Human Machine Interface for Connected Vehicle: Requirements, Development and Assessment

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1) Problem Statement

According to the National Highway Traffic Safety Administration (NHTSA, 2015), more than 90% of motor vehicle crashes are attributed at least in part to human errors. The study estimated that the immediate reason for the critical pre-crash events[1] is 41% due to recognition errors, 33% due to decision errors, and 11% due to performance errors. With the rapid advancement in automotive technologies, systems are continuously being developed and vehicles are becoming crammed with numerous in-vehicle technologies, many of which require mechanical and visual interactions from the drivers such as entertainment, navigation, Advanced Driver Assistance Systems (ADAS) and recent Connected and Automated Vehicle technologies. One of the key components of Connected Vehicle technology is the in-vehicle displays (known also as Human Machine Interface) that delivers real-time geo-specific Basic Safety Messages (BSM) and Traveler Information Messages (TIMs) to drivers. Designing a safe implementable Connected Vehicle application includes understanding the adverse impacts these new technologies may introduce. Some obvious safety issues stem from the fact that the majority of Connected Vehicle applications rely on Human Machine Interfaces (HMI) leading to the possibility of distracted driving.

Although there are a handful of studies that strived to provide guidelines for HMI design in a Connected Vehicle (CV) environment, the magnitude of these studies does not come close to the complexity and sophistication level of the WYDOT Connected Vehicle (CV) applications. It is worth mentioning that these studies mostly focused on a single CV application while Wyoming CV project has a full suite of connected applications. Moreover, while these studies attempted to evaluate the benefits of CV system on promoting traffic safety, they lack a clear understanding of the impacts of different HMI designs on drivers' recognition and reaction. A well-designed HMI has the potential to provide drivers proactive decision-making supports and thus reduce the potential of traffic collisions. On the other hand, inappropriate integration of various Advanced Driver Assistance Systems (ADAS) and their Human Machine Interfaces may mislead, distract, or even disturb drivers. Furthermore, the complexity of these new technologies may adversely affect drivers' safety, particularly, during high workload situations or under adverse weather and road surface conditions such as on Wyoming's roadways. In this regard, this study aims to support the Wyoming Connected Vehicle Pilot Deployment project by ensuring maximum benefits and

[1] "*the last failure in the causal chain of events leading up to the crash" NHTSA, 2015*

minimizing any potential adverse impacts of the new CV Human Machine Interface. Specifically, the following aspects will be investigated:

a) What kind of HMI design and modality (i.e., visual, auditory, or a combination of visual and auditory) best delivers the meaning of an alert?
b) What is the maximum number of alerts that can be displayed on a HMI without distracting drivers?
c) When should an early alert be displayed and how long should the alert remain on the HMI?
d) How to prioritize different alerts when they are displayed simultaneously on the HMI?
e) How effective an only auditory warning (beeps and/or voice) when a stakeholder's regulations do not allow a multi-modality HMI in their cabin?
f) Are additional language options suitable for the HMI for non-native English speakers?

To answer the aforementioned questions, this project intends to: 1) conduct a comprehensive review of the literature on requirements, standards, recommendations and best practices in designing Human Machine Interfaces, 2) synthesize recent existing HMIs from various automobile manufacturers and Advanced Driver Assistance Systems (ADASs), 3) interview WYDOT CV's stakeholders to collect their preferences and regulations on the use of in-vehicle Human Machine Interface, 4) recruit 40 professional commercial truck drivers as well as additional 40 light vehicle drivers to participate in a CV driving simulator testing and HMIs assessment at the University of Wyoming driving simulator lab (WyoSafe Sim.), and 5) provide recommendations to WYDOT on the best HMI designs.

The simulation scenarios will be selected to better support the WYDOT Connected Vehicle Pilot Deployment project and its various applications. WYDOT's primary means of conveying information to the public using roadside devices relies heavily on the English language and many commercial drivers do not speak English, natively. Connected vehicle technology allows WYDOT to relay information within a vehicle which presents opportunities for customized audible messaging in the driver's native language. Various simulation scenarios will be utilized to simulate and collect drivers' interactions with the proposed HMIs and third-party connected mobile applications.

Quantitative driving behavior data, such as the position of a driver's eyes (i.e., eye glance and gaze frequency and time), reaction time to alerts, speed selection and compliance, lane change and maintenance, and acceleration/deceleration behaviors, will be collected from SmartEye Tracking and SimObserver systems and the simulator's vehicle kinematics. In addition, a comprehensive post-drive questionnaire surveys will be employed to gather drivers' qualitative opinions regarding the readability, clarity, interpretability, accessibility, and ease of handling of the HMI. The efficiency and preference of the proposed HMI design options will be assessed in various real-world-like environmental and traffic conditions. The driving simulation testing will compare individual alerts versus multiple-alerts. Questionnaire surveys will be utilized to examine driver's preference to auditory warnings (beeps, male and female voice warnings), visual warnings, or a combination of visual and auditory ones. It is worth mentioning that some stakeholders on the WYDOT CV pilot do not allow the use of visual warnings and hence testing alternative auditory-alerting patterns may be essential. The study will also assess the use of grouped visual-alerting patterns ordered by different priority levels and presenting alters with higher priority closer to the driver (i.e., left side on the HMI). Findings from this study will provide a comprehensive guidelines for the optimal design of HMI in a way that drivers can perceive connected vehicle warnings promptly without being distracted.

2) Literature Review

The United States' and the world's surface transportation systems are at a historic turning point. The interaction between motor vehicles, drivers and other road users, road infrastructure, and traffic control devices are likely to change significantly in the coming few years. The advancements in automotive technology, innovations in communications and Big Data Analytics have unlocked new horizons for how our surface transportation systems are planned, designed, constructed, operated, and managed. Among these advances, Connected and Automated Vehicles (CAV) are geared towards improving mobility, enhancing safety, and reducing the adverse impacts of the transportation systems. The U.S. Department of Transportation's (USDOT) Intelligent Transportation Systems (ITS) Strategic Plan 2015-2019 focuses on Connected Vehicle and Automation as the two major program categories in research, development and adoption.

Nationwide, a handful CV test beds have been developed to provide the supporting infrastructure, instrumented vehicles, and communications for experimentation with the CV technology by the public and private sectors. The USDOT, technology innovators, automobile manufacturers, and academic institutions are progressively working on various issues to clear the speculation about how these technologies will be implemented in the future to improve safety and traffic operations without posing any risks to all users. The USDOT has launched Connected Vehicle V2I (Vehicle-to-Infrastructure) and V2V (Vehicle-to-Vehicle) with a $42 million Pilot Deployment Program in addition to a $40 million Smart City Challenge. With Wave 1 Pilots, $42 million already awarded in 2015, to 3 Pilot Deployments – New York City ($20 million); Tampa, Florida ($17 million); and Wyoming ($5 million), for concept development activities over a period of 50 months.

The primary objective of the CV Pilot in Wyoming is to reduce the number of weather-related crashes on Interstate-80 corridor in order to improve safety and reduce incident-related delays, while at the NYC pilot site the objective is to improve safety of travelers and pedestrians, and Tampa will showcase how traffic demand moves over the course of a typical day.

According to the Society of Automotive Engineers (SAE) Standard J3016, Connected Vehicle technology is considered Level 0 Automation (No Automation) where the driver remains in full-time control of all aspects of the driving task. The SAE J3016 defined 6 levels of automation (Level 0 to Level 5) as illustrated in Figure 1. Levels 0, 1 and 2 have been already widely implemented by various auto manufacturers such as Tesla, Audi, Volvo, Mercedes Benz, etc., and developers such as Google, Apple, etc. According to BI Intelligence, connected vehicle market is growing 10 times as fast as the overall car market and it is expected that 75% of the estimated 92 million vehicles shipped globally in 2020 will be built with internet-connection hardware. The market penetration may be accelerated by the fact that connected vehicle technology may be split between vehicle and a secondary device (an On-Board Unit and a tablet or a smart phone display) that can be used to retrofit older vehicles with the requisite technology.

In the near future, according to Bierstedt et al. (2014), by the end of this year Tesla expected to develop technologies to allow their vehicles to be autonomous for 90 percent of distance driven. Google Waymo expects to have autonomous cars on the market by the year 2018. By 2020, GM, Mercedes-Benz, Audi, Nissan, Volvo, and BMW all expect to sell autonomous cars. Despite the fact that many initiatives are striving to eliminate the human driver from the picture, human drivers will remain engaged in various driving tasks throughout the evolution to level 4 and 5 fully autonomous driving. Figure 1 illustrates that human drivers will be needed for "*execution of steering and acceleration/ deceleration*", "*monitoring of driving environment*", and "*fallback performance of dynamic driving task*" for levels 0 to 3 automation (SAE, 2016). During these stages, a Human Machine Interface will play a significant role in the success of these levels including level 0 "no automation" (i.e., Connected Vehicle only). No automation requires "*the full time performance by the human driver of all aspect of the dynamic driving task, even when* *enhanced by warning or intervention systems*" (SAE, 2016). Operating a vehicle is a complex task requiring constant monitoring of the road, in-vehicle systems, and performing timely decisions and maneuvers (Cummings et al., 2007). As mention earlier, human factors are a leading contributing factor for crashes (NHTSA, 2015). The NHTSA estimated that Connected Vehicle technology - a predecessor to Automated Vehicle deployment and a must have technology for level-5 full autonomous driving - alone has the potential to mitigate 81% of traffic accidents involving non-impaired drivers at full implementation

Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
Human driver **monitors the driving environment**								
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
Automated driving system **("system") monitors the driving environment**								
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	**High Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	-	

Human Driver Needed

Figure 1: Summary of Levels of Driving Automation for On-Road Vehicles (Source: adapted from the SAE Standard J3016)

While there have been various guides, standards and references available to facilitate a safe and efficient roadway design and operation including *A policy on Geometric Design of Highway and Streets* (AASHTO, 2011), the *Manual of Uniform Control Devices (MUTCD)* (FHWA, 2009), and the *Highway Safety Manual* (AASHTO, 2010), these manuals often lack the consideration of human factors, particularly, the impact of the interaction between drivers and in-vehicle technologies.

Importance of in-vehicle HMI

With the booming of vehicle technology and in attempts of promoting traffic safety, Advanced Driver Assistance Systems (ADAS) and Connected Vehicles technologies (CV) have been widely introduced into the market at a fast pace. ADAS and CV technologies are designed to improve drivers' situational awareness through Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) and Infrastructure-to-Vehicle (I2V) in a real-time wireless environment, thus reducing crashes caused by human errors (Shladover, 2017). One of the key components of ADAS and CV system is the on-board Human Machine Interface (HMI) that is capable of delivering real-time and timely geo-specific Basic Safety Messages (BSMs) and Traveler Information Messages (TIMs) to drivers. Nevertheless, in current practice there is a lack of clear understanding of the impacts of different HMI designs on drivers' recognition and reaction to the BSMs and TIMs. In practice, a well-designed HMI display has the potential to provide drivers proactive decision-making supports and thus reduce the potential of traffic collisions; while inappropriate integration of various alters may mislead, distract, or even disturb drivers. This is particularly significant during high workload situations or under adverse weather and road surface conditions.

In this regard, the design of HMI needs to balance a tradeoff between the readability of the notifications (i.e., maximum number of messages displayed on the HMI, display method and length of each message, etc.) and drivers' capability to safely recognize the received notifications. Developing HMI with consideration of human factors, such as drivers' ability to drive safely while effectively using the in-vehicle systems, has become increasingly important for the success of Advanced Driver Assistance Systems (ADASs), which aims to minimizing potential distractions introduced by these in-vehicle technologies.

HMI Design Requirements

In reality, safe driving is the primary task for non-autonomous vehicle drivers. Although the HMI allows the driver to interact with the vehicle, there has been a variety of design challenges that must be met prior to full implementation of HMI. As specified by the National Highway Traffic Safety Administration (NHTAS, 2009), the primary requirement of the in-vehicle HMI is to deliver timely needed or desired information while minimizing driver distraction. Other challenges include the need to protect the security and privacy of data, the need for the various technologies to be interoperable, and the need to ensure that the data generated and communicated by these new technologies are accurate and reliable. Similarly, Peter et al. (2014) pointed out that HMI devices are initially developed to provide services that enhance the efficiency of the driving tasks, and the general aspects and standards for effective HMIs include the following requirements: readability, clarity, interpretability, accessibility, and ease of handing. These requirements aim to organize and distribute the driving tasks so that driver's cognitive workload can be performed comfortably as well as the distraction could be minimized. Sentouh, et al. (2014) indicated that the implementation of HMI should address a number of challenges including but not limited to: what information is important for drivers; how an information is displayed; when, under what circumstances, and in what order the information should be presented to drivers. Olaverri-Monreal and Jizba (2016) summarized the issues involved in the field of human-machine interaction; it was concluded that in-vehicle HMI should provide an intuitively meaningful indication of the presence of a warning and its current status. Also, it is crucial to investigate driver distraction levels, as well as the modality and dimension of the visual warnings and their appropriate in-vehicle location.

For the design format of messages that will be displayed on the HMI, the Federal Highway Administration *(FHWA, 2015)* emphasized that the design of HMI should adhere to standard message formats. It is highly recommended to use familiar signs and messages that are provided by the MUTCD. This is because drivers may get confused of the meaning of non-standard signs. In addition, spatial compatibility is required for the design of a message in the context of communicating information to drivers. Objects in the physical environment should match the information provided in the signs *(FHWA, 2015)*. *Campbell et al. (2012)* summarized human factors that need to be incorporated into the design of roadside changeable message signs (CMS). Specifically, a good CMS design needs to maximize visibility and legibility, to choose an appropriate message length that drivers have the time to comprehend as they pass by the sign, and to compose a CMS message that is easy to comprehend. Some of these design requirements can also be considered during the design of HMI.

HMI Development Practices

In current practice, various technologies have been employed for the development of HMI. In general, these technologies can be classified into four categories *(Peter et al., 2014)*: mechanical interfaces, acoustic interfaces, visual interfaces, and haptic interfaces, respectively.

Mechanical interfaces require a mechanical control from the driver, which could be: press by hand, finger or foot; pull, slide or rotate by hand; or touch by hand or finger. The interfaces include pedal, steering wheel, button, switch, stalk, slider, and controller knobs. Some advanced practices have been developed in these ordinary interfaces to enhance the driving performance on roads such as electronic throttle control, electrical break systems, electrical steering systems, etc. *(Wang et al., 2016)*. Acoustic interfaces are common output interfaces since an acoustic (or auditory) interface does not require the driver to take off his/her eyes from the road, hence it could present a safer output than the visual one. These interfaces include beepers, voice feedback (i.e., warning messages), and voice control. Beepers are well-suitable for warning functions. However, it provides unknown information unless the driver recognizes the source of the beeper. In automated vehicles, the voice feedback interface has been improved to provide information about navigation systems, telecommunication systems, and safety warning messages. Voice control is a recognition-based interface that allows the driver to provide voice driving commands.

Visual interfaces are usually used to communicate continuous information in non-critical events. This is because visual messages could fail to deliver important information if the information displayed goes unnoticed by drivers. Over years, numerous visual interfaces were included in vehicles to suit different applications of automated and connected vehicles. The interfaces were promoted to indicator lights, LCD Displays, Organic Light Emitting Diode (OLED) displays, and Head-up Displays (HUD). However, one of the most detrimental effect of using visual interfaces is the increasing of visual workload *(Engström et al., 2005)*. Potential applications where the use of visual warnings a recommended is for the case where a visual warning is used to spotlight redundant or supplemental information that is provided in combination with an auditory or haptic warning as the primary modes of warning for imminent crash threats. Haptic interfaces provide the driver with information through the driver's tactile sense without requiring visual confirmation. Over the past few years, haptic information devices were developed to help the drivers focus on driving to increase safety and reduce inattention. Such as lane-keeping warning system that develops reaction torque when departing from the lane *(Motiglio, et al. 2006)*, and the haptic steering interface *(Steele and Gillespie, 2001; Boyle, 2012)*, which can give navigation by developing sequenced pulses on the wheel clockwise or anticlockwise according to the required direction.

Assessment of HMI Design

The most commonly used HMIs design assessment methodologies found in the literature are based on: 1) stated-preference questionnaire surveys; 2) field experiment testing; and 3) driving simulator testing. For questionnaire survey method, *Bazilinskyy et al. (2015)* conducted an international survey to gather drivers' opinions and preference on auditory interfaces. The results showed that the auditory interfaces are preferred for the application of Parking Assistance (PA) and Forward Collision Warning (FCW) systems. Another world-wide survey conducted by the Accenture Connected Vehicle Services *(Accenture Consulting, 2016)* showed that traffic conditions, and weather information are the most popular HMI applications. For field experiment method, *Fitch, et al. (2014)* investigated whether Collision Avoidance Systems (CASs) should present individual crash alerts in a multiple-conflict scenario or present only one alert in response to the first conflict. This is because in reality, secondary alerts may startle, confuse, or interfere with drivers' execution of an emergency maneuver. Testing results showed that drivers who received both the Forward Collision Warning (FCW) and Lane-Change Merge (LCM) alerts were significantly faster at steering away from the lateral crash threat than the drivers who received only the FCW alert. *Song, et al. (2016)* evaluated driver's response to HMI under two different types of warning systems, emergency warning and general warning, by combining various modalities. Study results showed that for emergency alerts, the most effective warning information was transmitted by integrating "*voice, graphic, and text*" or "*repeated computer tone and text*". In the case of a general warning alert, the "*repeated computer tone, voice, graphic, and text*" combination turned out to be the most effective.

In comparison with questionnaire survey and field experiment methods, driving simulator has the advantages of testing different HMI design alternatives in a controlled safe environment with a relatively lower cost. *Cummings et al. (2007)* investigated the impacts of single versus multiple warnings on driver performance. It was found that participants' reaction times and accuracy rates were significantly affected by the type of collision event and alarm reliability. Furthermore, the use of individual alarms did not significantly affect driving performance in terms of reaction time and response accuracy. *Osman et al. (2015)* tested the location of the visual HMI display in a connected-vehicle simulator experiment. Results revealed that the majority of respondent preferred the visual display to be provided as head-up display (HUD) in mid-section of the windshield. *Jakus et al. (2015)* investigated the effectiveness of integrating multi-modal interfaces and using single-modal interfaces. Three different displays were defined: a visual display, an auditory display, and a multi-modal auditory and visual display. Results showed that the interaction with visual and audio head-up displays was significantly faster and safer. Insignificant results was found between the visual only and audio-visual displays. However, the majority of the users preferred to use the multi-modal interfaces. *Naujoks, et al. (2016)* investigated the impact of false and unnecessary alarm on drivers' compliance, and concluded that false alarms led to decreased compliance rate. *Schwarz and Fastenmeier (2017)* investigated the effects of modality (auditory vs. visual) and specificity (low vs. high) on warning effectiveness. Results showed that the effects of specificity is dependent on the modality of the warning. *Francois et al. (2017a)* compared three speedometers display patterns in a simulated truck driving setting: digital, analogue, and redundant speedometers. It was found that the digital speedometer is more efficient and less visually distracting for absolute and relative reading tasks, whereas the analogue speedometer is more effective for detecting a dynamic speed change. The redundant speedometer had the best performance when compared to the two single types for each of the three reading tasks. *Naujoks et al. (2017)* explored the potential of using visual-auditory HMI to inform drivers in a non-distracting way. Based on driving simulator testing, it was found that participants clearly favored the HMI with additional speech-based output, which demonstrated the potential of using voice warnings to enhance the usefulness and acceptance of HMI.

Research Needs

Based on this literature review, it was found that in current practice, although there have been a handful of studies regarding the design and evaluation of various HMIs, there is still no clear-cut evidence showing what are the impacts of different HMI designs on drivers' recognition and reaction to the notifications displayed in a connected vehicle environment. This is particularly critical on the evaluation of multiple CV applications that displayed simultaneously on the HMI, since over-loaded HMI information may distract driver and lead to safety issues. In addition, at present there is no specific guidelines that provide recommendations to design efficient and safe HMIs for different drivers and vehicle types. Previous studies, in general, pointed out that the design of HMI has to consider drivers' ability to perform the primary driving tasks while using in-vehicle devices; therefore, user involvement in the design process is a key point for a high quality HMI. Through the literature review, however, it was found that the current form of user involvement in industry remains at the stages of concept assessment and usability tests *(Francois, et al., 2017b)*. With consideration of the pilot deployment of CV applications in Wyoming, a comprehensive assessment of the effectiveness of different HMI display designs is urgently needed to direct an efficient and safe development and implementation of HMI within the WYDOT CV Pilot.

3) Study Benefits

The WYDOT staff recognized the importance of developing a Human Machine Interface that is effective in delivering critical information while minimizing distraction risks that might be posed by the system. This study will provide guidance and recommendations on the best HMI design options for different stakeholders and end-users on the WYDOT Connected Vehicle project. Driving Simulators have been used in many prior studies as it is a very economical and a safer option compared to field studies. The Driving simulator has been also proven as a very cost effective tool to examine a broad variety of drivers' behavior experiments and scenarios that will not be safe to test in the real world.

4) Statement of Work

Seven tasks will be carried out to complete the study as shown in Figure 2.

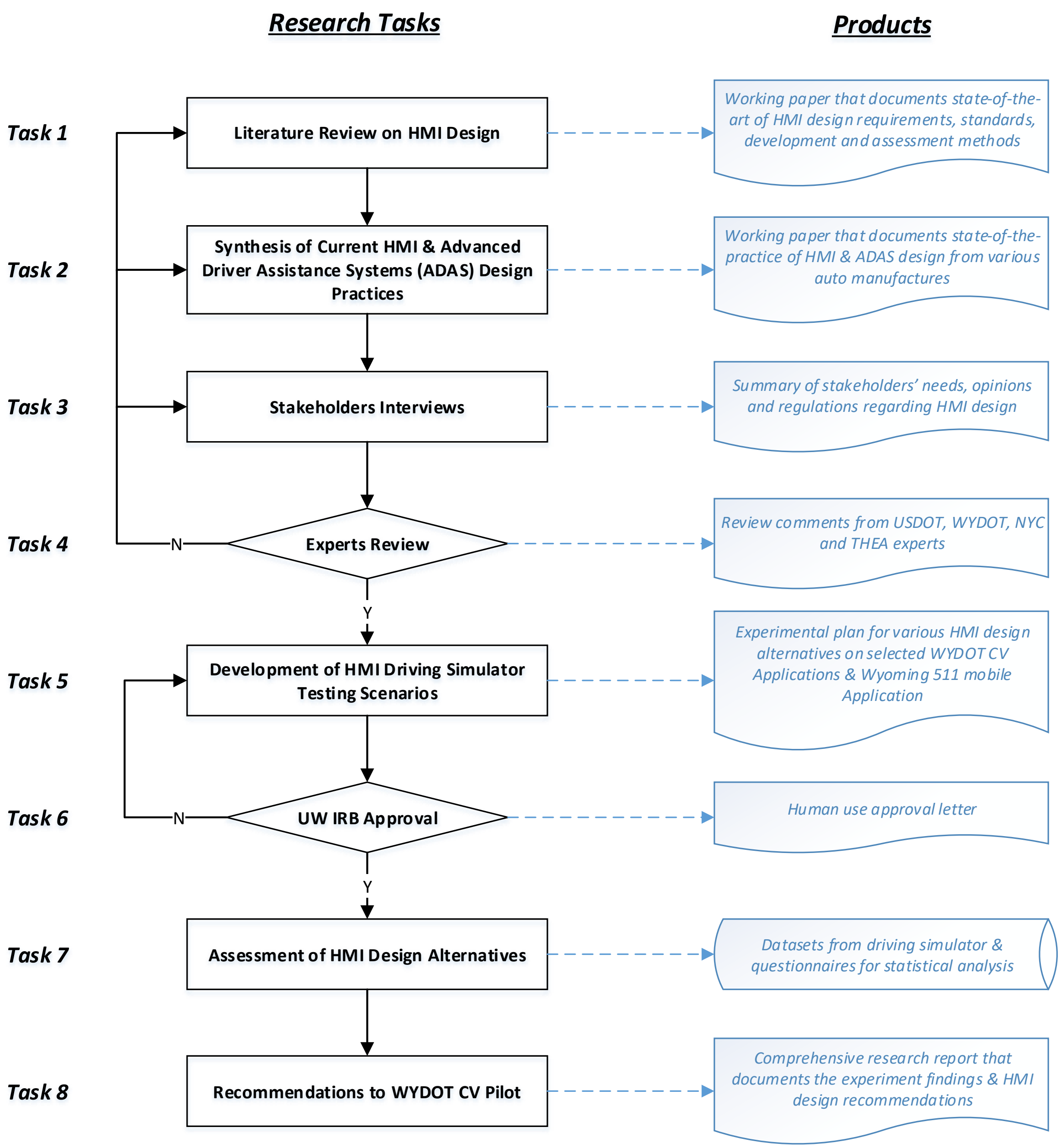


Figure 2: Proposed Research Tasks

Task 1 - Review of the Literature

A thorough review of the literature on the requirements, standards, and recommendations on developing a Human Machine Interface for Connected Vehicle technology will be carried out. Moreover, the literature on the impact of Advanced Driving Assistant Systems (ADAS) on human factors will be reviewed and summarized. Due to the fast-paced nature of Connected Vehicle technology, the review of the literature will extend over the first 12 months to ensure up-to-date information.

Task 2 - Synthesis of Existing Human Machine Interface

After reviewing the standards and recommendations in the area of transportation systems interfaces design, a review of existing HMIs from various automobile manufacturers and Advanced Driver Assistance Systems (ADAS) will be conducted. This review will help in narrowing down the best options and modalities for HMI that is more suitable to the WYDOT CV applications and their stakeholders.

Task 3 - Stakeholders Interviews

All stakeholders on the WYDOT CV project, including commercial trucking companies, Wyoming Highway Patrol, etc. will be interviewed in person or by phone. The main objective of this task is to collect stakeholders' needs, regulations and preferences on the proposed HMI design options for WYDOT CV applications.

Task 4 - Expert Reviews

While expert usability review of the proposed HMI options may not offer the level of confidence that observing real users does, it is a powerful tool to collect independent opinions on the HMI designs and recommendations from previous tasks. The experts will be selected from Wyoming, New York, and Tampa Connected Vehicle Pilot Deployment teams as well as the USDOT.

Task 5 - Human Use Approval

The principle investigator understands that any activity conducted as part of this study should minimize the risk to human participants, ensure participants consent and fully inform them of the possible risk associated with the research, and endorse equity and justice to all participants. The Office of Research and Economic Development at the University of Wyoming (UW) is responsible for the administration of research ethics. The PIs will work with the University of Wyoming Institutional Review Board (IRB) to get approvals to use human subjects in the driving simulation experiments. The IRB committee is composed of a diverse academic and scientific disciplines, as well as from the public. The approval procedure conforms to the US Department of Health and Human Services (HHS) regulations and policies for the protection of human subjects' rights and welfare.

For the purpose of this task, the principle investigator will develop an IRB proposal that contains a description of the purpose of the research project, description of human subject participants, recruitment procedure, number of participants, incentive to be provided, expected tasks, time needed to complete an experiment, method of data collection, participation termination process, equipment used, etc. The IRB proposal will explain the procedures of protecting the privacy and confidentiality of the participants (e.g., how, where, and for how long the data will be stored, who will have access to the data, and other confidentiality issues). Risks to subjects should be described in detail of any reasonably foreseeable risks or discomforts to the subjects as a result of each procedure/experiment, including discomfort or embarrassment with survey or interview questions, exposure to minor pain, discomfort, injury or harm from possible side effects from using research equipment such as the driving simulator. A description of the procedure to obtain informed consent or to provide information to participants will also be included in the proposal. As part of the IRB proposal, the PI will define the actual consent forms, as well as a description of when and by whom the subjects will be approached, how information will be relayed to subjects, and how collected feedback should be submitted.

Task 6 - HMI Driving Simulator Scenarios Development and Testing

Based on stakeholders needs, regulations and preferences as well as the expert reviews, driving simulator scenarios will be developed. Scenarios will be designed one time for heavy trucks and another time for light vehicles. The scenarios will include selected WYDOT CV applications such as Infrastructure to Vehicle (I2V) work zone, I2V situational awareness, V2V Foreword Collison Warning (FCW), distressed vehicle notification, crash ahead, parking availability, etc. Different HMI modalities will be examined such as visual only, auditory beep only, auditory male/ female voice only, combination of visual and auditory, alternations of grouped vs individual visual warning signs, etc. English and other languages (i.e., Spanish, French, etc.) will be considered for voice warnings.

An example of these simulation scenarios may include two individual-alert scenarios (forward collision warning and slippery road surface) or three multiple-alerts scenarios (work zone with forward collision warning in fog, slippery road surface due to snowy weather, and road closure due to accident in severe weather). Other scenarios will be developed according to WYDOT GIS/ITS department requirements and stakeholders needs.

Task 7 - Assessment of Drivers using CV HMI and Third-Party CV Mobile Applications

The study will recruit 80 drivers in total over the two years study period. In the first year, 40 professional heavy truck and snowplow drivers representing different stakeholders will be recruited to assess their preferences and performance with respect to different HMI options. In the second year, the study will recruit additional 40 light vehicle drivers to assess their preferences and performances with respect to various HMI alternatives and modalities. Moreover, other third-party applications such as the Wyoming 511 CV mobile application will be considered. The assessment will be conducted utilizing a driving simulator located at the University of Wyoming and survey questionnaires. A Cognitive Work Analysis framework will be utilized to provide recommendations for the best HMI design for WYDOT Connected Vehicle applications. Each participant will be provided a $50 gift card as an incentive for participation and completion of the simulation experiments.

Task 8 - Recommendations

The final task of this research will provide recommendations for HMI design options for various users, i.e., heavy trucks, snowplow, and light vehicles drivers. The study will aid in a better understanding of the adverse impacts of CV technology (i.e., interaction with in-vehicle HMI) on participants and will work on reducing these risks or eliminating them all together. In addition, the research results will benefit both the scientific community and authorities responsible for traffic safety and 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.

5) Work Plan and Implementation Process

Project Kickoff Meeting

A kick-off meeting shall be scheduled to occur within the first 30 days of execution by the University. The preferred method for the kick-off meeting is via teleconference or video conference. At minimum, the project manager and the principal investigator will attend. The

Research Center staff must be advised of the meeting and given the option to attend. Other parties may be invited, as appropriate. The subject of the meeting will be to review and discuss the project's tasks, schedule, milestones, deliverables, reporting requirements, and deployment plan. A summary of the kick-off meeting shall be included in the first progress report.

Deliverables

Quarterly progress report will be submitted. In addition, any major achievement, i.e., the completion of tasks will be reported to the project managers. Conclusions about HMI best designs will be reported immediately to the project manager to ensure timely implementation within the Wyoming Connected Vehicle Pilot, draft final report and a final report incorporating the project managers' comments and corrections will be submitted at the end of the project.

Progress Reports

The university will submit quarterly progress reports to the Research Center. The first report will cover the activity that occurred in the 90 days following the issuance of the task work order.

Draft Final Report

The Draft Final Report is due 90 days prior to the end date of the task work order. The draft final report will be submitted to the WYDOT Research Center. It should be edited for technical accuracy, grammar, clarity, organization, and format prior to submission to the Department for technical approval.

Final Report

Once the draft final report has been approved, the university shall prepare the final report. The university will email the final report in PDF as well as MS Word format.

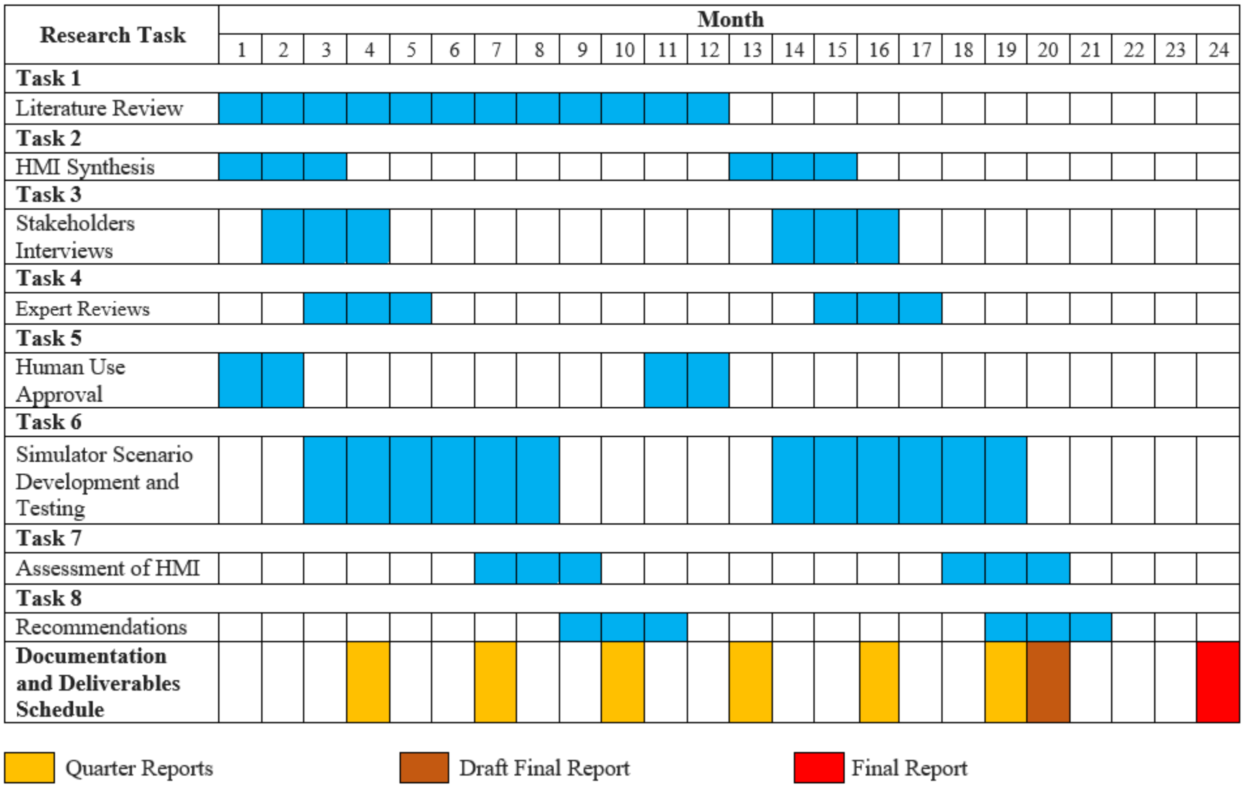
Project Closeout Presentations

The findings of this study will be presented to the WYDOT RAC at the conclusion of the project.

6) Timeline

It is envisioned that the total time required to provide comprehensive recommendations for Heavy Trucks and Light Vehicles HMI as well as third-party Connected Vehicle (CV) mobile applications, including the submission of the final report, would be 24 months beginning spring 2017. The first year will focus on developing and testing HMIs for Wyoming CV heavy trucks and the second year will focus on HMIs development and testing for connected light vehicles and third-party CV mobile applications such as the Wyoming 511 app.

Table 1: Work Plan Schedule



7) Budget

As shown in Table 2, the total cost of the project is $228,720. The total cost will cover all tasks listed above including the literature review, the stakeholders interviews, recruiting drivers for the simulator assessment, data collection and analysis, the expert review as well as technology transfer. In addition, the total 2 year cost will cover the salaries of one Postdoctoral Associate, and one month and a half salary for one faculty member over the two years. The overall cost is broken down into first year budget of $118,338 to assist WYDOT in the development of the best Human Machine Interface for Commercial Heavy Trucks and Snowplows. Second year will focus mainly on Human Machine Interface development for light vehicles and third-party mobile applications such as the Wyoming 511 app. The cost for second year is $110, 382.

Table 2: Project Budget

Budget Year 1: 2018-2019		
Heavy/ Commercial Truck and Snowplow Drivers (Total = 40 drivers)		
CATEGORY	Budgeted Amount from WYDOT	Total
Faculty Salaries	$8,848	1-month PI salary
Administrative Staff Salaries	$0	
Other Staff Salaries	$45,000	Post-Doc - 1 year
Student Salaries	$0	
Staff Benefits	$26,850.23	
Total Salaries and Benefits	**$80,698**	
Student Support Other Than Salaries	$0	Tuition/No indirects
Permanent Equipment	$500	No indirects
Expendable Property, Supplies, and Services	$11,000	Sim Warranty and Tech Support 2018
Domestic Travel	$1,500	
Foreign Travel	$3,000	
Other Direct Costs (specify)	$2,000	$50 Gift Cards for 40 Participants
Total Other Direct Costs	**$18,000**	
F&A (Indirect) Costs	$19,640	20% WYDOT
TOTAL COSTS for 1st Year	**$118,338**	
Budget Year 2: 2019-2020		
Light Vehicle Drivers (Total = 40 drivers)		
CATEGORY	Budgeted Amount from WYDOT	Total
Faculty Salaries	$4,424	0.5-month PI salary
Administrative Staff Salaries	$0	
Other Staff Salaries	$45,000	Post-Doc - 1 year
Student Salaries	$0	
Staff Benefits	$24,644.29	
Total Salaries and Benefits	**$74,068**	
Student Support Other Than Salaries	$0	Tuition/No indirects
Permanent Equipment	$500	No indirects
Expendable Property, Supplies, and Services	$11,000	Sim Warranty and Tech Support 2019
Domestic Travel	$1,500	
Foreign Travel	$3,000	
Other Direct Costs (specify)	$2,000	$50 Gift Cards for 40 Participants
Total Other Direct Costs	**$18,000**	
F&A (Indirect) Costs	$18,314	20% WYDOT
TOTAL COSTS for 2nd Year	**$110,382**	
TOTAL COSTS for 2 Years	**$228,720**	

8) 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 traffic safety and 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.

9) Data Management Plan

A Data Management Plan (DMP) is attached to this proposal. The plan provides a description of the nature, scope, and scale of data that will be collected during the course of the project. The plan provides information on how the data will be collected, shared, where the data will be housed, who will have access to the data, and any backup strategies that will be implemented. Since this project will collect human subjects' data, the University of Wyoming Institutional Review Board will review the DMP on how the privacy, security, confidentiality, etc. will be protected.

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