment of the obtained safety benefits is challenging and still unclear. Enough data to evaluate the system performance in the after implementation period are not available, which hinders the use of traditional HSM methodologies. Additionally, penetration rates are considered among the key factors affecting the benefits obtained from the CV system as well as it affects its safety evaluation. In order to adopt the HSM methodologies in the evaluation process, a significant proportion of vehicles on the roadways should be equipped with CV technology. While many automobile manufacturers such as GM and Toyota have models already equipped with Dedicated Short Range Communication (DSRC), the market penetration rates are still low. This also would delay the ability to use traditional evaluation methodologies. With these concerns, new innovative approaches are required to investigate the safety effectiveness of this newly introduced technology. Experiencing several factors that impede the immediate use of traditional safety approaches as well as having the CV pilot in Wyoming, this research proposes alternative methodologies, including real-time risk assessment and microsimulation modeling, to assess newly emerging CV technology by integrating real time information, obtained from the Wyoming's CV pilot, into microsimulation analysis level. Surrogate Measures of Safety (SMoS) will be mainly used as the main safety measure. To investigate the suitability of the data obtained from the CV environment to identify SMoS, a synthesis study would be conducted using the Second Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS) data. The NDS data is the largest naturalistic driving behavior data, where approximately 3,300 vehicles were involved in this study. The participants' vehicles were equipped with Data Acquisition Systems (DAS) to collect various vehicle dynamics and driving behaviors. Data was collected between 2010 and 2013 from six states in the US.

The safety performance simulation will employ the VISSIM simulation with the Surrogate Safety Assessment Model (SSAM) for safety performance evaluation, as it is known that microsimulation software cannot directly simulate traffic crashes. High-resolution data will be collected from the demonstration phase of the Wyoming CV Pilot and will be fed into microsimulation models to evaluate the performance of the CV system. The evaluation of the CV technology will be conducted in two assessment levels: 1) whole corridor performance evaluation using microsimulation "before-after analysis", and 2) individual level utilizing real-time risk assessment analyses "with and without the technology". Details about the proposed methodologies will be further explained in the forthcoming sections.

Expected Outcomes

CV technology have the potential to significantly transform the nation's roadways and transportation management strategies. They offer potential safety benefits, but there is a need for a thorough and effective evaluation of the performance of CV systems and understanding the factors that affect the performance of the CV systems. Traditional performance evaluation methodologies are usually challenged by the relatively few number of CVs that are capable of receiving and transmitting information from and to the infrastructure or other CVs. In addition, the variability of weather events in Wyoming presents extra challenges to the analysis of Pre- and Post-system implementation data. Therefore, this research proposes using non-traditional performance evaluation methodologies, which have the ability to control the confounding factors that may affect system performance. This provides a more credible environment for the comparison of system performance between the Pre- and Post-deployment periods. This project will enable WYDOT to objectively assess the effectiveness of the Wyoming Connected Vehicle Pilot Deployment Program. Eventually, findings from this research will be of significant importance to assist the WYDOT staff on identifying the best traffic management strategies and allocation of resources.

Relevance to Strategic Goals

This project fits under the local and rural roadways safety area. The proposed project and its expected outcomes will help in better preparing for the era of Connected and Automated Vehicles.

The outcomes will aid in selecting the most cost-effective emerging technologies to reduce crashes and/ or their severities.

Educational Benefits

Students will be involved in various tasks including; conducting review of literature, data collection from the Wyoming CV Pilot, defining modeling framework and estimation methodology, assessing different CV applications, participating in documenting the results and writing and presenting scientific journal papers. This project will also contribute in updating Traffic Safety class with more relevant research methodologies that are more suitable for the era of CAV.

Technology Transfer

The research results will be disseminated through technical paper publications and presentations in academic venues and press releases using media outlets. The technology transfer activities in this project will benefit both the scientific community and authorities responsible for decision-making, and will be a key to ensure the least adverse effects of new technologies such as Connected Vehicle on the safety of drivers.

Work Plan

The work plan is divided in 4 main tasks and developed for a two-year performance period. The tasks are as follows:

Task 1: Review of literature and practice related to CV Safety Assessment (NTP – Month 6 – Extended throughout the project period)

Conducting a comprehensive literature review about recent real-time risk assessment and micro-simulation modelling to assess CV technologies. The review of literature will look into readily available data similar to CV data such as NDS data, Surrogate Measures of Safety (SMoS), and how this research could benefit the evaluation of CV.

Task 2: Data Acquisition and Processing for the Wyoming CV Pilot Deployment (Month 3 – Month 12)

The Wyoming CV Pilot traffic performance data, which are expected to be acquired from the Wyoming Department of Transportation (WYDOT), will be used in this research. Several datasets with high resolution will be collected to perform the research.

Task 3: Real-Time Risk Assessment (Month 6 – Month 15)

Disaggregate real-time crash risk assessment investigates the dynamic factors that could lead to an increase in crash probability. This modeling technique focuses on individual crashes and their precursors to predict the probability of crash risks. Individual speed data, detailed weather information and hourly traffic volumes are the three main datasets used to conduct the analysis. Assessment of crash risk factors for vehicle with and without CV technologies would help in quantifying the obtained benefits of the CV. Several statistical approaches will be used to conduct the analysis. Parametric, non-parametric, and Bayesian modelling techniques will be used to model the risk probabilities. With and without CV evaluation approach will be mainly utilized in this analysis. Additional techniques utilizing trajectory-level data will be investigated.

Task 4: Microsimulation Modeling for Safety Assessment (Month 12 – Month 20)
Traffic simulation modeling using VISSIM and SSAM software will be conducted for the analysis of traffic safety performance measures. Microsimulation modeling allows for the analysis of conflict-event safety surrogates such as time-to-collision, distribution of speeds, speed variation, number of lane changes, etc. It is anticipated that the CV deployment will result in changes to speed selection, lane changing and car-following behavior for CV-equipped drivers that can be modeled in a microsimulation environment. In this regard, this initial system performance proposes a VISSIM simulation framework for the Cheyenne-Laramie (mileposts 316 to 353) or Elk Mountain (mileposts 237 to 290) Variable Speed Limit corridors. The selected corridors are located at the most population density areas in Wyoming, which carries the highest traffic volume on I-80 in Wyoming and represents the most challenging situation along I-80 in Wyoming. Real-time information obtained from the CV datasets would be integrated into the microsimulation models to simulate the driving behavior of the CVs and non-CVs, including the car-following and lane-changing behavior. Additionally, weather conditions will be taken into account while developing the simulation models.

Task 5: Providing recommendations for WYDOT and Independent Evaluators (Month 20 – Month 22)
Through microsimulation and real-time risk assessment, the effectiveness of the WYDOT CV will be determined. Recommendations and results will be provided to the WYDOT and the USDOT Independent Evaluators.

Task 6: Final report (Month 20 – Month 24)
The research team will summarize the study in a formal final report. Technical reports and memos will be developed throughout the study. The final report will compile all developed documents including the review of literature and practice, methodologies to assess the efficacy of the WYDOT CV, Performance Measurements, Developed Models, Evaluation Results and recommendations.

Project Cost

Total Project Costs:	$183,322
MPC Funds Requested:	$ 60,000
Matching Funds:	$123,322
Source of Matching Funds:	Wyoming Department of Transportation

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