A Study of a Traffic Controlling Robot for Safer Work Zones

Interactive Qualifying Project

Submitted for Approval to: Professor El-Korchi and Professor Mallick

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Abstract

Roadway construction sites are potentially dangerous work zones and pose a significant challenge to contractors and State Highway Agencies for maintaining adequate safety of workers and the traveling public. Currently, the use of humans and traffic signs are the typical methods of maintaining work zone safety. The purpose of this project is to explore the use of an advanced, autonomous and robotic system that has the ability to monitor traffic and provide real-time alerts to workers and motorists to increase safety in a roadside construction zone. Through a literature review, a survey of the traveling public and highway agencies, and analysis of the survey data, recommendations for the integration of a robotic system that could enhance the safety of roadway construction zones are provided.

Introduction

In today's world, there are numerous issues concerning the common motorist and the safety of roadside construction workers who have to operate in close proximity to them. Things like negligent driving and speeding pose some high concerns and threats to the roadside construction worker. Recommendations were evaluated and examined to make in terms of having a device with the ability to monitor roadside construction workers as well as ongoing traffic. The team has completed extensive research in today’s most innovative technologies to deliver the best device possible.

The United States has more than four million miles of roadways, and more than sixty percent of freight is transported on highways [1]. Therefore, keeping roads in functional condition is a top priority for the highway agencies. Unfortunately, in most cases, the entire road section cannot be closed during construction because of significant effect on the economy. Therefore, road construction and maintenance work is typically carried out in one or two lanes, while keeping the other lanes open for travel. This partial closure of roads leads to a significant challenge for maintaining work zone safety.

Construction is one of the least automated industries in the world. Manual intensive labor is the central source of work. The construction field is part of a $10 trillion-dollar global industry that is afflicted with difficulty in efficiency and safety hazards [2]. Robots are different as they do not experience human fatigue and will operate for extended periods of time without human error. The fewer injuries that occur will result in a faster schedule and lower operating costs involved in workers’ compensation. Robots and automated systems combined on a job site are able to solve these problems, make small differences in the operating expenses, and overall create a safer industry.
Our group followed a detailed procedure using a multitude of techniques to gather data about whether or not an automated safety system for roadway construction sites is possible to create. The current available technologies were examined to see if they could be integrated into the system. The likelihood that current technology could be utilized to improve the safety of roadside construction zones was considered.

Stakeholders were identified providing input about the current situations related to this area of research. These stakeholders were important to utilize in order to gain first hand knowledge about specific topics and scenarios that did not get highlighted in the original research. The data collected from the stakeholders was produced through a series of interviews, questionnaires, and surveys, each made systematically to provide important feedback. Once all the data was collected, a careful analysis of every aspect that has to do with the framework of this system was evaluated. The most practical and effective features were methodically chosen and justified with the intent of proposing a possible design structure based on the research conducted and survey response analysis.

Literature Review

The research conducted was aimed at finding the leading causes for unsafe roadside construction zones, and to discover current methods and technologies that increase worker safety in all work environments. Conducting research on safety methods implemented in environments that have similar dangers to a construction zone, which include heavy traffic, moving machinery, and other operating workers, provide insight in order to develop the most effective construction safety system. Research was also conducted to discover common driver tendencies that cause potential dangers for roadside construction workers.

According to the National Census of Fatal Occupational Injuries in 2017, the leading cause of fatalities were related to transportation incidents involving motorists and roadside workers. The transportation and material moving occupational group and the construction and extraction occupational group accounted for 47 percent of worker deaths in 2017 [3]. Due to these findings, the research for this project was concentrated on the current safety procedures and technology. From this research, further analysis was conducted to formulate an outline for the proposed functions and design of the system.

Current Practices

Use of Flaggers

Flaggers often work long shifts both day and night, and in hazardous weather conditions, leading to the flagger experiencing fatigue. Currently, flaggers are used to control and monitor traffic on road and highway work zones. The typical layout of a construction site on a roadway or highway has the flagger, or
traffic guard, at a distance from the site to control the flow of traffic. These men and women are usually the first ones to be seen when driving past a construction site. The main responsibilities of a flagger are to direct traffic in a safe manner while standing directly in the line of traffic, but the flagger is not directly coordinating the traffic flow with the workers. While being a flagger is not a desirable job by only making around 12 dollars an hour on average [4], it is an important one. They have a great deal of responsibility, however, their safety is compromised due to natural human fatigue and distractions. As traffic monitors, flaggers must be clearly visible to oncoming drivers. However, not all roads are designed the same. Some roads may have a curve, a change in elevation, or site blocking obstacles that make flaggers less visibly apparent. In addition, negligent drivers as well as fatigued or negligent flaggers make flagging a dangerous profession. Ideally, a robot could entirely replace the flagger’s job by not only being programmed to perform the duties of a traffic flagger, but to be more effective at controlling traffic flow through road and highway work zones, ultimately limiting hazards, and keeping workers safe in the work zone.

Automated Flagger Assistance Device (AFAD)

New developments of traffic automation have been brought to light all around the world. From this, the idea of a device that can monitor traffic and make real time and accurate judgements to increase safety is the main objective of this project. For example, the Minnesota Department of Transportation (MnDOT) have implemented an automated flagger assistance device (AFAD) with the intention of eliminating the need for a human flagger to stand along the road right near traffic [5]. This device is controlled by a worker who is able to stand a safe distance away from the road and control the AFAD. Currently, the only function of this AFAD is switching displays from “STOP” to “SLOW” as seen in Figure 1. While this device alleviates potential threats to the worker, it may not be enough due to inconsistency in driver patterns. This device is part of the beginning ideas for creating a device that can be used to keep roadside construction workers safe.

*Figure 1: Automated flagger device from MnDOT[5]*
Wearables for Roadside Construction Workers

There are certain pieces of equipment that can be worn by workers to give them more protection and offer a higher level of safety on the worksite. The exoskeleton suit allows for human workers to complete more difficult tasks such as lifting heavier objects without injury. These devices take away the stress of a heavy load from squatting, bending, and walking. The result of the exosuit or wearable technology will reduce injury and strain, increase productivity, and allow for more employment opportunities. The industry is currently short of 200,000 workers, so it will give some of those with disabilities and previous injuries an opportunity to work.

There are different types of exo-suits available on the market. The exosuit can be fitted as power gloves, arm and shoulder support, back support, standing and crouching positions, and whole body suits. According to the 2018 Q4 Commercial Construction Index, 23% of contractors will adapt some sort of this technology in the next few years [6]. Nearly three quarters of contractors think that some sort of wearable technology or an exosuit will improve on site safety. Not only that, but wearable exosuit technology can improve labor productivity by being able to exert less energy while working with assisted support provided by this wearable.

Amazon’s wearable Robotic Tech Vest keeps workers safe when working near moving robotic systems. A worker is shown wearing this vest in Figure 2. With built in sensors integrated in the robots and vests, the robots are able to sense when a worker in the vest is near and will stop to avoid the worker [7]. This technology is used to blend the workspace with both humans and robots.

![Figure 2: Amazon’s wearable Robotic Tech Vest][7]

The combination of wearable technology and a central robot that recognizes each worker's location will allow for each worker to be notified of potential dangers by using 3D technology. The robot will use the 3D technology to monitor foreign objects entering the construction area and monitor its surroundings. For example, the robot will alert the worker of a truck approaching the workers location through the wearable
technology through the helmet or suit. Cars approaching the construction site at an excessive speed will be monitored through the robot and will alert the nearby workers. The suit can utilize the best of both worlds by implementing the technology of the suit and communication through the robot to maximize safety and reduce injury.

Artificial Intelligence

Artificial intelligence is a growing, innovative tool that industries are leaning towards to assist in production and safety. Germany is currently developing cameras that are able to read and react to different types of movements in certain areas. The MOBOTIX 7 System platform is built with advanced artificial intelligence software that can hold and store applications capable of a variety of uses. The Mobotix M73 Model, as seen in Figure 3, is a state of the art tool that is able to hold any application installation desired [8]. This will prove to be helpful when monitoring traffic through roadside construction zones.

![Figure 3: MOBOTIX M73 model camera][8]

This technology would be a vital asset in monitoring traffic worksites. With the capabilities of this camera, traffic can be closely watched to make sure there is not anything out of the ordinary. Not only will it be able to watch out for obscurities that could harm workers, it could also control the flow of traffic before there is a build up. Vehicle and traffic recognition software can be used to detect such problems. This camera is also capable of monitoring the workers as well as the entire site to make sure there are not any red flags that workers do not know about, such as fires or any other intrusions. This camera is also capable of monitoring the workers themselves with facial recognition software. This allows the camera to closely watch workers to make sure that they are completing the potentially dangerous tasks with complete attention to ensure a safer work zone.

There is a wide array of functioning artificial intelligence applications that can be easily downloaded and installed to the MOBOTIX M73. Applications such as “AI-Spill,” which is able to detect if a worker has
fallen, or “AI-Road 3D,” which analyzes traffic conditions and patterns, keep up the fluidity of traffic around a construction site. When all of these applications are put to use and fully integrated within our device, it will enhance worker safety and protection immensely [9].

**Intelligent Transportation Systems**

The Intelligent Transportation System (ITS) and smart work zones are used to anticipate and prevent congestion caused by highway work zones. The intelligent transportation system’s purpose is to better monitor and manage traffic flow through and around work zones to increase safety for roadside construction workers and for road users.

By minimizing delays, there will be less traffic congestion, road confusion, and aggressive drivers. Intelligent transportation systems utilize a variety of technology including portable camera systems, queue detection information, merge guidance, and variable message signs [10]. Figure 4 shows a camera system and an ITS queue detector being used to detect current traffic conditions and identify changes and abnormalities within traffic flow. After processing current traffic conditions, merge guidance is used to inform the drivers when to merge lanes for maximum safety and efficiency. If traffic is busy, drivers are instructed to merge late so all lanes can be used at once, keeping traffic flow as quick as possible. If traffic is clear, drivers are instructed to merge early to avoid confusion near the work sight and to prevent high speed vehicles from approaching the work zone and still needing to merge [11]. Along with the detection of traffic, radar guns are also attached to detect speeds of vehicles approaching work zones. Then, the variable message sign displays the appropriate message to drivers. According to vehicle speed and distance from the work zone, the variable message sign may inform the drivers that there is a work zone ahead or to slow down. Figure 5 shows a variable message sign.

![Figure 4: ITS Queue Detector](10)

![Figure 5: ITS Variable Message Display](10)
RFID Technology

In order to keep the workers safe from vehicular accidents inside of any construction zone, a system that is able to track moving objects and produce feedback when there is a possibility of an accident is necessary. A new prototype called “HASARD (Hazardous Area Signaling and Ranging Device)” has been introduced by the National Institute for Occupational Safety and Health (NIOSH) in some “construction-like areas to improve the safety of workers.” [12] This device uses RFID technology in conjunction with auditory and visual feedback to assist in preventing accidents between workers and vehicles. It utilizes, “a special secure wireless communication line of Very-High Frequency (VHF) active Radio Frequency (RF) technology near 700 MHz and consists of an in-cab device and a hand-held device.” [12] The ‘in-cab’ device is located inside of the vehicle, and the ‘hand-held’ device is kept with the workers on the ground. The devices interact through radio frequency, and when they get too close to each other, both the worker on the ground and the worker in the vehicle are alerted by a visual and auditory stimulus. Construction zones can be loud and have many moving elements at once, which could prevent a worker from noticing just a single visual or auditory stimulus alone. However, by providing both visual as well as auditory feedback in a construction zone, it allows the workers to be able to notice the stimulus and react.

LiDAR

The LiDAR is an active sensor that sends light energy to the ground in pulses and returns back to its platform. They are known for their distance measurement information having the ability to create 3D models of tunnels, bridges, and other objects. LiDAR is used in aerial surveying and can also be found in “...surveying, forestry, and urban planning...” and in Google maps cars as well. “It detects pedestrians, cyclists, stop signs and other obstacles.” [13] One current LiDAR, created by Velodyne, utilizes “...a rotating head featuring 64 semiconductor lasers, each firing up to 20,000 times per second.” This allows for a “...28.6 degree vertical field of view” [13]. When this apparatus is sped up to about 900 rpm a 360 degree field of view is created allowing computer programs to identify objects such as street curbs, trees and vehicles.

The LiDAR system is currently being used in applications of self-driving cars, topography, and other mapping-type industries. With the LiDAR’s ability to detect objects quickly and accurately, “...with accuracy of about 15 cm vertically and 40 cm horizontally...”, it could be integrated into a multifaceted system designed to increase worker safety in a construction zone [13]. A possible use for the LiDAR system is to work in conjunction with an artificial intelligence system and gain an overview of the construction site and its boundaries, in turn, being able to recognize any potentially dangerous situations and alert workers via a feedback system to prevent accidents from occurring. The LiDAR would collect a vast dataset of the environment: moving vehicles, workers, and equipment. This constantly updating dataset of the construction
zone could be processed by the artificial intelligence system, which could learn to detect possible dangerous situations in the ever-changing environments and scenarios of a construction zone.

**Airport Runway Traffic Safety**

The ability to direct airport traffic is important and deals with aspects both in the air and on the ground. One method of increasing safety that the Federal Administration of Aviation has been using is Runway Status Lights (RWSL). Runway Status Lights are positioned at the intersections of the runway. These lights automatically light up when a plane is on the runway signifying that the runway is busy. When these lights are on, it allows for other aircraft and ground vehicles to know not to cross the runway. Even when these lights shut off, the vehicles need a secondary confirmation from air traffic control that they are able to cross. The RWSL is used in conjunction with the airport’s Airport Surface Detection Equipment, Model X (ASDE-X) and Air Traffic Control. The ASDE-X is comprised of many different surveillance equipment such as, “Surface surveillance radar located on top of the air traffic control tower and/or surface surveillance radar located on a remote tower, multilateration sensors located around the airport, Airport Surveillance Radars such as the ASR-9, Automatic Dependent Surveillance—Broadcast (ADS-B) sensors, and Terminal automation system to obtain flight plan data.” [14] The data that is gathered from these devices are used together in order for the ASDE-X to be “…able to determine the position and identification of aircraft and vehicles on the airport movement area, as well as aircraft flying on final approach to the airport.” [14] The system allows for Air Traffic Control to be able to see at “...night or during inclement weather when visibility is poor” [14] and has built in alarms to alert air traffic control if an incident may occur.

The concepts behind the airport RWSL and the ADSE-X could be introduced into a traffic safety system. When an aircraft is on the runway the lights will turn red signaling all traffic that there is an obstruction, and that they should not proceed. This could be transformed and enhanced to fit into the work and traffic safety environment. These lights could be portable and easily laid out in any working traffic environment. It could work in unison with an imaging device such as the LiDAR system and/or the ADSE-X. The LiDAR system would be able to detect the moving objects in the work zone, while the ADSE-X can track the vehicle's position through an artificial intelligence platform. These devices could be used to detect vehicles entering and exiting areas to provide safety for the workers and to protect the moving vehicles. This system could be used with devices such as helmets, earphones, and exoskeletons so that not only a visual stimulus will be presented, but auditory and physical stimuli could be presented as well.

**Safety**

The safety aspects of this device are the most important considerations of the project. There are many scenarios and potential variables that need to be taken into account when analyzing and developing a device
that will lead to the safest worksite possible. Worker health and safety is the driving force behind all design and research of this project.

Currently, there are no specific Occupational Health and Safety Administration (OSHA) standards for robots involved in the construction and industry field. Part 1926 of OSHA relates to the safety requirements of construction sites, including danger signs, caution signs, exit signs, directional, and traffic signs. Section 1926.200(g)(2) states, “All traffic control signs or devices used for the protection of construction workers shall conform to standards set by the Manual on Uniform Traffic Control Devices....signaling by flaggers and the use of flaggers shall conform to standards established by the Manual on Uniform Traffic Control Devices.” [15] Since there are no safety regulations by OSHA about robots themselves, the requirements upheld by OSHA still need to be met in regard to signaling tools used for this device [16].

It is crucial to recognize the hazards present in every work environment. In addition to Unawareness when working on the job site, utilizing robotic technology can be fatal due to the human attention needed to operate it. The standards and guides for street and highway construction is found in Part IV of the Manual on Uniform Traffic Control Devices (MUTCD) [16]. The methods and uses of the robot will be in compliance with the standards and procedures of the MUTCD since there are not any for a robot at the moment [16]. The robot system may be present at detours or diversions on a road system. At detours, the traffic is directed onto another roadway and should be clearly marked the whole length, so motorists know how to return to the original highway [16]. These detours can be poorly marked and/or hard to maneuver at high speeds with little room. At diversions, traffic is diverted onto a temporary roadway.

MUTCD explains how traffic is controlled in different scenarios based on the type of roadway present. 6C-5 explains one lane, two way traffic control which includes the flagger method, flag transfer method, pilot car method, temporary traffic signal method, and the stop or yield method. 6C-5 part discusses how human flaggers are managed for this type of situation [16]. When poor visibility and traffic is not maintained by one flagger, traffic may need to be controlled by a flagger at the other end. The figure below is an example (Figure VI-3) from MUTCD of one lane-two way traffic control [16].
Figure 6: Diagram of Traffic Control During Roadway Construction (MUTCD VI-3)[16]

The main objective is for traffic control devices to safely move traffic and pedestrians through and around traffic control zones while protecting the on site workers and equipment. Part 6E discusses hand-signalizing control of flaggers, and how flaggers are responsible for the public safety of drivers, pedestrians, and all the roadside workers on the construction site [16]. The qualifications of the human flagger must meet a minimum of qualifications which include:

- Sense of responsibility for the safety of the public and workers
- Training in safe traffic control practices
- Average intelligence
- Good physical condition, including sight and hearing
- Mental alertness and the ability to react in an emergency
- Courteous but firm manner
- Neat appearance

One of the purposes of having a robotic device in a construction zone is to exceed these qualifications and minimize any faults that may be generated from human error. The section of hand signaling control also explains the clothing that must be worn for the flagger during nighttime and daytime work. The section goes on to include hand signaling devices and hand signaling procedures in depth. The flagger locations must also be placed at a location where there is enough space from the construction zone so approaching vehicles have sufficient space to slow down or stop before passing. Table VI-1, Guidelines for length of longitudinal buffer space, describes how the distance should be determined based on the approach speeds, friction factors, and pavement and tire conditions [16]. The warning signs used for the robotic device must conform to the standard
signs explained in the MUTCD. Poor recognition of warning signs will result in poor awareness of the situation. The robotic device developed will need to include these fundamentals to ensure the most effective results. Figure 7 below shows the use of hand signaling devices by a human flagger.

Figure 7: Hand Signaling Used By a Human Flagger (MUTCD)[16]

The images presented below are from an I-95 expansion project in Broward County, Florida. The same project is shown in different locations of the project in the northbound and southbound direction, as well as at night and day time. The images in Figures 8 and 9 show potential dangers and accidents that occur which would affect the safety of workers on highway projects. The nighttime images in Figures 10 and 11 show the little amount of safety lights, hazard signs, and warnings present on the job site at night. Approximately 25% of accidents occur in the evening even though less than 9% of the workforce is on the site [17]. The daytime images have little to no safety signs and warnings present which can lead to accidents as shown in Figure 8 and Figure 9. There are OSHA standards currently in effect that can be maximized with the use of a robot. The National Highway Work Zone Safety Program provides the standardization of traffic control devices and traffic control plans as well as introducing innovative technologies to improve safety. This is essential to the creation of new safety devices such as robots to enhance the safety of these construction zones. All the people present on the job site must be in accordance with MUTCD 6E-3 high visibility clothing which includes wearing a reflective bright colored vest, a hardhat, long pants, safety classes, and closed toe shoes. Flaggers are
prone to being struck by vehicles, especially in situations where the flagger is not seen by motorists and equipment operators. There is a steady increase in traffic across the country and it's not uncommon for many highway systems to increase in the number of lanes in both directions. There is often little room to work with and many cars passing by, making a single human flagger hard to see.

Figure 8: Daytime construction on I-95 Southbound (Vanscoy, 2019)

Figure 9: Accident on I-95 Southbound (Vanscoy, 2019)

Figure 10: Ineffective Safety Devices During Nighttime Construction. (Vanscoy, 2019)

Figure 11: Vehicle Passing Construction Zone at Night (Vanscoy, 2019)

Figures 8-11 were photographed by Jacob Vanscoy, Summer 2019 in Broward County, Florida
According to OSHA’s statistics of highway construction accidents, an active construction zone is expected every 100 miles on a national highway system [17]. According to the Bureau of Labor Statistics, in 2018 transportation accidents were the most common fatal incident at 2,080 which accounts for around 40% of all fatal work related accidents. Accidents involving contact with objects and equipment increased 13% (from 695 to 786), driven by a 39% increase in workers caught in running equipment or machinery and a 17% increase in workers struck by falling objects or equipment [18]. This suggests that a robotic system should be developed to slow down drivers, increase the awareness of drivers, and to encourage drivers to keep and maintain a safe following distance. There are other instances that also relate to motorists involved in accidents as this includes confusing or distracting work zones, absence of warning signs, incorrect speed limit signs, and equipment problems. These issues can be minimized or even prevented with proper communication between the work zone and drivers.

Resilience

Resilience associated with a system is dependent on its ability to continue its function due to partial damage of the system. Based on the disciplines of the systems, resilience can be defined differently. The concept of resilience is characterized as a property of the social and ecological system, which facilitates the system to acknowledge and endure changes. In the scope of engineering, resilience is a concept that has developed only within the last decade. Zhang et al. stated that the “identity of a resilient robot depends on whether there is a unique challenge or problem with the concept of resilience, thus a resilient robot.” [19] However, similar concepts such as “reliability”, “dependability”, “survivability”, “sustainability”, and “robustness” are closely related concepts to “resilience” and it is important to make the distinction.

Reliability is defined as “the ability of a system or component to perform its required functions under stated conditions for a specified period of time”; that is, how a system is sensitive to random failures [19]. Reliable systems are focused on how the system functions subject to the external disturbance; they are in the strategy of prevention and absorption during the event (robustness). The definition of dependability is the ability of a system to deliver a service that can justifiably be trusted and to avoid failures [20]. The dependable system or robot refers to the faith in a robot for its fulfillment of functions under a condition from the perspective of the user of the robot. A resilient robot adds more faith to the user. That is to say, a robot that has reliability, robustness, and resilience is a highly dependable robot. Survivability is the ability of a system or an object to live or exist, especially in spite of difficult conditions. Long-term physical survivability of most robotic systems today is achieved through durable hardware [21]. Sustainability refers to a system’s ability to sustain or to maintain itself. A sustainable robot may have redundant parts which are used to replace the failed parts when failures happen [22]. Robustness is defined as “an ability that allows a system to maintain its
functions against internal and external perturbations or noises” in that way, how a system is insensitive to noises [20]. For the robot to be robust, it must be designed by durable, weather resistant materials.

In the culmination of all these factors, resilient robots and or robotic systems must possess the following qualities: (1) durability: a component of one function that can be trained to achieve another function against the system malfunction; (2) compatibility: the ability to replace the damaged components; (3) repeatability: redundancy brought in to deal with the faults caused by an internal/external environment; and (4) cost-effectiveness: the reusage of the remaining systems to reduce costs by extending system life. In relation to the project, considerations must be made about the materials and technologies used to increase the resilience of the system.

**Sustainability**

Robots are expected to work continuously, yielding a precise desired response around the clock. A robot will need a power source to continue to work. Unlike a human, a robot does experience the emotional, physical, and mental stresses that humans do. As a result, robots can function at peak potential without any interruptions, although they do require extensive maintenance and power supply. Throughout the research, the team will explore different options to potentially power the robot for its intended purpose. The robot will need to adapt to different conditions that are present on the job site; it will experience different environmental and traffic conditions. With this in mind, there will need to be a source of power that will be able to operate through these different factors. The robot can function off of a charging battery, solar power, or a gas generator. The most reliable source of power will reduce costs in the long run and keep the robots functional at all times. Creating a source of power that is not reliable will defeat the purpose of enabling a robot to outperform a human operator and its long lasting capabilities [23].

Most mechanical vehicles and equipment on a job site are powered through batteries, gas, or electricity from a main power source. In order for the robot to function at all times, the source of power must be easily accessible and reliable in all conditions and environments. Additionally, a low costing source of power will make the robot a more appealing choice for project sites since it could be less expensive than a human worker. Gas and direct power from a main power source is the most accessible way to have power. Over time, the cost of the gas may be expensive if it is constantly operating. This is also the case if you involve the power coming from a third party to keep it running such as an electric company.

Certain components of the robot system, such as a LiDAR camera, could be powered by a computer battery. The computer battery is fairly inexpensive, portable, and easy to maintain. The computer battery would be beneficial as it could be powered through solar sources quickly and efficiently. The initial costs of
the solar panel are expensive but it would reduce costs over time since the source of energy is renewable. Solar power is a clean renewable resource that reduces the use of natural gas and other non renewable sources for electricity. Compared to non renewable energy such as natural gas, solar power produces no pollution to the environment. Solar energy also allows for solar independence as electricity will not be dependent on any main power grid in the occurrence of a power outage. A solar panel’s energy gained from the day can be stored in a battery at night [24]. Most construction projects are located outside that would allow solar sources to be easily accessible. In case the equipment fails or the power fails, a backup uninterruptible power supply system (UPS) would maintain power to essential systems and operations of the robot. The UPS will deliver immediate and continuous power against power interruptions and protects data on computer systems [25]. In case the equipment fails, the UPS could power the robotic system while the solar equipment can be replaced or fixed.

**Legal Aspects**

For a technological system or robot to perform the work of a traffic flagger, legal aspects must be taken into consideration. In 2008, road detailing was opened to Massachusetts civilians, superseding the old regulations which reserved traffic detailing to police departments and state police [26]. According to Roberta R. Schaefer [27], a long time advocate of civilian traffic flagging and former employee of the Worcester Regional Research Bureau, the 2008 regulation has had little effect on road construction sites. *Figure 10* illustrates Massachusetts spending on law enforcement compared to civilian flaggers from 2006 through 2017. From January 2017 to August 2018, civilian flaggers have only earned $511,701 while police have earned $45,141,121 on road construction projects [28]. Schaefer is quoted, “Nothing has changed as a result of that law. You still see cops standing in front of manholes drinking coffee and talking on their cell phone.” The former Massachusetts Governor, Devol Patrick, pushed for the 2008 law due to statistics showing that civilian flagging is much cheaper than hiring police officers. Additionally, at some road construction sites there is an abundance of police. If properly trained, civilian flaggers are capable of managing traffic through road construction zones. Contrarily, Worcester City Manager Edward M. Augustus Jr. believes that construction zones are always safer when police detailers are present. This debate has been ongoing for decades. However, cost and safety are not the only factors influencing who manages traffic at roadside construction zones. Police officers make a significant amount of money through traffic detailing. Because of this, police unions are unlikely to support a robot taking over traffic detailing responsibilities [27]. Regardless, there are still instances cited where flaggers and police officers prove to be incompetent, whether it be due to undertraining, fatigue, or negligence. If technology could be used to manage traffic flow, not only would states save a significant amount of funds and resources, but the risk for the civilian flagger and police detailer would be reduced.
In order to gain a full understanding of the situation it was important to research the current practices in relation to roadway construction zone safety. The team decided it was also important to look into current technologies involving automated flagger devices. In researching flagger responsibility and dangers, our team developed recommendations that can be used to reduce the amount of human error and incorporate a robotic device that enhances the safety of the construction zone. With the information the team gained, we were able to suggest improvement for certain deficiencies that these devices had, and provided educated recommendations for a device that would encompass more functionality to improve worker safety. Additionally, artificial intelligence was an interesting innovation the team thought necessary to incorporate as a helpful tool when monitoring traffic. LiDAR’s ability to detect objects quickly and accurately proved to be extremely useful given its ability to pick up vehicle motion and provide quick feedback to the device. Through these current practices the team was able to develop strong recommendations that will be useful in developing a device that enhances roadside construction worker safety.

Objective

In the development of this project, numerous aspects and considerations available were examined to understand the need for a robotic device that could monitor traffic and roadside construction workers to optimize safety for the construction zone. The objective was to determine whether there is a need for a better traffic signaling method for enhancing work zone safety, and whether a robotic system is considered to be
acceptable. The objective was accomplished through a literature review, a survey of traveling public and highway agencies, and analysis of the survey data. With the integration of today’s modern technologies and the current processes of roadside construction work, the team provided recommendations for a device that improves the safety of roadside construction workers.

Methodology

*Figures 13-17* show the flow chart of the project’s main topics and was used in the methodology behind determining the safety system’s feasibility. The flow chart was used as a method of organization of tasks and is separated into fragments as for ease of understanding and clear texts. The flow chart will be more clearly explained in the following methodology section. The completed flowchart is located in Appendix 1.

Tasks and subtasks were established and accomplished in order to achieve the desired result of examining the aspects and the feasibility of creating a system that manages traffic and monitors the workers’ safety on the construction site. The initial steps the team established were to first conduct a literature review, second to develop a survey, third to conduct the surveys, and lastly to analyze the responses from the survey. From the literature review our team made certain conclusions regarding the important points that needed to be included in the surveys.
**Figure 13:** Top left of the group’s flow chart: shows Resiliency and Purpose aspects of project

**Figure 14:** Middle of flow chart: shows title and Research and Sustainability topics

**Figure 15:** Middle of flow chart: includes Research aspects (not completed)
The team began by exploring how robotic systems and technology can be used in unison to help roadside construction workers carry out work without risking their lives. Research on current safety methods
used in all types of construction environments was conducted in order to find the most prevalent causes of deaths and injuries and what safety aspects to focus on. Through extensive survey questions sent out to various WPI students and faculty as well as DOT representatives, we were able to gain a better understanding as well as discover the underlying causes of death and injury such as speeding and distracted driving. This assisted us in shaping our analysis of the development and implementation of a device. After making observations based on current practices, the team began to conduct research on different types of technology with different capabilities that could be used together to create a system that would be able to manage traffic and monitor the workers on the construction site. This included research into robotic technology used in different industries including the Amazon exo-suit and systems used for airport worker safety. The system would have to have the ability to recognize dangers, such as speeding or distracted driving, in and out of the construction zone and alert the workers in order to maximize their overall safety.

As the group took a deeper look into the potential dangers of roadway construction and what the safety system should be able to accomplish, individual and group tasks with subtasks were identified and delegated. The group created a flowchart using the application called FlowdiaDiagrams. See chart in Appendix 1. This type of chart allows for grouping of the different components related to the project. These main components are divided into subcomponents allowing the group to differentiate between the different aspects of each topic and work on them accordingly. A Gantt chart was created (originally in Google Sheets, and later in Microsoft Project) to keep each group member on track and ensure continuous progression throughout the terms. The Gantt chart is a timeline that shows the tasks, team member(s) assigned to them, and the deadline for each task. The Gantt chart is updated weekly to track current progression. To efficiently plan weekly meetings, the group used a website called when2meet.com. Using this program, each group member was able to enter when they were available during the week. The program compiles this information and creates a chart that shows the group’s availability as a whole, ensuring that the majority of the group members will be able to attend a set meeting time.
Figure 18: Gantt Chart Displaying Group’s Work and Scheduling throughout B-Term.

The second term was dedicated to researching the wide variety of physical and practical aspects of the system in order to investigate the feasibility of the system being integrated into current practices. The group researched numerous current technologies such as LiDAR and artificial intelligence systems to examine whether or not it would be possible to incorporate them into the system. With the current advancements in technology, the group explored the possibility of future technological developments being integrated into this safety system. Based on this research the team concluded that technologies such as LiDAR and or artificial intelligence could be incorporated in the proposed robotic system to improve construction zone safety.

Societal aspects for the feasibility of this system were initially examined, such as, how the device will affect the economy, employment, the government, and the environment. Social aspects include public perception on the use of robots at road construction sites, law makers, and workers present at road construction sites in addition to other stakeholders. Part of the public perception will be affected by how the robot affects the environment. Total cost for purchasing and running the robot will also play into public and law maker perception. Cost effectiveness and environmental factors must be balanced out in order to maximize stakeholder approval. Although the group did not focus on data collection for the societal or environmental impacts, the societal factors still apply to the project. A robotic system that can enhance the safety of construction workers is a significant societal benefit. It has the potential to save lives, enhance work conditions, in addition to the economics and productivity factors associated with a better work environment.
For the literature review, the team researched the legal aspects and feasibility of the integration of a robotic system to improve construction zone safety. Certain legal aspects include OSHA regulations, state law, and federal law, which regulate different equipment and personnel required for road construction sites. Many states have not yet passed laws allowing cameras on the work zone [29]. It provided parameters for the other aspects of the system that must be met and potential guidelines that could change due to the progression of technology. Initially the team planned on assessing the legal aspects of construction and highway environments more in-depth to examine the legal feasibility of this system. However, due to the lack of sufficient data and feedback in regard to legal concerns, the group did not conduct further research on this topic.

To further solidify and improve the data collected, it is necessary to identify stakeholders and conduct research on the different aspects of the safety system according to their personal experience. The major stakeholders considered were the general travelling public, Departments of Transportation, road construction companies, and experts in the field of robotics. Surveys were sent to the WPI community and to DOT representatives to provide feedback from the travelling public and from DOTs. An interview was conducted with Professor Carlo Pinciroli from WPI, who holds a PhD in Robotics Engineering. Surveys were also sent out to multiple road construction companies, but no responses were received, most likely due to the COVID-19 pandemic. Conducting thorough research must take into account the various representatives of the construction and department of transportation industries. Some additional examples of the stakeholders that were established were construction workers, police officers, safety agencies, department of transportation officials, and engineers focused on surveillance, image detection, robotics, and artificial intelligence. Consulting the stakeholders is important because they have a deeper knowledge about their professions that can be used as data. Once the stakeholders for this project have been determined, the team conducted surveys, and interviews in order to strategically gather personal opinions, facts, and possible trends from said stakeholders. The questions were carefully formulated in order to completely eliminate bias. They were created around driver’s tendencies when traveling through a construction zone. The data collected in this process was used to decide whether or not the information gained through the initial literary analysis was pertinent to justify the recommendations our team provided for this system.

Conducting surveys is effective because they generally yield larger response populations compared to other research methods. Proper surveys are able to produce insight and meaningful results without compromising integrity due to conductor bias. To avoid bias in surveys, several considerations were taken into effect. Survey questions avoided phrasing that bias the audience into answering a certain way. This is known as a leading question. For this project, an example of a leading question could be the following. Question: Why do you think a robot with flashing lights is effective for getting drivers’ attention? This is a leading question because it provides a judgement: that the flashing lights will grasp the attention of drivers. Identifying leading
questions will be implemented during survey and questionnaire drafting. Additionally, loaded questions may bias results because survey members may answer randomly due to the fact that the question is not applicable to them [28]. An example of a loaded question would be: Do you feel safe when driving on the highway? This question assumes all respondents drive on highways. Other factors that will be considered to avoid are slang terminology, acronyms, and double negative phrasing, all of which can confuse the audience.

Surveys were conducted using google survey, and an interview was conducted with Worcester Polytechnic Institute robotics professor, Carlo Pinciroli who specializes in robotic simulators. The surveys were designed to be mostly multiple choice but had to be tailored to the target group of respondents. For the purpose of this project, groups were separated into construction contractors and companies, state DOTs, and the WPI community. A specific survey was made for each group instead of one survey for all to gain better insight into each group’s preferences, beliefs, and behaviors. The purpose behind open-ended or long answer questions is to better engage the respondents because they tend to conform with controversial norms and allow respondents to better communicate the reasoning behind their behavior. Although multiple choice questions are quick and precise which means that more of them can be utilized within one survey to give the respondents a break from long answers and provides a direct response. The combination of both open-ended and multiple choice questions within a single survey allows for the respondents to give clear answers, and allows them to provide an explanation which further aids in the conclusion made by those analyzing the responses.

The questions posed in each survey were deliberately created with each group of respondents taken into consideration. The surveys were made anonymous in an effort to provide an environment for respondents in which they would feel at ease to answer truthfully. A disclaimer was added to ensure respondents knew the results were being used for research purposes and could not be sent back to their workplaces to be used against them. Each question was drafted with the parameters of being unbiased, balanced, and straightforward. In an effort to keep the respondents engaged, the surveys were kept relatively short with the majority of the questions being multiple choice. A target group such as the WPI community or Department of Transportation (DOT) representatives were considered for each survey, and questions based on the respondents perceived knowledge and experience were formulated to gain a better understanding of their mindset towards the idea of the project. For example, a question for the DOT survey was “Do you believe that non-human devices are capable of improving roadside construction worker safety?” which was asked with the purpose of understanding each DOT representative's opinion based on their previous involvement and expertise. Questions such as these were asked in each survey to get the perspective from each group of respondents.

Interviews were conducted to gain more detailed insight and feedback than possible from a survey. The questions asked went in-depth about capabilities and or limitations of current technology. The interview was conducted with Professor Carlo Pinciroli who is very knowledgeable about the pros and cons of current technology. Formulation of the interview questions was similar to the survey questions; however, they are
more detailed since the respondents can verbally discuss their answers and thoughts. For the case of this project, the feedback from Professor Pinciroli was used in place of the answers from the construction company and contractor survey since there were no responses\(^1\). This however was circumstantial based on the feedback, and lack of feedback that was received from the construction companies and contractor survey. The feedback from Professor Pinciroli was extensive and provided the team with many helpful considerations for the project. It was sufficient but not from the perspective the team had initially hoped for in regard to gaining an understanding from the construction companies and or contractors.

\[\text{Figure 19: Gantt Chart Displaying Group’s Work and Scheduling throughout C-Term.}\]

\[\text{Figure 20: Gantt Chart Displaying Group’s Work and Scheduling throughout D-Term.}\]

A Gantt chart was created for both C and D terms to keep each group member on track, and ensure continuous progression throughout the terms. The Gantt chart shows the timeline for the term, different tasks, and the deadline for each task. The Gantt chart is updated weekly to track current progression. \textit{Figure 19} is the Gantt chart for C-term, and \textit{Figure 20} is the Gantt chart for D term.

\(^1\) Due to the impact of the COVID-19 pandemic leading to the closure of nonessential businesses, it is possible that the construction contractors and companies did not receive our survey or respond to our emails
Both the surveys and the answers were made and recorded in Google Forms. The questions asked in the surveys can be seen in Appendix 2-4 and the answers recorded by Google Forms can be seen in Figures 21-42. Google Forms recorded the feedback from the surveys and displayed the data in pie charts, horizontal bar graph, or a list of written feedback if the question asked for a written answer or explanation. Each question and its response were analyzed to form a conclusion that related to the project. For example, one question in the WPI community survey asked: if respondents speed over the legal speed limit of 5 MPH or more, and the answers were recorded and displayed in a pie chart with percentages, see Figure 26. From these responses, over 93% responded to have sped over the legal limit at some point which led to the conclusion that drivers have a tendency to speed. Similar questions in the WPI community survey and the DOT survey provided responses that showed a trend of drivers speeding whether it was through a construction zone or not. Other questions provided evidence that drivers were aware of construction zones, yet continued to not exercise caution due to distracted driving, speeding, etc.

From the survey feedback, individual conclusions were made based on the responses for each question which were then compiled to formulate an overall conclusion of driver tendency and receptivity of a robotic system to improve roadwork construction site safety. As seen in Figures 31 and 44, the results for each survey, WPI community and DOTs respectively, were compiled to understand the overall tendencies and form a conclusion. Using a horizontal bar chart with the percentages displayed, the results could be compared and contrasted next to each other to form an overall understanding of the data received. Based on the feedback from the WPI community, it suggests that drivers are visually aware of traveling through a construction zone and understand established laws but are negligent. The proposed device should alert workers rather than change driving patterns. Similarly, the feedback from the DOT survey indicated that negligent driving is a recurring issue. Additionally, a robotic device could be useful with proper funding and implementation.

Once all of the responses from the surveys were reviewed, the team was able to make an overall conclusion about driver tendencies which proposed the ideal implementation of the proposed device and its components. Based on background research of current technologies, interviews with Professor Pincrioli and Mr. Donovan, and survey feedback from DOTs and the WPI community, our team formulated recommendations concerning the components and application of a robotic system or robotic technology that could improve the safety of roadway construction zones.

By the end of C-term all the research was completed. D-term was dedicated to cultivating and analyzing the entirety of the research from the past two terms. Data from interviews, surveys, and questionnaires was collected and analyzed. The group examined the data and determined what the most feasible and practical components the safety system will need to incorporate in order to have the possibility of becoming a reality in the future. This occurred by analyzing the current technology and safety practices with the feedback from the surveys and coordinating the issues addressed in the surveys to possible solutions. When
going through this decision making process, the team considered all aspects of research including technical aspects, legal aspects, psychology, sustainability, safety, resilience, and input from the stakeholders. After a careful decision making process which entailed many iterations of analyzing the data from the surveys, compiling the data, and comparing the trends to possible current solutions, the group was able to provide their recommendations. A framework was formulated in the form of a conclusion in the report. It states all of the necessary components and provides a structure for this system so that it could be created in the future.

Results

The surveys were created in Google Forms, and the same platform recorded the responses and displayed the data in pie charts, horizontal bar graphs, and lists of written feedback when necessary. Conclusions were made both individually based on the responses to each question and holistically after the analysis of the complete survey responses. Additionally, trends and conclusions were noted based on the comparisons of the feedback from both the DOT and WPI community surveys. With these results our group further developed recommendations for the robotic safety system. Figures 21-30 are the recorded responses from the WPI community. These responses were compiled, in Figure 31, and analyzed comprehensively to provide a better understanding of general driving tendencies and prominent concerns regarding a robotic safety system. Figures 32-43 are the recorded responses from various state DOT representatives. From these results the team gained an inside perspective of the safety issues that workers experience and the solutions that DOT representatives look to improve them. Additionally, from the compilation of their feedback, as seen in Figure 44, the team was able to conclude whether or not a robotic safety system would be an effective solution.

The group analyzed statistics such as the most prevalent dangers in roadside construction zones and what are the main causes of these incidents. Based on responses from numerous Departments of Transportation, distracted driving and speeding were determined to be the leading causes of accidents in the work zone. According to the survey results, 68.8% DOT representatives agree that distracted driving is the leading cause of accidents, and 18.8% of DOT representatives reported speeding to be the leading cause. This information provided insight for realistic scenarios of hazards on a roadside construction site. Through the research the group conducted, speeding and distracted driving consumed the majority of potential dangers for roadside construction workers as opposed to weather conditions. The focus became more structured around this information to alleviate these issues.
WPI Community Survey Responses

When driving on the highway, are you aware well in advance when you are about to drive through a construction zone?  
93 responses

![Pie chart showing survey responses]

**Figure 21: WPI Community Survey Question 1**

When driving on the highway, are you aware well in advance when you are about to drive through a construction zone?  
93 responses

![Pie chart showing survey responses]

**Figure 22: WPI Community Survey Question 2**
Figure 23: WPI Community Survey Question 3

How often do you encounter a construction zone while driving?
93 responses

- Often: 51.6%
- Sometimes: 37.6%
- Not often: 10.8%
- Never: 0%

Figure 24: WPI Community Survey Question 4

What time of day do you typically see roadside construction going on?
92 responses

- Day: 42.4%
- Night: 19.6%
- Both: 34.8%
- Never: 0%
- Morning: 0%

Figure 25: WPI Community Survey Question 5

Do you exercise caution when traveling through a construction zone?
92 responses

- Yes: 40.2%
- No: 51.1%
- Only when I get to the site: 0%
- If I see a cop/there is active work: 0%
- When deemed close enough to any construction workers for their safety: 0%
Do you speed over 5 MPH of the indicated speed of the construction zone?
90 responses

- Often: 37.8%
- Sometimes: 12.2%
- Not Often: 43.3%

Figure 26: WPI Community Survey Question 6

Have you ever received a citation going through a construction zone?
90 responses

- Yes: 100%

Figure 27: WPI Community Survey Question 7
Figure 28: WPI Community Survey Question 8

Have you received any of the following citations? (select all that apply)
31 responses

- Texting while driving: 1 (3.2%)
- Speeding: 20 (64.5%)
- Negligent driving: 3 (9.7%)
- Running a red light/stop sign: 5 (16.1%)
- None: 4 (12.9%)
- Marked Lanes Violation (you tell me what?): 2 (6.5%)
- They haven’t caught me yet 😎: 1 (3.2%)

Figure 29: WPI Community Survey Question 9

What type of signs are more likely to catch your eye? (Select all that apply)
93 responses

- Fixed electronic: 47 (50.5%)
- Moving Electronic: 59 (63.4%)
- Fixed non-electric: 26 (28%)
- Moving non-electric: 16 (17.2%)
- Yes: 1 (1.1%)
- Blinking electronic: 1 (1.1%)
- Cones usually alert drivers more even if...: 1 (1.1%)
- Combination: 1 (1.1%)
What are the usual times you travel to and from your daily activities/work? (Select Morning and Afternoon)

88 responses

Figure 30: WPI Community Survey Question 10

Figure 31: Compiled WPI Community Survey Results
DOT Representative Survey Responses

**Figure 32: DOT Representative Survey Question 1**

On average, how many projects are each DOT representative assigned at any given time?
15 responses

- 1 Project: 20%
- 2 Project(s): 20%
- 3 Project(s): 13.3%
- 4+ Project(s): 46.7%

**Figure 33: DOT Representative Survey Question 2**

How involved are DOT representative in the safety of their assigned projects?
16 responses

- Not at all: 75%
- Slightly involved: 25%
Do you believe that the implementation of a non-human device that monitors the flow and potential dangers of traffic in order to enforce worker safety could be beneficial?
16 responses

Figure 34: DOT Representative Survey Question 3

How involved are DOT representative in the safety of their assigned projects?
16 responses

Figure 35: DOT Representative Survey Question 4
Figure 36: DOT Representative Survey Question 5

How much oversight does each DOT representative have with their projects?
16 responses

81.3% 18.8%

Figure 37: DOT Representative Survey Question 6

Which of the following are major causes of construction zone accidents? (Select all that apply)
16 responses

<table>
<thead>
<tr>
<th>Cause</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speeding</td>
<td>14</td>
<td>87.5%</td>
</tr>
<tr>
<td>Distracted Driving</td>
<td>16</td>
<td>100%</td>
</tr>
<tr>
<td>Rain</td>
<td>3</td>
<td>18.8%</td>
</tr>
<tr>
<td>Snow</td>
<td>4</td>
<td>25%</td>
</tr>
<tr>
<td>Low visibility</td>
<td>5</td>
<td>31.3%</td>
</tr>
</tbody>
</table>
Which of the previous options contributes to the most accidents?
16 responses

- Speeding: 68.8%
- Distracted Driving: 18.8%
- Rain: 4.4%
- Snow: 4.4%
- Low visibility: 2.7%
- Not paying full attention: 2.7%
- Not properly following construction signage: 2.7%

Figure 38: DOT Representative Survey Question 7

From a historical perspective, how many vehicles passing through a construction zone exceed the speed limit by 5 MPH?
16 responses

- All: 43.8%
- Most: 25%
- Some: 18.8%
- Few: 4.4%
- None: 4.4%
- Unsure: 2.7%

Figure 39: DOT Representative Survey Question 8

How is funding involved with future research on safety improvement implementation?
11 responses

- $0 - $10,000: 36.4%
- $10,000 - $50,000: 18.2%
- $50,000 - $100,000: 18.2%
- $100,000 - $250,000: 18.2%
- Greater than $250,000: 9.1%

Figure 40: DOT Representative Survey Question 9
Do you believe that non-human devices are capable of improving roadside construction worker safety?
16 responses

Figure 41: DOT Representative Survey Question 10

Would you trust a non human device to sense if a potential hazard is approaching and alert the roadside construction workers?
16 responses

Figure 42: DOT Representative Survey Question 11
Figure 43: DOT Representative Survey Question 12
Analysis

Through the team’s rigorous research, a structured analysis can be developed to organize important key components that are necessary to fulfill the requirements needed to develop recommendations for this robotic system. An automated flagger assistance device is useful for controlling traffic for a single lane road but is not practical when multiple lanes need to be controlled at one time with lanes merging, closing, and changing as the construction site emerges. What is useful about the AFAD is that it can be controlled from a safe distance away from the road. As the team spent time conducting research on the AFAD, the idea of a person being able to stay away from traffic and control the flagger from a distance was appealing to us.

The team developed system recommendations for a device that allows for it to communicate with the workers on the job site through the use of modern day wearable technology. The exosuit was developed in order to alleviate any extra stress put on the worker’s body while lifting and moving heavy objects. Along with the exosuit, Amazon’s Robotic Tech Vest comes equipped with the built in sensor capabilities that the team is looking for. With these two pieces of technology in mind, a wearable device can be developed that sends and receives a signal from our main device that allows the device to monitor the workers and communicate with them at all times. Also equipped in this device will be a camera similar to the MOBOTIX M73 camera. A camera with artificial intelligence capabilities is extremely sought after. This will allow the device to read and
recognize the vehicles on the road traveling before they reach the worksite and will be able to assess if there are any vehicles that would cause potential danger to the workers at the site. While it could monitor traffic on the roadways, the camera could also detect abnormalities inside the construction zone. It would be able to provide feedback alerting the workers to move to a safer location. Intelligent Transportation Systems (ITS) software would be extremely beneficial to use for this device. This device can better manage the traffic before it passes by the jobsite by signalling to drivers through UHF and VHF frequencies that would be detected through their global positioning systems (GPS) and alert them that there is roadside construction occurring up ahead and that they may need to merge [30]. An alert like this will mitigate any confusion, frustration, or aggression presented from the driver when there is a change in the flow of traffic. By changing the drivers’ attitude towards the adjustment in traffic may alleviate unintentional vehicular accidents impacting the jobsite.

The concepts behind the airport RWSL and ADSE-X could be introduced into a construction site traffic safety device. The two concepts would allow the movement of vehicles and persons to be tracked and could provide visual feedback with the lights when there is a possible danger. An active sensor such as the LiDAR would be a practical addition to a construction site safety device. With its ability to quickly and accurately detect images, it could be used in conjunction with intelligent devices to be able to provide feedback to the workers in order to increase awareness and safety. The concept of a system being examined and not just one singular safety unit allows for there to be an integration of many different technologies in order to maximize the factor of safety in a construction site atmosphere. An example of this integration could include using the LiDAR sensor along with the RWSL and ADSE-X. The LiDAR system would be able to detect the moving objects in the work zone, while the ADSE-X can track the vehicle's position. Through some type of artificial intelligence platform. These devices could be used to detect vehicles entering and exiting areas to provide safety for the workers and to protect the moving vehicles. This system could be used with devices such as a helmet, earphones, or an exoskeleton so that not only a visual stimulus (the lights) will be presented, they could be presented in a tactile (exoskeleton) and an auditory (helmet/headset or loudspeaker), as well.

Through surveying a multitude of participants from the WPI community and the Department of Transportation, we obtained a clear image of the underlying issue and tendencies that drivers and DOT representatives commonly face. One of the main issues that immediately stood out was the concern of speeding and lack of adherence to the posted traffic laws. From Figure 26 roughly 81% of drivers speed over 5 miles per hour through a construction zone. It is apparent that speeding is a major concern and problem for keeping a safe work environment along a busy road. With this information it is important to note, from Figure 21 33% of drivers are unaware or unsure if they are about to drive through a construction zone. Therefore, if more signage or a better system is implemented to make drivers more consciously aware that they are driving through a construction zone, it could potentially mitigate the major problems of speeding and negligent driving. From
this we also can see from Figure 22 that 39% of drivers do not know when to reduce their speed when approaching a construction zone.

Introducing better ways to educate the driver would serve a good purpose in preventing speeding through a construction zone. From Figure 29, roughly 63% of drivers felt as though moving electric signage would catch their eye the most as opposed to a regular posted sign. This suggests that using electronic signs that blink or flash a message will force drivers to give their attention to it and potentially their driving as well. In part with gaining the drivers attention, there is a lack in regulating the law in a construction zone. 100% of people who answered the survey selected that they have never received a citation when traveling through a construction zone. This either implies that people exercise caution all the time when traveling through a construction zone or as the previous data states, people are unaware of it or neglect the laws and do not get caught in doing so. Adding more law enforcement to construction areas could have a positive effect on reducing negligent driving. According to Figure 31, the busiest times of driving occurs in the morning between 0600 to 1000 and in the evening between 1600 to 1900. From this data, we can suggest that the roads are busiest during people’s commute to and from work. This is important because construction should be conducted during hours of minimal traffic to lessen the possibility of an accident. According to our response, 1% of drivers stated that they typically drive from 2200 to 0400. This time frame suggests the best possible time to work on a construction zone located on a major road would be after dusk and before dawn.

As a team, we reached out to various anonymous Department of Transportation representatives to gain an understanding of how safety measures and roadway construction processes are conducted. According to the response received from the 1st DOT question, 87% of DOT representatives are assigned to more than one project at any given time and 20% are assigned more than four projects. The majority of representatives may be too far stretched in their involvement to be able to give each project the proper attention for safety considerations on the jobsite. From Figure 32, each representative expressed that they are always involved in the safety of the project. This is important because there is constant attention towards work zone safety. The idea of having a device capable of improving roadside construction worker safety is, of course, something DOT representatives have stated. Roughly 70% of representatives believe that implementing a device is capable of improving worker safety. This is rather important because it shows that DOT representatives are accepting of adding a device that could potentially help regulate and increase the safety of workers.

Conclusion

When considering the feasibility of a robotic device that closely monitors workers on a roadside construction site along with the traffic passing by, it is important to evaluate all aspects of the situation. Through extensive research and analysis conducted by the team, it is reasonable to conclude that a device
composed of the different integrated types of technologies aforementioned would be practical and necessary in order to efficiently carry out the purpose of this project. We have built off of our research and determined what can and should be incorporated into the device. Innovative tools such as artificial intelligent cameras, RFID and LiDAR systems, and transportation systems proved to be very essential in developing a device capable of keeping roadside construction workers safe. These tools are capable of reading and recognizing potential dangers of traffic; the most prevalent being distracted driving and speeding. The necessary characteristics for this safety device can now be further examined and the appropriate data can be collected so that a foundation for the blueprints of a final product can be established.

Through substantial analysis of survey responses, new ideas pertaining to the safety and feasibility of a device that mitigates roadside construction worker accidents were established. It is important to fully analyze responses received from the WPI community as well as members of the Department of Transportation to develop an understanding of real life problems and tendencies that the motoring public experiences. Analysis of surveys with a focus group of college students produced data showing possible trends of young adults from all areas of the country allowing the group to examine and make generalizations about the potential driving tendencies in different environments following contrasting laws and regulations. Surveys directed toward state departments of transportation paved the way for the group to make generalizations for the population of a specific region. Comparing and contrasting the opposing perspectives allowed for the team to confirm generalizations made and make suggestions for mitigating worker risk according to these generalizations.

Driver tendencies play a large part in developing solutions to problems that arise from negligence in recurrent driving patterns when traveling through a construction zone. It can be concluded that speeding and distracted driving are prominent issues that need to be considered when developing a device to keep workers safe. Other factors include but are not limited to weather, visibility, and time of day. In order to mitigate roadside construction risk, drivers must be made more aware of construction zones earlier and more frequently by providing stimuli that cause the driver to psychologically want to follow the regulations such as, bright flashing signs, more strict legal consequences, or notices that create emotions of guilt or remorse.

Implementing a device that serves this purpose requires numerous hours of testing and experimenting before it can be feasible and gain the trust of the workers and DOT representatives. By understanding these driving patterns this device can be composed of functions that look to mitigate any negative patterns and improve working conditions for these workers. Even with the addition of these aspects, it is difficult to fully alleviate distracted driving and speeding among other unsafe trends due to the personal freedom of choice. However by continuing to improve on these aspects, drivers should become more cognisant of construction zones and begin to show more effort and care while driving to protect and save the lives of construction workers everywhere.
References


[27] E. Thompson, “10 years after state OKs civilian flaggers, police still prevail at construction sites,” Telegram and Gazette


Appendix

Appendix 1: Design Flow Chart
Appendix 2: Survey Questions for Construction Companies and Contractors

The following questions are focused on construction companies and contractors:

1. What issues have your project(s) had involving worker safety regarding incidents with oncoming traffic?
2. What are your primary safety regulations that concern working within the proximity of traffic?
3. How were these issues addressed?
4. Are your employees trained prior to working on the jobsite?
5. Would an in depth safety orientation course make a difference on the jobsite?
   a. Yes
   b. No
   c. Other
6. Are your employees educated enough in proper safety protocols to carry out their tasks with low risk of danger?
   a. Yes
   b. No
   c. Other
7. Would giving more awareness to drivers signaling an oncoming construction site be beneficial to the workers safety (Signage, Lights, Warnings, etc.)
   a. Yes, there are enough
   b. No, there needs to be more.
8. Would you trust a robotic device to sense and alert your workers if a danger was approaching?
   a. Yes
   b. No
   c. Explain
9. How common are car accidents to occur in a construction zone?
   a. Not at all
   b. Uncommon
   c. Common
   d. Very common
10. What time of the day are you doing major roadside work?
    a. Daytime (Dawn to Dusk)
    b. Nighttime (Dusk to Dawn)
    c. Other
11. What period of the week do you find roadside construction to be the safest?
    a. Friday to Sunday
    b. Monday to Thursday
    c. Other
12. How would you compare roadside work at night compared to day?
    a. Safer at night
    b. Safer during the day
13. Do your workers wear any reflective vests or devices to make drivers more aware of their presence?
   a. Yes
   b. No
   c. Other
14. Are the correct signs being displayed depending on the environmental circumstances being presented?
   a. Yes
   b. No
   c. Other
15. What are the different types of signs you use in a construction zone? (Select all that apply)
   a. Regulatory
   b. Warning
   c. Guide
   d. Other
16. In your experience, how effective are these signs?
   a. Effective
   b. Effective but could be better
   c. Slightly Effective
   d. Not effective at all
17. How effective are those work signs you use and why do you choose those?
18. What type of communication do your workers use to communicate on the site? (Select all that apply)
   a. Radio
   b. Signal (Non-verbal)
   c. Face to face (Verbal)
   d. Cellphone
   e. Other
19. In your experience, what have you seen as potential dangers to roadside work? (Select all that apply)
   a. Lack of driver focus (speeding/reckless driving)
   b. Machine work/operation
   c. Weather conditions
   d. Other
20. How do you best address those issues to roadside work?
   a. (Explaination box)
21. Where do you find the most dangerous zones for roadside construction to be?
   a. Bridges
   b. on/off ramps
   c. Blind corners
   d. Busy roads
   e. Highways
   f. Other
Appendix 3: Survey Questions for DOTs

The following questions are focused on the State Department of Transportation:

1. Do you believe that non-human devices are capable of improving roadside construction worker safety? Please explain your choice.
   a. Yes
   b. No
   c. (Explanation box)

2. Would you trust a non-human device to sense if a potential hazard is approaching and alert the roadside construction workers?
   a. Yes
   b. No

3. Where, if possible, do you see robots being implemented in the future of roadside construction?
   a. Assisting traffic
   b. Keeping roadside workers safe
   c. Reducing traffic jams
   d. Alleviating accidents
   e. Other

4. Do you believe that the implementation of a non-human device that monitors the flow and potential dangers of traffic in order to enforce worker safety could be beneficial? Please explain your choice.
   a. Yes
   b. No
   c. (Explanation box)

5. How is funding involved with future research on safety regulations?

6. How often are DOT officials present on an assigned roadside construction project?

7. Where do you see the most issues arising from roadside incidents?
Appendix 4: Survey Questions for WPI Community

The following questions are focused on the WPI community (Staff and student body):

1. When driving on the highway, are you aware well in advance when you are about to drive through a construction zone?
   a. Yes
   b. No
   c. Unsure

2. Do you know when to slow down when going through a construction zone in accordance with the law in your state?
   a. Yes
   b. No
   c. Unsure

3. How often do you drive through a construction zone?
   a. Often
   b. Sometimes
   c. Not often
   d. Never

4. What time of day do you typically see roadside construction going on?
   a. Day
   b. Night
   c. Other

5. Do you exercise caution when traveling through a construction zone?
   a. Yes
   b. No
   c. Only when I get to the site
   d. Other

6. Do you speed over 5 MPH of the indicated speed of the construction zone?
   a. Often
   b. Sometimes
   c. Not often
   d. Never

7. Have you ever received a citation going through a construction zone?
   a. Yes
   b. No

8. What type of signs are more likely to catch your eye?
   a. Fixed electronic
   b. Moving electronic
   c. Fixed non-electric
   d. Moving non-electric
   e. Combination

9. How often do you text and drive?
   a. Very Often
   b. Often
   c. Sometimes
10. How often are you on a phone call while driving?
   a. Very Often
   b. Often
   c. Sometimes
   d. Rarely
   e. Never

11. Have you received any type of citation for distracted driving?
   a. Yes
   b. No

12. What are the usual times you travel to and from your daily activities/work? (Select Morning and Afternoon)
   a. 0600-0800
   b. 0800-1000
   c. 1000-1200
   d. 1200-1400
   e. 1400-1600
   f. 1600-1800
   g. 1800-2000
   h. 2000-2200
   i. Other________

13. What severe weather conditions are you able to work under?
   a. Heat (>90 degrees)
   b. Freezing(<32 degrees)
   c. Light Rain
   d. Heavy Rain
   e. Sleet
   f. Snow
Appendix 5: Questions for Professor Pinciroli

The following questions are focused on robotics for professor Carlo:

1. Do light conditions affect a robot’s ability to detect oncoming objects?
   ○ The robot needs to be able to function properly at day and night?

2. Can robot’s calculate the angle that an object is coming from / Can a robot calculate where an object is projected to go?
   ○ The robot needs to be able to tell if an oncoming vehicle is headed for the work zone

3. Can a single robot detect speeds of objects from different directions at the same time?
   ○ Can the robot simultaneously monitor traffic halted from one side and travelling around the work zone from the other?

4. Through artificial intelligence, is it possible for a robotic device to develop an understanding of potential traffic hazards?
   ○ Speeding cars, reckless driving

5. What would be the best way to power a robotic system for this particular work?

Comparing differences between solar, gas, and battery powered devices