MPC-686
February 10, 2022

Project Title

Developing a Collision Warning and Collision Avoidance System for WYDOT Snowplows

University

University of Wyoming

Principal Investigators

Muhammad Tahmidul Haq, Ph.D., P.E.
Postdoctoral Research Associate
Wyoming Technology Transfer Center
University of Wyoming
Phone: (307) 761-8078
Email: mhaq@uwyo.edu
ORCID: 0000-0003-3307-288X

Suresh Muknahallipatna, Ph.D.
Professor and Graduate Coordinator
Dept. of Electrical and Computer Engineering
University of Wyoming
Phone: (307) 766-3174
Email: sureshm@uwyo.edu
ORCID: 0000-0003-4153-524X

Khaled Ksaibati, Ph.D., P.E.
Professor and Director
Wyoming Technology Transfer Center
University of Wyoming
Phone: (307) 766-6230
Email: khaled@uwyo.edu
ORCID: 0000-0002-9241-1792

Research Needs

According to the National Highway Traffic Safety Administration (NHTSA), rear-end collisions are most frequent in traffic crashes causing most traffic injuries and property damages. A rear-end collision typically occurs when the leading vehicle is stopped or travelling at a very slow speed. In addition to this, driver inattention/distraction, following too close, and poor visibility due to adverse weather are the contributing factors behind the majority of such collisions. Most of the automotive companies adopted an emerging safety technology called forward collision warning and collision avoidance system to assist drivers in avoiding head-on crashes, as illustrated in Fig. 1. However, rear-end collision warning technologies are still limited to the automotive industry.

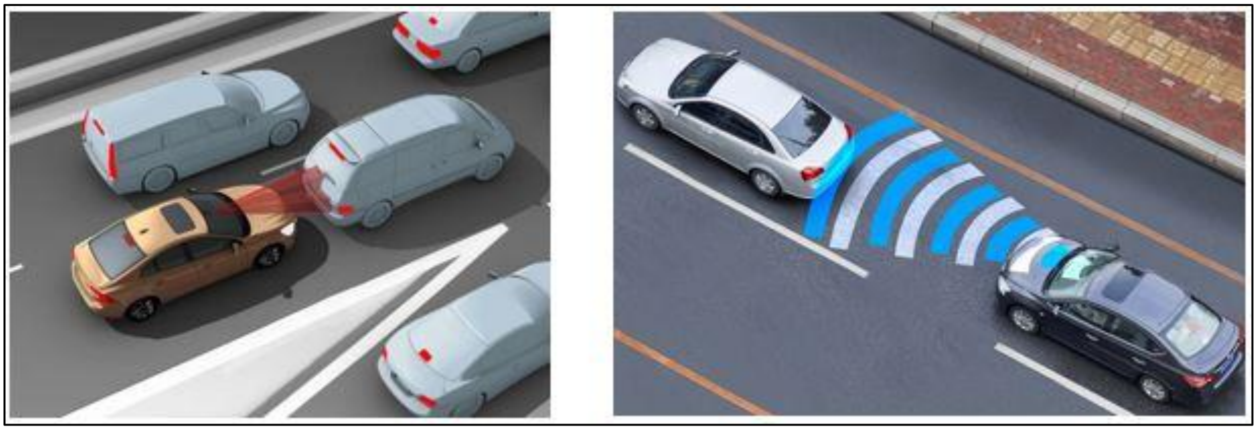

Fig 1. An Example of Forward Collision Avoidance System
(Source from left: Thiel, 2017; Data Bridge Market Research, 2019)

State Department of Transportation's (DOT's) maintenance vehicles typically operate in hazardous traffic conditions and pose a rear-end collision risk for motorists following them. For instance, snow removal and de-icing using winter maintenance trucks (commonly called snowplows or plow trucks) elevate the risk of rear-end collision between the plow and trailing vehicles as these operations are typically performed at reduced speeds directly in the roadway travel lanes, often under reduced visibility conditions. Collisions involving snowplows and other slow-moving maintenance vehicles in work-zone areas can result in substantive property damage, vehicle repair, and medical costs.

Wyoming Department of Transportation (WYDOT) own and operate various maintenance vehicles for conducting various operations. Winter maintenance of roadways is one of the major challenges for WYDOT since traffic safety and operations are severely affected by the harsh winter climate throughout the state. WYDOT spends a significant portion of its total budget on winter road maintenance. In 2015, WYDOT's winter maintenance costs were about $21 million, but between 2016 and 2020, the costs have fluctuated between $26 million and $32 million annually (Fredregill, 2020). A large number of snowplows are usually out during the winter season, maintaining the roads by clearing the snow and putting down materials to facilitate traffic movement. WYDOT's snowplows typically travel slower at speeds of 25 to 45 mph, depending on conditions (WYDOT, 2021). While operating snowplows in adverse weather, motorists often end up with rear-end crashes for poor visibility due to the disturbance of the snow. As evidenced by the February 2021 snowstorm which resulted in 10 snowplow rear strikes within five days, demonstrated in Fig. 2 (The Trucker, 2021).

Public driving into a snow cloud, not realizing they are following too close to the plow and hitting the backend of the operating truck. Although WYDOT officials urge motorists to stay a safe distance behind a plow until it is safe to pass, the occurrence of snowplow strikes has become regular over the past few years. Based on the WYDOT crash database, 121 crashes involving snowplows were recorded for the last five years (2016-2020), resulted in 239 vehicles involvement. Fig. 3 provides the year-wise breakdown of those crashes. As seen, there were 22 crashes for the 2015-2016 winter season, 13 crashes for 2016-2017, 25 for 2017-2018, 31 for 2018-2019, and 30 for 2019-2020, indicating an increasing trend. In other words, an average of 24.2 snowplow trucks is hit each year. In the case of a two-lane road, motorists passing a snowplow on the right side often end up colliding with a wing plow that sticks out from the side of the truck.

Fig 2. Collision of Snowplow near Rawlins on Interstate-80
(Source: The Trucker, 2021)

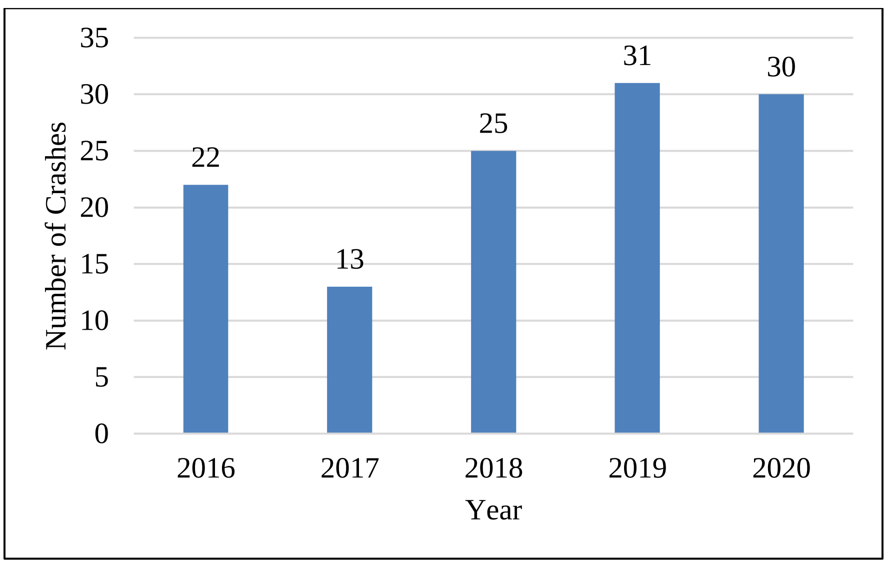

Fig 3. Year-wise Crashes involving Snowplows from 2016-2020

WYDOT's other pavement operations such as highway stripping, sweeping, pothole filling, and friction testing also involve slower-moving vehicles, as illustrated in Fig. 4. These slower-moving vehicles at work zones also face a considerable threat to rear-end crashes due to the absence of properly equipped collision warning and collision avoidance systems. Therefore, developing low-cost rear-end collision warning systems for WYDOT maintenance vehicles should be one of the major concerns nowadays.

Fig 4. An Example of Slower-Moving WYDOT Vehicles
(Source: WYDOT District 4 Facebook Page)

The color and type of warning lights are always critical components to warn the drivers that they are approaching a maintenance vehicle. The Wyoming state legislature has recognized the need for different colored warning lights to prevent rear-end collisions with snowplow trucks. In 2017, the Wyoming legislature passed a law allowing the use of one or more flashing blue, white, or amber lights, visible from five hundred feet in front of the vehicle (Wyoming Legislature, 2017). However, some recent studies recommended the use of green warning lights to detect and recognize the snowplow (Ohio DOT, 2012; Michigan DOT, 2018, 2020; Missouri DOT, 2018), which could be more efficient for the motorists in order to respond appropriately. Therefore, evaluating the type and appropriate color or a combination of the color of warning lights should be necessary to maximize the conspicuity of WYDOT's maintenance vehicles.

Research Objectives

The main goal of this study is to develop a collision warning and collision avoidance system for WYDOT snowplow trucks and other maintenance vehicles –

- To maximize the capability of preventing crashes and
- To minimize the severity of crashes.

In support of this broader goal, the study is aimed to fulfill the following five objectives:

1. Develop a rear-end collision warning and collision avoidance system using multiple sensors based on the outcomes from an extensive safety analysis, simulation models, and the responses from the surveys.
2. Evaluate the performance of color and type of warning lights in reducing crashes involving snowplows and other maintenance vehicles.
3. Test the performance and effectiveness of the prototype using a WYDOT's winter maintenance truck equipped with the technology and proposed warning lights.
4. Perform a benefit-cost analysis of the proposed collision warning and collision avoidance system before the full-blown implementation of the final products.
5. Develop a guideline on how the subset of multiple sensors with warning lights from the proposed warning system can be transferred and employed in other slow-moving WYDOT maintenance vehicles to reduce the potential risk of rear-end collisions.

To develop a rear-end collision warning and collision avoidance system, the required number and type of sensors (e.g., rear-facing Lidar or Radar) will be developed and tested on the maintenance vehicles. The potential idea is to have technology that will activate if a vehicle enters within a designated distance behind the maintenance vehicle. Once a vehicle is within this designated area, the LED lights would become larger and brighter than the normal lights on the back. If this did not alert the trailing vehicle behind the maintenance vehicle and it continued to get closer, a warning light with a rear-facing air horn would sound to alert both vehicles. Another advantage of this system would provide advance warning to plow operators considering differential speeds, minimum acceptable distance, and appropriate reaction time. While receiving the warning signal, the plow operator could raise the plow to reduce the disturbance of the snow cloud. This action would allow the oncoming vehicle to see the plow and avoid a collision. Also, the advance warning by developing the minimum acceptable distance and adequate perception-reaction time would allow the plow operator to move away from the travel lane and avoid a collision. In summary, the study seeks to provide a comprehensive information of benefits of using the proposed collision warning and collision avoidance system.

Research Methods

The method of this research will include the following steps:

At first, a literature review will be conducted regarding the existing research studies, guidelines, and best practices from different agencies related to winter highway maintenance. The literature review will provide some recommendations to establish the design criteria for rear-end collision warning systems, analysis methodologies, results interpretation, and potential strategies for implementation. Also, a review of available technologies and their effectiveness will be studied to see if any current DOTs have such technology operational.

Then, a survey will be performed on WYDOT's maintenance personnel including snowplow operators to collect information regarding the current practices, challenges, safety concerns, and expectations while doing maintenance operations. The research team will divide the survey into two sections: 1) Survey on Wyoming Snowplow Operators and 2) Survey on WYDOT's Snowplow Safety Subcommittee. The questions of the survey will be related to safety for the maintenance vehicle operators and may include the following information:

- Operating speeds of snowplows under different weather conditions.
- Major challenges and safety concerns for winter maintenance/other highway operations.
- Preference on type of warning system (e.g., voice-activated, flashing lights, lights with different colors indicating warning severity, etc.).
- Suggestions regarding corrective actions in response to a warning (e.g., plow lifting, move onto the shoulder, etc.).

Afterward, a comprehensive safety analysis will be performed by preparing historical crashes involving snowplows with the level of details associated with each crash. Descriptive statistics will be provided indicating the trends of the crashes involving snowplows. The reasons behind significant spikes will be examined. The research team will also investigate the contribution of any unexpected weather conditions (e.g., sudden snowstorm/slush) behind crashes. To overcome any missing information in the crash database, the research team will conduct phone interviews with the drivers involved in crashes. After analyzing descriptive statistics, an advance statistical model will be developed to identify the significant contributing factors related to the crashes involving snowplows. A special analysis will be conducted to determine if the snowplows crashes are taking place near the turn arounds where the snowplow drivers need to slow down considerably to turn around. In addition to this, a GIS map could be developed for snowplows crash locations. The map will be used to perform a more refined analysis to study hot spots with the intensity of snowstorms. Color coding will be provided to clearly identify trouble locations. Such maps will provide WYDOT with valuable information to determine where to concentrate their efforts on improving snowplow operation and safety with respect to snowfall intensities.

The next step focuses on evaluating the effectiveness of using different colors and types of warning lights in maintenance vehicles. WYT2/LTAP center will be working in collaboration with the WYDOT's snowplow safety subcommittee to accomplish the task. Two different field tests will be developed and performed. The first test will be conducted by WYDOT's snowplow safety subcommittee to evaluate the effectiveness of green warning lights. A tentative description of the test is outlined below:

- The test will be performed by replacing the single blue light with green at the right rear corner of the sander (passenger side), and replacing an amber cab light with a dual amber/green light on the top left corner (driver side) of the snow plow dump box to investigate the use of green warning lights against blue lights on improving snowplows safety.
- 10 snowplow trucks will be used and equipped with the proposed arrangement of warning lights. WYDOT has five field districts that will provide the testing snowplows (each contributing two, which will sum up a total of 10).
- The testing snowplows will be driven along different classifications of roads. For instance, some will be driven along interstates while some on the primary (principal arterial) or secondary roads (collector and local roads).

The second test will be more comprehensive and it will be performed by the WYT2/LTAP center. Instead of evaluating the use of only green warning lights, the research team will investigate various possible color configurations to identify the most suitable multiple combinations of warning lights under different weather and daylight conditions. A tentative description of the test is outlined below:

- Snowplow trucks will be equipped with different combinations of colors (blue, green, amber, and white) and the type (LED vs. regular) of warning lights, which will be tested to determine the best warning light configuration.
- The tests will be performed under different weather and daylight conditions, while each identical condition will be utilized to determine the appropriate combination of light based on the feedback on visibility distances provided by the driver of the trailing vehicle behind the snowplows.
- Visual impairment (e.g., short-sighted during the night, color blindness, etc.) will also be taken into account while performing the field test.

Next, the research team will develop several simulation models to determine the minimum acceptable distance and perception-reaction time for various differential speeds between the snowplow and the approaching vehicle. The simulation models will help to determine the effectiveness of distance measurements by multiple sensors to allow the operator or the approaching vehicle to avoid a crash. In addition to this, the different color combinations of the warning lights could also be evaluated in the simulation environment and the results can be validated using the findings from the field study.

The next step involves prototype instrumentation development and software set-up. The hardware of the prototype device shown in Fig. 5 will consist of three sensors, namely, the thermal camera with a recognition range of 2000 ft, a radar with a distance range of 600 ft, and a LIDAR with a distance range of 200 ft interfaced to an embedded computer with graphic processing unit compute capability for near-real time analysis and machine learning algorithm execution. The stepwise operation to detect a vehicle, vehicle distance, vehicle lane position, warnings to snowplow driver, turn-on warning lights, and raise the snowplow is shown in Fig. 6.

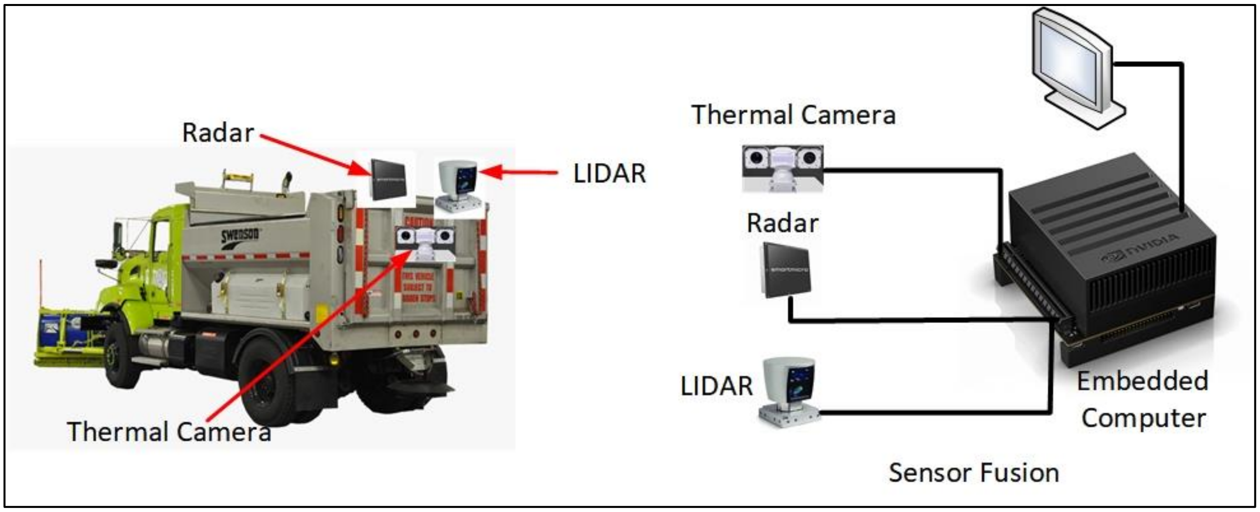

Fig 5. Hardware Prototype

The software framework flow is designed to detect a vehicle, vehicle distance, vehicle lane position, warnings to snowplow driver, turn-on warning lights, and raise the snowplow. The multiple levels of rear vehicle detection operations are as follows:

Level 1: Using the thermal images with a Machine Learning (ML) algorithm, the IR energy source detection and the distance estimate of the energy source will be performed. If the distance estimate is less than or equal to 2,000 ft, the thermal image will be passed to Level 2 recognition operation.

Level 2: In level 2, using the object segmentation ML algorithm, the IR energy source will be classified it as a vehicle or not. If the IR energy source is classified as a vehicle, warning information will be provided to the snowplow driver. Furthermore, the Level 3 distance measurement will be triggered using the radar if the estimated distance from the thermal image is less than 600 ft.

Level 3: The radar being an active device, will provide an accurate distance measurement of the vehicle. By analyzing the distance measurements produced by the radar sensor and thermal camera together, false positive and negative warnings will be eliminated. If the radar distance is below 600 ft, a vehicle close proximity warning will be provided to the driver. Also, the LED warning light of an appropriate color will be turned on, indicating to the rear vehicle driver the presence of a slow-moving maintenance vehicle. If the rear vehicle continues to move further towards the snowplow, and the radar distance measured is 200 ft, the Level 4 LIDAR detection will be triggered.

Level 4: In level 4, the LIDAR sensor will be used to perform a scan to construct a 360º point cloud. Using another ML algorithm, fine granular distance measurement will be performed along with the detection of rear vehicle position (attempting to pass the snowplow truck). Based on the position of the rear vehicle, a sound warning and LED warning light of an appropriate color will be triggered. If the detected vehicle position indicates a passing attempt, the snowplow will be raised to reduce the snow plumes.

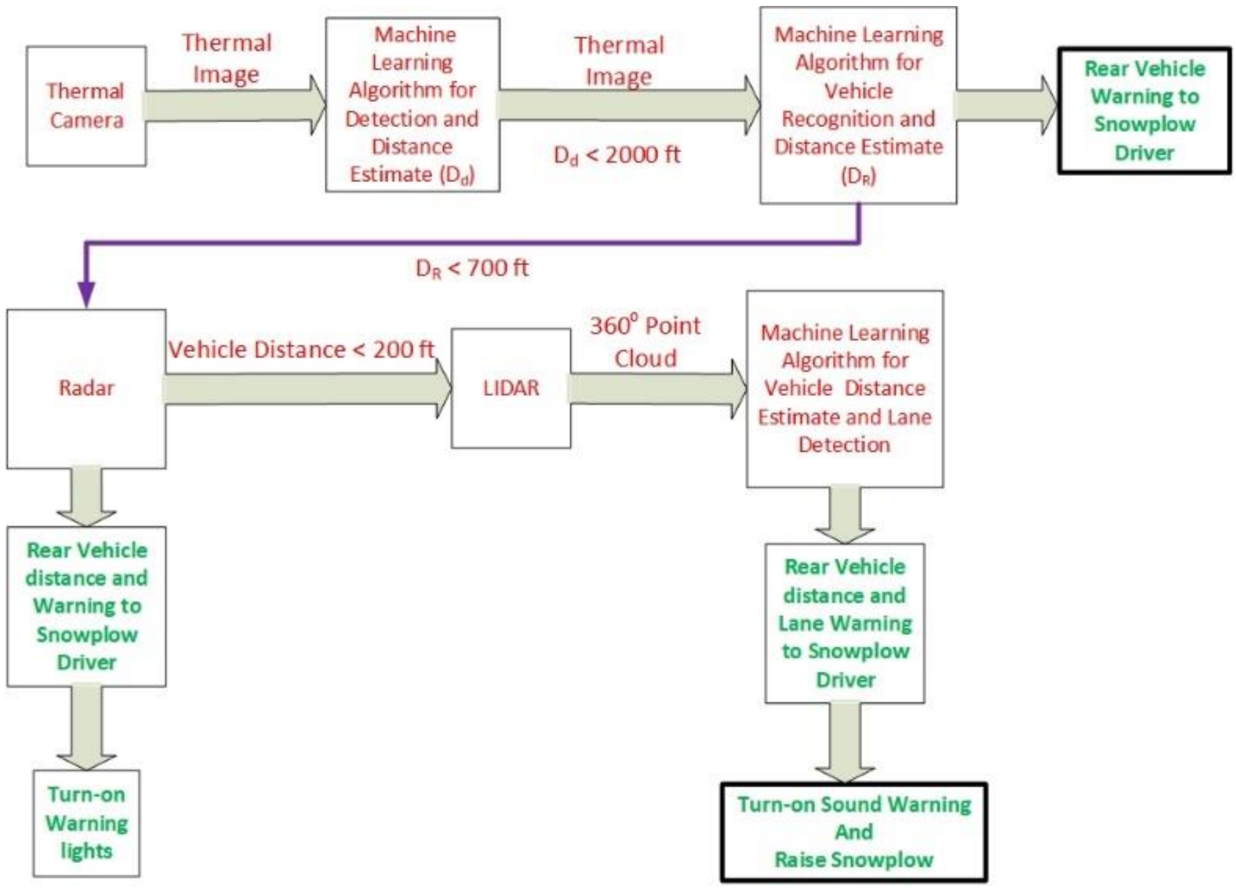

Fig 6. Software Framework of the Prototype Device

After developing the prototype, a Benefit-Cost analysis (BCA) will also be performed before the full-blown implementation to compare costs to DOT vehicles and downtime, man-hours lost vs. installation and operation of the protection system. In addition to this, the research team will evaluate the monetized value of the crash cost savings for installing the warning systems.

In the last step, the research team will develop a guideline on how a subset of multiple sensors along with the warning lights from snowplow trucks can be transferred and employed in other slow-moving maintenance vehicles to reduce the potential risk of rear-end collisions. Finally, after the installation of the warning systems, a before-after crash study will be performed to see if the number of snowplow-related crashes declines.

Expected Outcomes

The outcome of this project is a set of collision warning and collision avoidance systems containing multiple sensors and warning lights to be used by WYDOT and other jurisdictions in the state. This system would be essential for not only improving the safety of snowplow operation but also for reducing the potential risks of a collision involving other maintenance vehicles at work zones nationwide. To be specific, the following deliverables are expected from this study:

- Responses from the surveys.
- Best operational warning lights configuration.
- Results of comprehensive safety analyses.
- Simulation outcomes.
- Feedback from the snowplow operators equipped with the collision warning systems.
- Final prototype fully developed with ITS technologies.
- A manual describing how to set up the advanced prototype, conduct field experiments, and interpret results.
- A full-blown implementation plan.

Relevance to Strategic Goals

USDOT has five strategic intent areas, one of which is the safety area. This research project is anticipated to enhance the safety of motorists and snowplows or other maintenance vehicle operators. Therefore, it is classified under the safety area. This study is aimed at significantly cutting the number of crashes, particularly rear-end and sideswipe crashes involving any maintenance vehicle, during snowplowing operation in winter and other maintenance operations in summer in the state. The liability to WYDOT is extremely high if the safety of the maintenance operators is not ensured correctly. The detail provided regarding the methodology in the previous section elaborated the methods to reach each of the goal.

Educational Benefits

Students will be involved in all aspects of this study, and it will provide a good material for transportation courses in safety, operations, planning, and Intelligent Transportation Systems (ITS). Since the study contains multiple tasks including survey, field experiment, data collection, and data analyses, this fact cannot be possible except by providing an organized group of the students to do the project together as a teamwork activity. The data analysis will include safety methodologies (e.g., statistical and machine learning techniques), simulation modeling, as well as various software tools, giving the students an opportunity to expand their knowledge in these fields.

Technology Transfer

The study team will submit the findings for publications in various Journals and possibly for presentation at the Transportation Research Board (TRB) Annual Meeting.

Work Plan

1. Literature Review
2. Comprehensive Survey
3. Extensive Safety Analyses
4. Evaluating Color and Type of Warning Lights
5. Simulation Models
6. Prototype Instrumentation Development and Software Set-Up
7. Field Testing of the Prototype
8. Benefit-Cost Analysis
9. Initial Implementation of the System
10. Transferability of the Technology to Other Maintenance Vehicles
11. Establishing Educational Program
12. Preparing the Final Report and Full Blown Implementation Plan

The entire study is anticipated to be completed in 28 months after receiving the notice to proceed from WYDOT. Progress reports will be provided to WYDOT quarterly. The proposed timeline of the study is presented in Fig. 7. This will be the main timelines, however, some of the tasks will be conducted throughout the entire study (such as literature review with new information, newly available methodology to improve the proposed system, and progress reports). The findings of some of the tasks such as the warning lights can be shared with WYDOT immediately for quick implementations prior to the completion of the study.

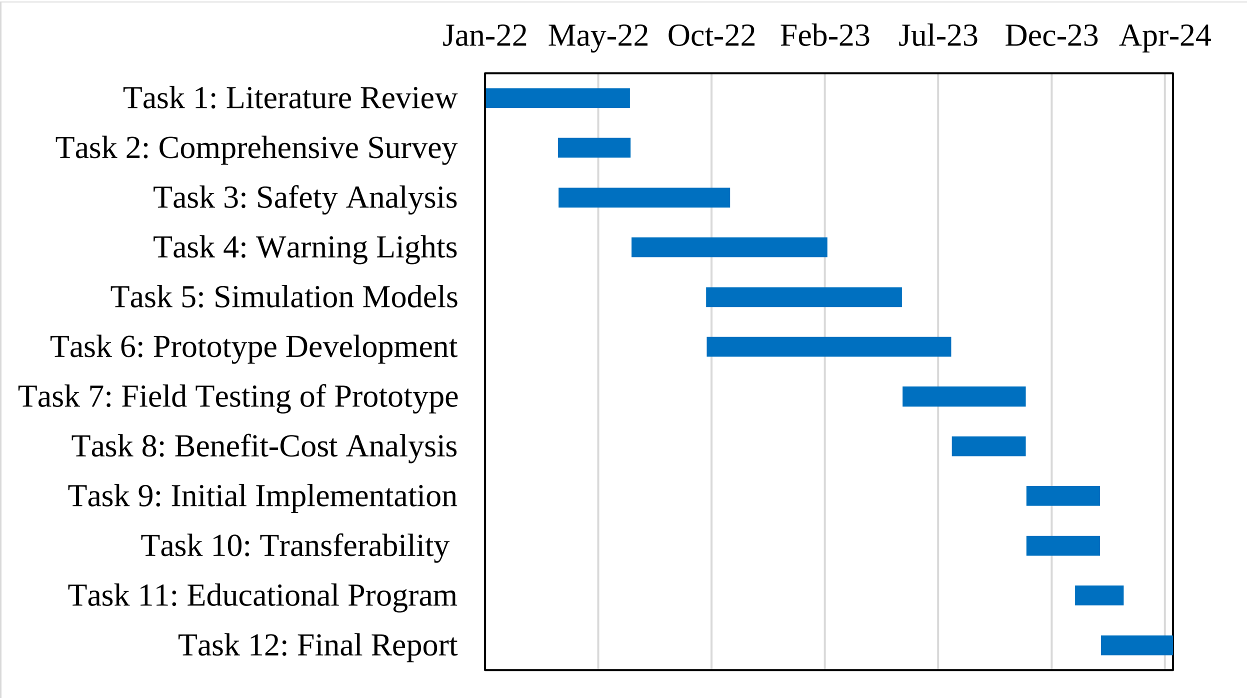

Fig 7. Proposed Study Timeline

Project Cost

Total Project Costs:	$276,949
MPC Funds Requested:	$106,903
Matching Funds:	$170,046
Source of Matching Funds:	Wyoming Department of Transportation

References

Data Bridge Market Research. (2019). Forward Collision Warning System for Automotive. openPR. Retrieved from https://www.openpr.com/news/1786541/forward-collision-warning-system-for-automotive-key-players-are-delphi-technologies-robert-bosch-gmbh-denso-corporation-autoliv-inc-becker-mining-wabtec-corporation-siemens-collins-aerospace-alstom-general-electric-honeywell-international-inc.html

Fredregill, I. (2020). WYDOT Spends 30% of Budget to Keep Wyoming Roads Clear During Winter. Cowboy State Daily. Retrieved from https://cowboystatedaily.com/2020/02/04/wydot-spends-30-of-budget-to-keep-wyoming-roads-clear-during-winter/

Michigan DOT. (2018). Evaluation of a Collision Avoidance and Mitigation System (CAMS) on Winter Maintenance Trucks. Final Report, Michigan Department of Transportation.

Michigan DOT. (2020). Effectiveness of Green Strobes on Winter Maintenance Vehicles and Equipment. Final Report.

Missouri DOT. (2018). Evaluation of Green Lights on TMAs. Final Report

Ohio DOT. (2012). ODOT Gives Snowplows, Drivers Green Light for Winter. Retrieved from https://ttspec.com/wp-content/uploads/2018/07/ohio-dot-green-lighting.pdf

The Trucker. (2021). Multiple snowplows hit on Wyoming interstates, highways over five-day period. Retrieved from https://www.thetrucker.com/trucking-news/the-nation/multiple-snowplows-hit-on-wyoming-interstates-highways-over-five-day-period

Thiel, W. (2017). GEAR UP: 4 Accident Avoidance Systems You Can Add to Your Car. Web2carz. Retrieved from https://www.web2carz.com/autos/everything-else/6310/gear-up-4-accident-avoidance-systems-you-can-add-to-your-car

WYDOT. (2021). Multiple snowplows hit over a five-day period. Retrieved from http://www.dot.state.wy.us/news/multiple-snowplows-hit-over-a-five-day-period

Wyoming Legislature. (2017). General lighting restrictions; authorized emergency vehicles. SENATE FILE NO. SF0019. https://wyoleg.gov/2017/Introduced/SF0019.pdf