Final Design Report
Cabler Barrier Alert System

Prepared For
Texas Department of Transportation*
Ideal Client

Presented to
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Executive Summary

Cable Barrier Alert System

The project for this semester was to continue the development of a device that can detect and relay information regarding the collision of a vehicle with a highway cable barrier. The team began making progress on the project from the progress made in the fall semester. This progress included a design concept that would utilize the detection of the removal of certain U-bolts from the highway cable barrier post. The device would then take the binary information of the removed U-bolt to perform a magnitude analysis and then relay this information with a Bluetooth signal.

The current working design concept remains essentially the same with a few exceptions. The first of which is that the body of the device which will be mounted to the side of a highway cable barrier post has been extended such that a plurality of U-bolts can be affixed to the single device. Another design change that was made from last semester's design is the use of radio frequency to transmit the collision information to a nearby hub rather than the use of a Bluetooth signal. The team believes that similar to the operation of a car's key fob, a radio signal will be able to use a low amount of power to reliably transmit a signal across a greater distance than Bluetooth. The final notable design change is that the team is currently attempting to create the internal circuitry using a software-integrated circuit rather than purely using a digital circuit.

In this report, the team discusses some of the design aspects that have been evaluated throughout this semester. The first of which is the overall system. In this section, the team breaks down various aspects of the system which include the functional flow, physical layout, geometric layout, coding diagrams, bill of materials, and our current prototyping plan. The next section of this report discusses the team's engineering analysis. This section explains a few of the design areas that the team has identified as needing engineering analysis and shows the types of analyses that were performed to evaluate them. The next section covers the building and fabrication process that was used by the team to develop the prototype. The next section of the report discusses the testing and validation of the design. This section outlines and explains a few of the testing and validation methods that the team intends to use to ensure the proper functionality of the design. The next sections of the report discuss issues relating to the safety of the design, reliability of the design, societal impacts of the design, and future work to be done. The final section outlines the team's work timeline assessment. This includes our initial Gantt chart which shows when certain tasks must have been started and completed for timely completion of the project.

The team has developed the design and a working prototype of the highway cable barrier node. Additional parts that go beyond what the team was capable of accomplishing during the semester include the development of a hub unit that can receive and interpret the radio frequency signals from each of the post

devices. The team created a modified prototype that establishes a proof of concept. This type of modification simply uses LED lights to illustrate that a radio frequency signal is being transmitted rather than having an operational radio transmitter

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Table of Contents

EXECUTIVE SUMMARY....1
Functional Flow Diagrams....9
Physical Layout Diagrams:....12
Geometric Layout:....13
Bill of Materials:....16
Estimated Cost for Prototype:....18
"THE BUILD" -FABRICATION/CONSTRUCTION/PRODUCTION/SYNTHESIS/CODING....21
Testing/Verifying/Validating/Experimental Plan....23
SAFETY/HAZARD ASSESSMENT AND EVALUATION....23
SOCIETAL FACTORS AND IMPACT....26
FUTURE WORK....27
TEAM AND PROJECT ORGANIZATION, PLANNING, AND EXECUTION....28
APPENDIX....30
A. List of Abbreviations and Terminology....30
B. References....31
C. Order of Magnitude and Detailed Calculations....32
E. Detailed working drawings/models/assembly....34
F. Testing/Validating/Verification/Experimentation....35

List of Figures and Tables

Figure	Page Number
Figure 1. The Complete Functional Flow Diagram.	2
Figure 2. The cable barrier post unit subsystem from the functional flow diagram.	3
Figure 3. The hub unit & server subsystems from the functional flow diagram.	4
Figure 4. Diagram of the system's general physical layout.	5
Figure 5. The physical layout of the node system.	5
Figure 6. The isometric view of the CAD model of a node.	7
Figure 7. The profile view of the CAD model of a node.	8
Figure 8. The exploded view of the CAD model of a node.	9
Figure 9. The force exerted on the U-bolt depending on the car's size and speed.	12
Figure 10. The added cable tension force depending on the car's size and speed.	13
Figure 11. The Gantt chart for the Spring 2024 Semester.	20
Table 1. Components of the CAD Model.	6
Table 2. Bill of Materials.	10
Table 3. Hazard Assessment.	16
Table 4. Reliability Assessment.	17
Table 5. Future Work.	19

Glossary/Nomenclature

Term	Definition
Cable Barrier	A type of roadway safety barrier made of steel wire rope stretched between posts along the median of a highway. Designed to absorb impact energy and redirect vehicles. Also called a cable guardrail or wire rope safety barrier.
Closed-Circuit System	An electrical circuit pathway that forms a complete loop and allows current to flow around the entire pathway uninterrupted. Can be used to detect when a cable detaches from its post during impact, as it will open the loop and interrupt the flow of current.
Communication Protocols	Rules governing the order and format of transmitting impact data to different recipients like police versus highway agencies.
Data Collation	Compiling and synthesizing multiple data sources like vibration, tension, location, etc. into one dataset representing the impact event.
Data Logging	Storing impact data that has been collected to allow for future analysis and system troubleshooting.
False Alarm	An erroneous or mistaken alert triggered by the system that does not correspond to an actual vehicular impact. Needs to be minimized.
Feedback Loop	Confirming that the alert notification has been successfully received by the intended agency, to ensure reliability.
High-Tension Cable Barrier	A type of cable barrier that uses cables under high tension between 4000-9000 lbs. Allows for greater vehicle redirection with multiple impacts before needing repair.
Location Detection	Determining the precise location along the cable barrier where an impact occurred. Required accuracy is within 200 meters.
NAND gate	A logic gate that produces a false output only if all its inputs are true.

Noise Filtering	Processing and analysis of sensor data to remove noise and distinguish real impacts from ambient vibrations or other disturbances.
Notification Latency	The time delay between impact detection and transmission of the alert notification to emergency services. Required to be under 5 seconds.
Ohm's Law	The mathematical relationship between current, voltage, and resistance in an electric circuit. Allows calculation of distance along a circuit by measuring changes in voltage.
Pull-Down Resistor	A resistor connected between a signal line and ground in an electronic circuit, ensuring that the signal line remains at a low voltage (logical 0) when not actively being pulled high by another component. It prevents the signal line from floating and helps maintain a stable state in the absence of an active signal.
Sampling Rate	The rate at which an electronic signal is measured over time. Determines how frequently sensor data like accelerometer vibration is collected.
Short Circuit	A (usually unintended) connection is formed between two points in an electrical circuit with low resistance, bypassing the intended load and causing excessive current flow.
Spring-Loaded Contacts	Electrical connectors are equipped with a spring mechanism that applies force to maintain contact between two surfaces, ensuring a reliable electrical connection.
Severity Classification	Categorizing impact events into minor, moderate, or severe based on metrics like vibration intensity or cable tension changes.
Timestamping	Recording the time when a sensor detects an impact event. Required accuracy is within 5 seconds.
TxDOT Design Manual	The Texas Department of Transportation document detailing requirements and guidelines for roadway design elements like cable barriers.

Introduction

The goal of this project is to design, build, and validate an automatic crash detection and alert system that will integrate with highway median cable barriers in Texas. The prospective client for this project is the Texas Department of Transportation (TxDOT), which currently lacks any method of notification concerning the status of cable barriers along Texas roads. Additionally, emergency services do not have infrastructure in place that will alert them about impacts with the structures. Without a reliable collision alert system, those involved in crashes may have to endure long wait times from first responders, especially in rural areas with poor cell service. TxDOT must also wait to be alerted of maintenance needs through outdated channels or by passers-by. To address this issue, the team's goal is the creation of a system that can accurately sense cable barrier impacts, determine event parameters including timing, intensity, and location, and transmit relevant alerts to pertinent recipients. The group laid the foundation for the design process by constructing a quality function diagram (QFD). This diagram sets up the initial parameters that the group's design must ultimately satisfy. The group spent the Fall 2023 semester using the iterative design process to land on a preferred embodiment. After working in the Fall 2023 semester, the team developed a system of nodes that connect to a gateway and communication hub which work together to analyze and disperse data. The nodes are sturdy housing with a single 'false U-bolt' trigger mechanism. Designed for easy installation, these nodes are fully self-contained- battery-powered with Bluetooth connectivity, and may be attached to the posts of cable barriers using gear claps. The communication system utilizes a NAND gateway, with MQTT processes used as an information delivery system. The team plans to use feedback to aid in the adaptation and development of a finalized concept.

Detailed Design Overall System:

This section will cover the functionalities and physical characteristics of the system and the cost associated with the creation of a working model.

Functional Flow Diagrams

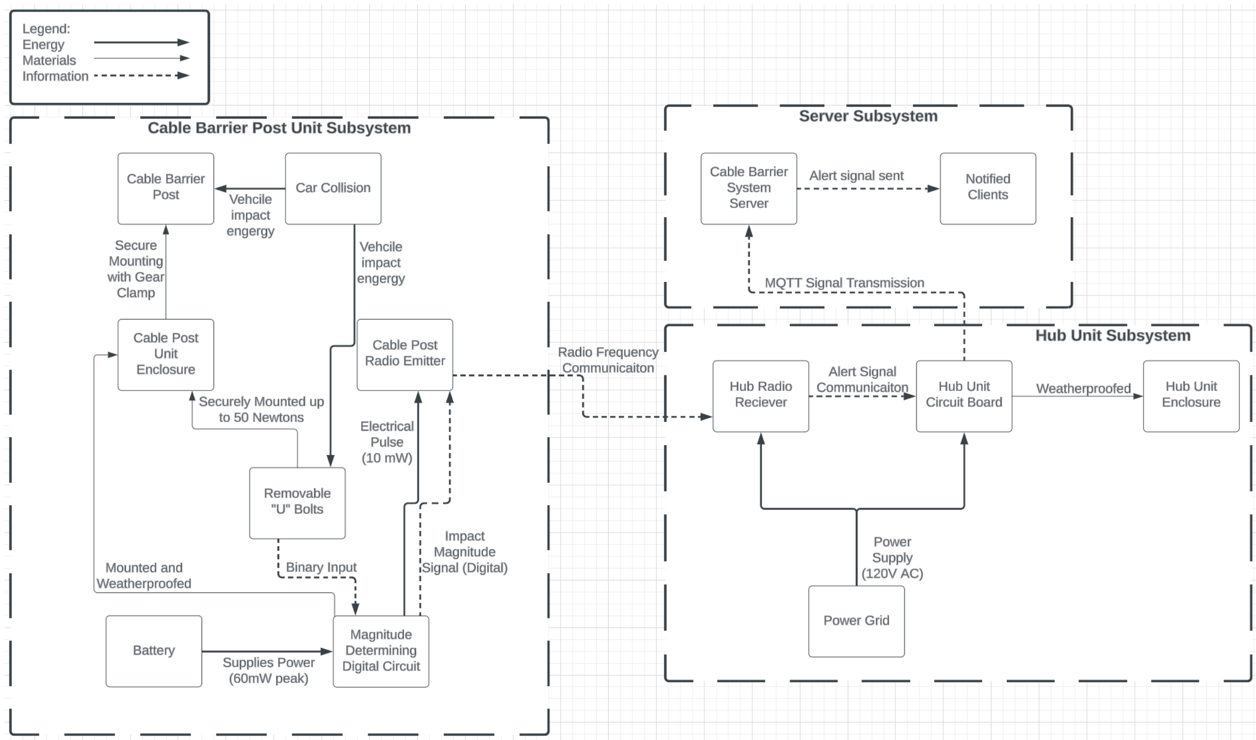


Figure 1. The Complete Functional Flow Diagram.

Figure 1 illustrates the entirety of the functional flow diagram and, in particular, the relationship between the different subsystems. The scope of the project focuses mainly on the cable barrier post unit (node) subsystem as this subsystem is what needs to be proven for the proof of concept. However, it is important to consider how this particular subsystem will interact with the subsequent subsystems in making the product functional as a whole.

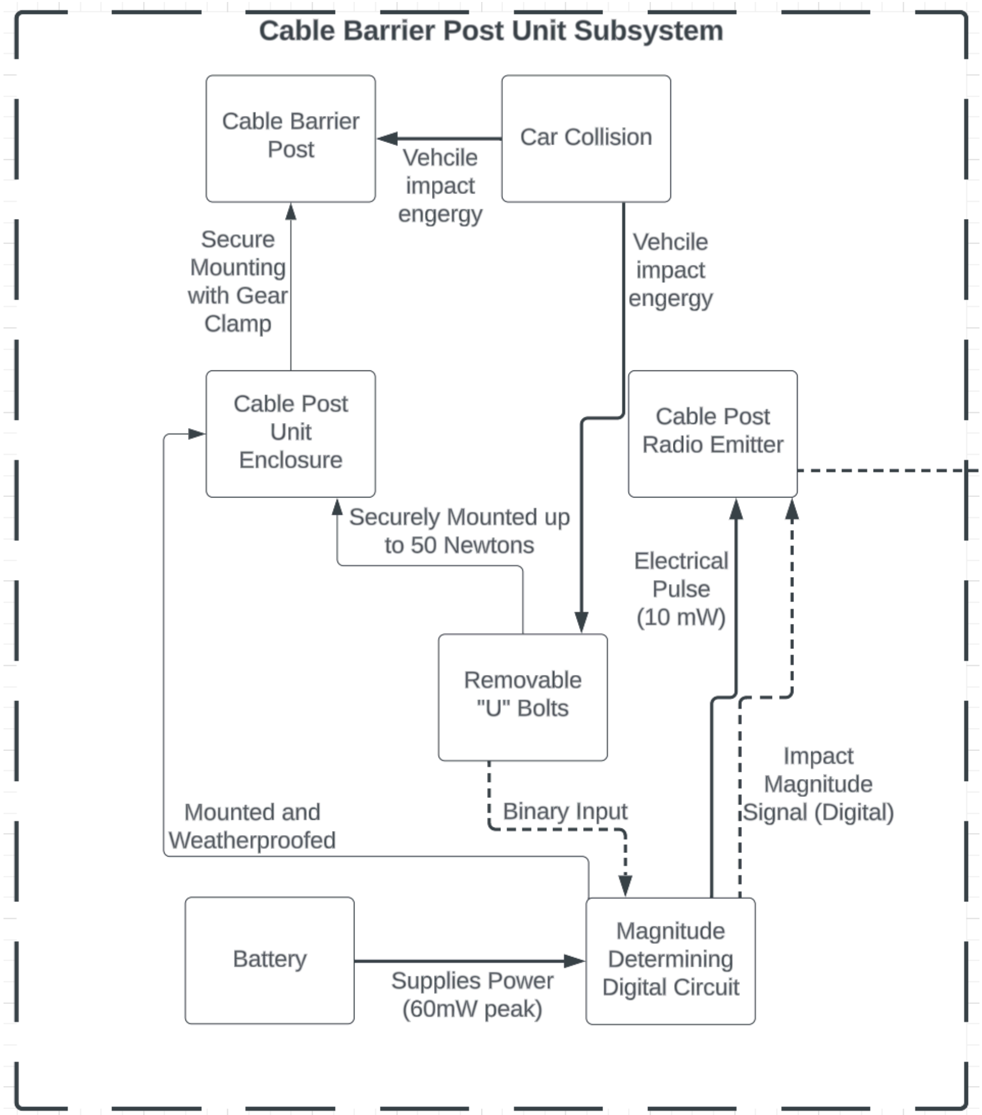


Figure 2. The cable barrier post unit subsystem from the functional flow diagram.

Looking specifically at **Figure 2**, the functional flow of the cable barrier post unit (node) subsystem can be analyzed. Notably, the functional information flow begins with the removable U-bolt which provides binary input information the magnitude determining digital circuit. The circuit will then interpret the information that has been received and send an impact magnitude signal to the radio emitter. This signal is then transmitted to an external subsystem for further signal processing.

Also notable are the supporting components that play a vital role in delivering the information gathered by connected systems. For example, by following the bolded arrows, the path of energy flow can be seen. Here, the power supply begins with a battery which provides a peak power output of about 60mW. This will ensure that the circuit can reliably operate and has a suitable amount of power for the radio emitter when needed.

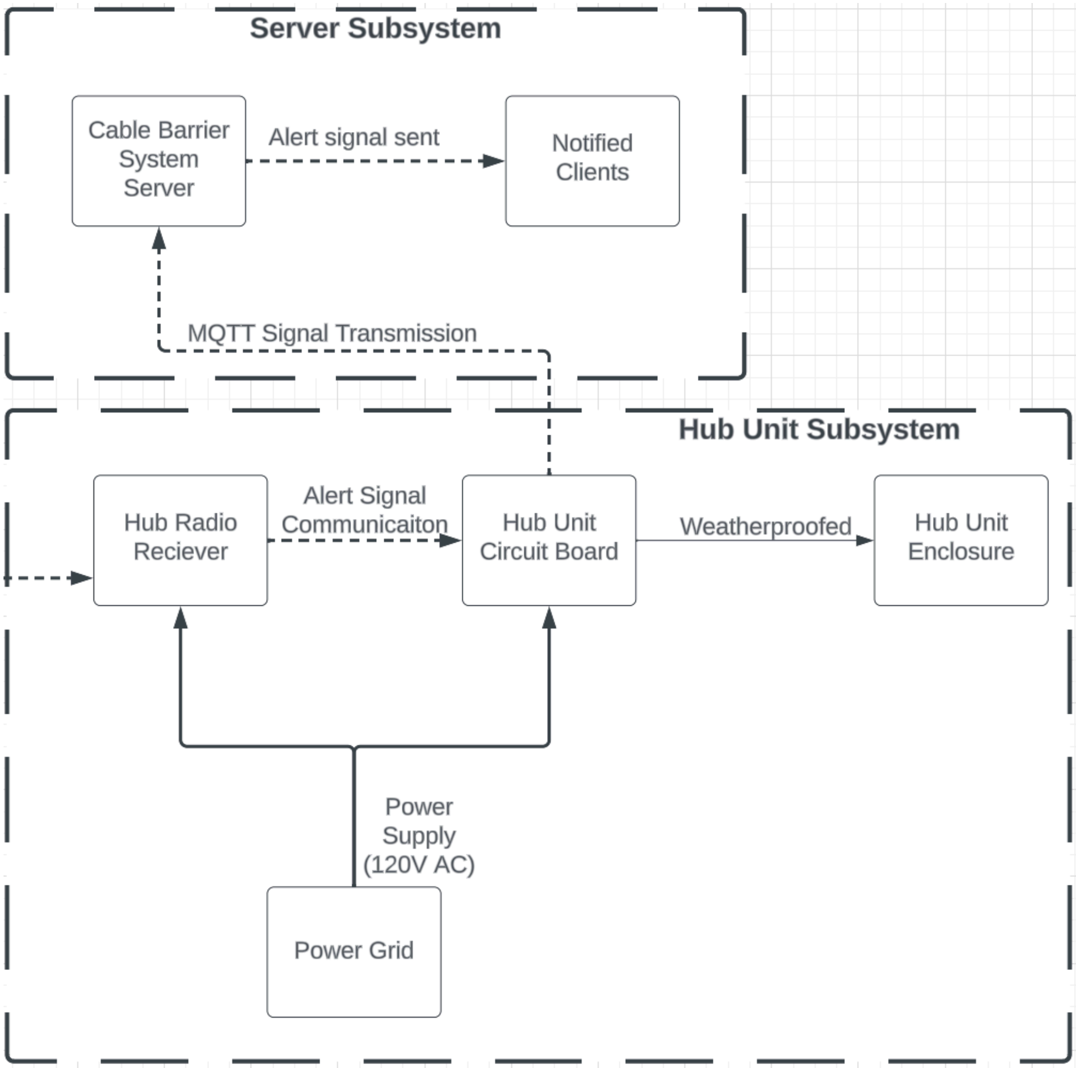


Figure 3. The hub unit & server subsystems from the functional flow diagram.

Following the signal flow illustrated in **Figure 3**, the signal is first introduced to the Hub Unit Subsystem when it is received by the radio receiver up to 300 miles away. This signal is then delivered to the hub unit's circuit board which will process the information as needed before utilizing the MQTT system to send the information to a server. Once the signal has reached the server, it can easily be transmitted to clients who have subscribed to notifications of specific severity levels.

Physical Layout Diagrams:

The physical layout is particularly applicable to the overall system and the mechanics of the system. **Figure 4** shows the most general version of the physical system, where the post, hub, and emergency services contact points are all miles apart.

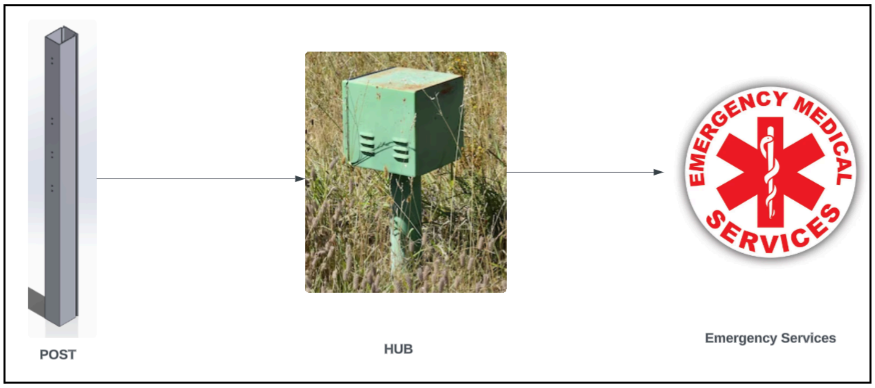


Figure 4. Diagram of the system's general physical layout.

The node system combines the post, gear clamps, bolts, and node housing into one system. **Figure 5** shows the general locations of these elements and how they interact with each other.

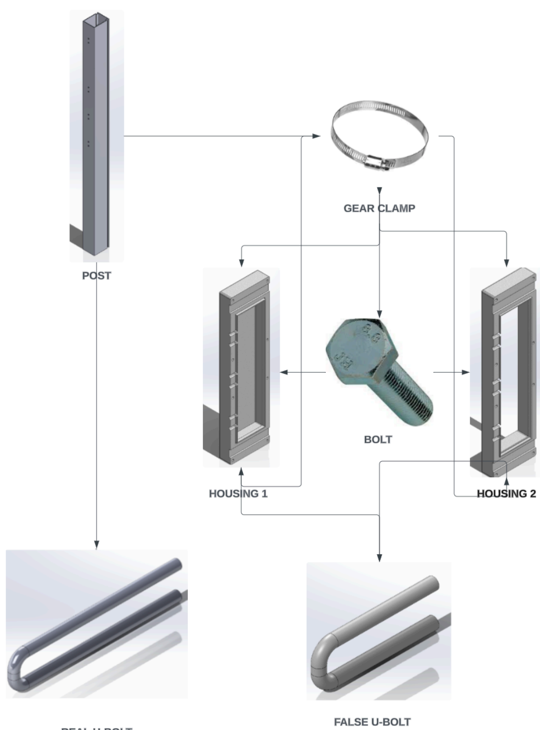


Figure 5. The physical layout of the node system.

As seen in **Figure 5**, the real U-bolt connects directly to the post and will enclose the high-tension cable. Mounted to the post will be the node assembly which will be connected to the post using the gear clamp. The node assembly comprises housing 1 and housing 2 which will be connected together using bolts. Additionally, the false U-bolts will mount to the node and also enclose the high-tension cable.

Geometric Layout:

The CAD model of the node housing and U-bolts was created using Solidworks. **Table 1** shows the components of the CAD model, which is shown in **Figures 6, 7, and 8**.

Table 1: Components of the CAD Model.

Component	Quantity
Node Housing 1st Half	1
Node Housing 2nd Half	1
U-bolt	3

Figure 6 shows the isometric view of all the components together. The holes for the U-bolts as well as for the gear clamps to attach the node housing to the post are completed when the two sides of the node housing are secured together.

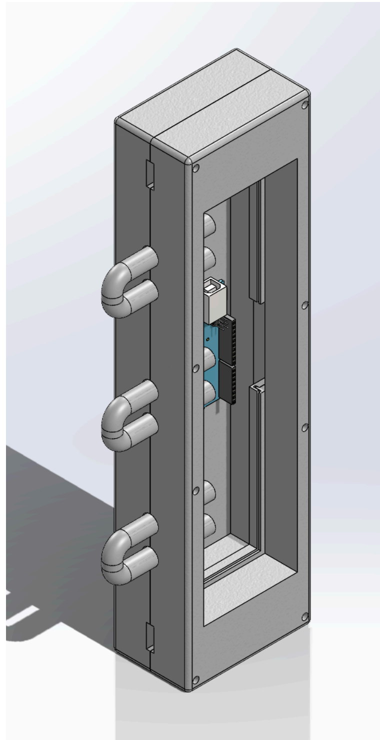


Figure 6. The isometric view of the CAD model of a node.

The profile view, shown in **Figure 7**, looks through a viewport that was created for demonstration purposes. In a real, fully functional product, this hole would not exist, but currently, it is more important to show the inner workings of the mechanics and circuitry in presentations than to have a completely realistic model of the external node housing.

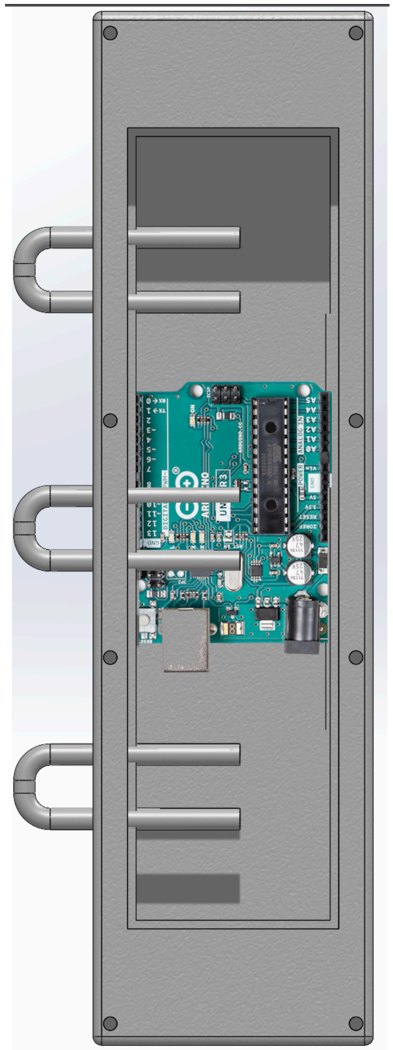


Figure 7. The profile view of the CAD model of a node.

There are two pieces to the node housing, as seen in the exploded view in **Figure 8** below. These will be attached with #10 screws as well as an inner lip on both pieces that secures the node housing in place.

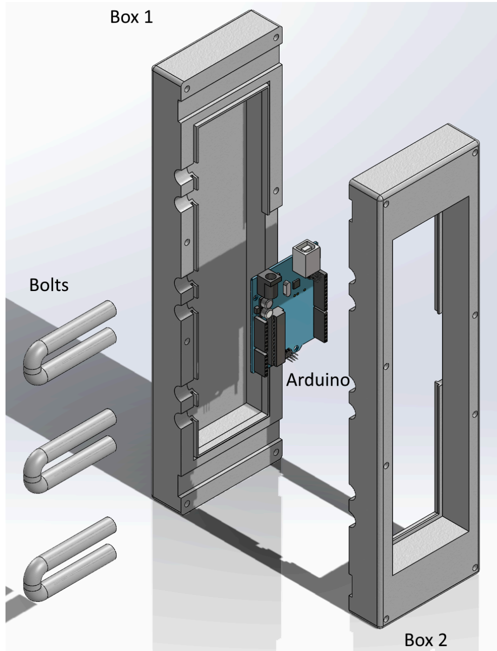


Figure 8. The exploded view of the CAD model of a node.

Bill of Materials:

Table 2 below shows a summary of the parts that are required to build a working concept of a node of the Cable Barrier Alert System. Abbreviations in the table include COTS – commercial off the shelf used as is, COTS-M – commercial off the shelf with modifications, as well as M – manufactured.

Table 2: Bill of Materials.

Part	Number of Units	Sourcing Method	Estimated Cost (Per Unit)	Comment
Arduino Uno	1	COTS	$27.60	Needed for internal circuitry of node - powered via USB connection
LED	3	COTS	$5.00	External indication of severity level
Mini Breadboards	6	COTS	$1.00	Used to connect false U-bolt to circuitry
Breadboard-friendly Audio Jack	3	COTS	$2.00	Used to facilitate U-bolt to circuit connection
5 K-ohm Resistor	3	COTS	$0.10	Used as a pull-down resistor to prevent floating state readings
Basic Wired Earbuds	3	COTS-M	$2.00	Used to procure male end of audio jack system for U-bolt connection- will be shorted to create a complete circuit
Set of Breadboard Wires	1	COTS	$5.00	To complete internal circuitry
USB 2.0 Cable Type A/B	1	COTS	$7.60	Connects Arduino Uno to a power source
Box of Screws	1	COTS	$5.00	To connect sides of the node housing
Node Housing	1	M	$7.00	3D PRINTED, the outer housing of the node- consisting of two sides of the node housing to be screwed together
False U-Bolts	3	M	$1.00	3D PRINTED, the mechanism that will be detected to indicate the severity level
Gear Clamps	6	COTS	$1.50	Mounts node to the post
Nylon Rope	12	COTS	$1.52	To simulate the high-tension cable
60 lb. concrete mix	1	COTS	$3.98	To mount the simulated post
2 x 4 lumber	4	COTS	$2.94	To use as a simulated post
5 Gallon Bucket	2	COTS	$4.48	To hold concrete/simulated posts
Silver Spray Paint	1	COST	$10.44	To paint the simulated post

Cost Estimation: $150.88

Estimated Cost for Prototype:

The developed cost estimation with a bottom-up approach, focusing on main functionalities before filling in the blanks of specifics. A breakdown of each part and the estimated cost can be found in the Bill of Materials, **Table 2**. A figure showing the node will be included below the list for reference. The items to procure include those COTS – Commercial Off the Shelf used as is, COTS-M – Commercial Off the Shelf with Modifications, and items that the team will create under M – Manufactured. The current cost estimate for project materials is $89.50, and includes the parts as follows:

Arduino Uno (COTS), LEDs (COTS), a breadboard (COTS), breadboard-friendly audio jacks (COTS), a 5 K-ohm resistor (COTS), multiple pairs of basic wired earbuds (COTS-M), beadboard wires (COTS), USB 2.0 Cable Type A/B (COTS), screws (COTS), node housing (M), and U-bolts (M).

None of these items have been provided and will be procured or created by members of the team. Both the node housing and U-bolts, both manufactured elements, will be created through 3D printing.

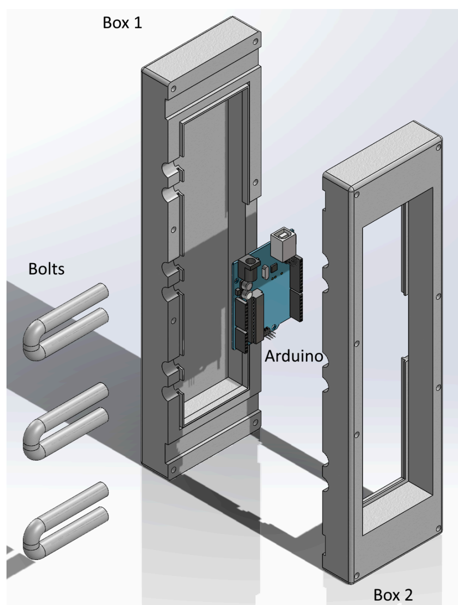


Figure 8. The exploded view of the CAD model of a node.

Detailed Design: Engineering Analysis

The project required a thorough analysis of critical areas to ensure the robustness of the system. Mechanical data analysis involves calculating the forces experienced during vehicular collisions, considering various car types and speeds (see **Figures 13 & 14**). This analysis guided decisions to optimize the system's mechanical functionality, specifically addressing scenarios where a car crashes into the cable carrier, resulting in the shearing of U-bolts. Consequently, the team adjusted the size of the false U-bolts to be identical to the U-bolts attached to the cables and posts. The two figures below display the results of these calculations.

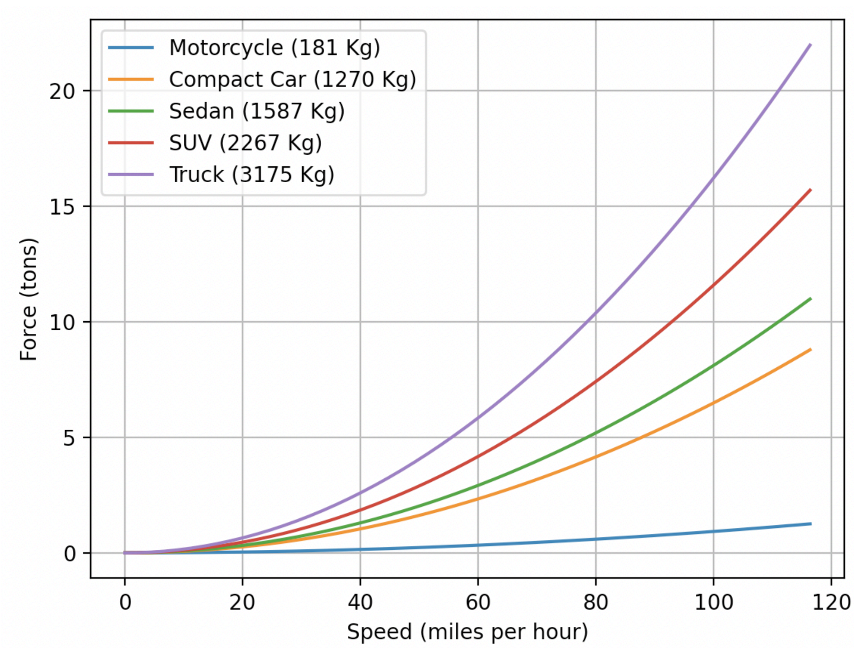


Figure 9. The force exerted on the U-bolt depending on the car's size and speed.

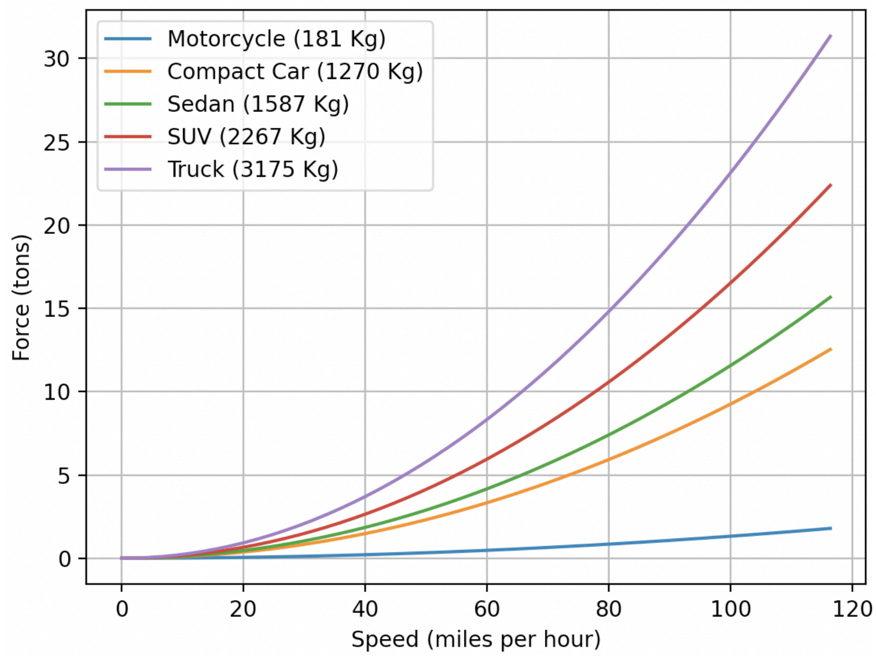


Figure 10. The added cable tension force depending on the car's size and speed.

The assessment of data behavior plays a crucial role in system functionality, focusing on how the system recognizes the removal of a false U-bolt and responds to such incidents. This involved the development of a comprehensive state diagram mapping out the system's behavior through different states. The significance of this analysis extended to fulfilling essential functions, such as notifying emergency services and accurately classifying the severity of vehicular collisions. By addressing data behavior intricacies, the team ensured the system's efficacy in real-world scenarios.

The integration of failure mode and effect analysis (FMEA) was imperative to identify potential weaknesses within the system and assess their potential impacts. This analysis not only highlighted vulnerabilities but also informed modifications to the design, strategically minimizing points of potential failure. By conducting FMEA, the team proactively mitigated risks, enhancing the overall reliability and resilience of the system. These analyses collectively demonstrate the team's adeptness in identifying, evaluating, and refining key aspects, ensuring a comprehensive understanding and optimization of the project's critical components.

“The Build” -Fabrication/Construction/Production/Synthesis/Coding

The team met several times to complete the fabrication and construction of the prototype. In addition to meetings focused on integration, team members took on large amounts of independent work to develop the individual components of the design. In this section, we will tackle how the team worked independently and together to produce the prototype. In particular, the details of each sub-system and how the subsystem became integrated will be discussed. The integrated components of the build are as follows: Node housing and internal geometry, node internal electronics, Arduino board software, and model cable barrier posts.

Over the entire Spring semester, Jared iterated upon and used resources at Zachary to 3D print node designs. This iterative process began early in the semester and only came to an end just before a final build was completed. Furthermore, this process involved the iteration over node housing and internal geometry. Second for consideration is the node's internal electronics. The individual components of internal electronics were purchased online via Amazon. Once the supplies were received, the team - led by Jo - soldered electronic components to ensure a reliable connection that was tested originally on breadboards. The soldering took the close effort of two team members and generated the expected results. Next is the sub-system of the Arduino board software. The team detailed the exact requirements for what the internal electronics were to do, and the software needed to perfectly allow for these functions. Pryce, along with the consulting of the rest of the team, generated the code for the Arduino board that is held within the node. The code makes the electrical components perform their intended functions. The model cable barrier posts were fashioned by the whole group apart from Connor due to his remote circumstances. The model cable barrier posts were put together first by pouring concrete mix into buckets to hold the posts in place, and then by positioning the posts correctly and installing U-bolts.

Once each sub-system was fully developed, the team met for a series of final build meetings. In these meetings, the team brought together each sub-system and fashioned each together to create the final prototype. The integration began with the uploading of created software to the internal electronics. Once it was tested that the electronics were achieving the desired results, the internal electronics were mounted into the node housing and internal node infrastructure. Following this integration, the node was introduced into the model cable barrier system. The full prototype came together effectively and generally as expected.

In terms of lessons learned on the fronts of DFA and DMA, the team made some notable realizations. The first of these realizations was the consideration of sequencing the build properly. The idea here is that when carrying out the construction of a build, the order in which components will be added must be precisely known and optimal for a smooth construction process. When the team went to integrate the internal electronic components inside the housing of the node, considerations of space that were not previously thought about proved troublesome. If the team had more carefully considered the final positioning of the internal electronics before the build process on the internal node infrastructure, time and resources would have been saved. Another example of DFA and DMA consideration is the notion of designing the node housing and the node internal infrastructure within the same CAD model. The internal infrastructure of the node that ensures the correct internal placement of electrical components and the housing of the node was not considered in simultaneous twain. If the node was one nonmodular piece, the design would have been simplified greatly. This would have helped in reproducibility and overall build ease.

Testing/Verifying/Validating/Experimental Plan

The main parameters that our team verified were the ability of the device to detect a binary change in U-bolts and process that information into a collision magnitude metric which can then be transmitted. Referring back to our QFD, one particular parameter we had was that the device must have a threshold for processing an event. Within design development, the magnitude of a collision has been defined through the detection of the removal of a plurality of U-bolts wherein, when more of the U-bolts are removed, the magnitude calculated is greater. To test this functionality, the team armed the system with all three U-bolts securely in place. Then, the team removed a U-bolt one at a time and reviewed after the removal of each U-bolt that the proper magnitude calculation was being displayed by the circuit. Since this test focused on whether the circuit results in the correct magnitude calculation, transmission of the signal is not needed. Rather, displaying the resulting magnitude calculation through a sequence of LEDs was adequate. The system worked as expected and the circuit properly distinguished between minor and major ‘collisions’. This test was performed 5 times with 100% accuracy.

The next functionality that was tested was the mechanical functionality of the node. To set up a test of this nature, the simulated cable barrier post was set up with the node attached in front of a car. The car was then accelerated to observe an impact of 25 mph. Using this method, the team validated that the false U-bolts would dislodge as the original U-bolts did. The parameter used to evaluate the success of this validation procedure is the proper classification of collision in consideration of the test itself. This test was performed 5 times with 80% accuracy.

Other areas in which the team could perform future tests:

- Testing base power consumption of the device and peak power consumption for signal transmission
- Testing the effects of signal transmission with diminished power supply
- Testing operability in extreme heat and cold
- Testing for the required device installation frequency (e.g., 1 device per 2 posts, etc.)
- Validate signal receipts within specified ranges and during a variety of weather conditions

Safety/Hazard Assessment and Evaluation

In **Table 3** below, a few of the safety risks that the team has identified have been tabulated.

Table 3: Hazard Assessment.

Hazard	Probability of Occurrence	Severity	Risk Assessment
Installation Injury	Improbable	Marginal	Medium
Node Fire on Impact	Improbable	Catastrophic	Medium
Failed Transmission	Occasional	Critical	Serious
Injury to tamperer	Remote	Marginal	Medium

For the hazard identified as a failed transmission, the group has given this a risk assessment of being serious. This is because if a node is destroyed on impact it will not be able to send a signal which would ordinarily be considered a critical failure. However, the team has taken precautionary measures to mitigate this harm by making it such that the node will routinely send a nominal status signal. If this signal is not received by the hub, then the hub will know that a collision has occurred. The team has also taken precautionary measures to ensure that the hazard of “Node Fire on Impact” does not occur. That is, the group has specifically used only low-voltage power sources on the node such that even in the event of a short circuit or damage to the battery, the risk of spontaneous combustion is very low.

Reliability Assessment

To assess the reliability of the design, the group considered various aspects of the functional flow diagram and considered what could impede the flow of energy or information. The results are shown below in **Table 4**:

Table 4: Reliability Assessment.

Issue:	Primary Function:	Corrective Action
Low node battery voltage	Provide power to the node circuitry and radio transmitter.	Replace battery
U-bolt failed to remove	Detect if the cable has been displaced from the post	Implement G-load switches to determine if forces were exerted on the post
Radio Transmitter out of Range	Transmit magnitude information	Add more hub units near nodes
Incorrect Magnitude Signal	Allow the hub to determine the magnitude of the impact	Send all impact detections to authorities regardless of magnitude

While this is a preliminary investigation into the reliability of this system and more would need to be done before the launch of the system as a product, many important areas can already be identified. The two areas that the group has identified as being most important would be issues with the low battery voltage in the node and failing to have a U-bolt removed. As noted later in the Future Work section, one of the areas that may need improvement in this system is a low-cost solution for powering the node. The reliability aspect of that future work is certainly incorporated and would need to be addressed. The other potential issue with the design's current reliability would be the failure of certain U-bolts to be removed as intended. This reliability issue could be addressed by the implementation of G-load sensors. These would give a binary input to the node's circuitry if a certain G-load threshold has been met. Therefore, the node can be set up to detect the removal of U-bolts as well as a sudden acceleration of the post which would indicate an impact.

Societal Factors and Impact

The highway cable barrier alert system could impact society in a variety of ways. The first and most obvious way is by performing the desired task of letting authorities know when a collision has occurred with a highway cable barrier. In addition to letting emergency responders be aware of the crash, it will also let any relevant maintenance crews know of the crash so they can complete necessary repairs quicker.

Potential societal drawbacks from this design might stem from the reliance on the system's operation. This could result in potential issues because the system will likely not be flawless in its operation while drivers may be anticipating the system to work every time. This could cause some drivers to potentially delay in calling 911 for help since they believe that the highway cable barrier alert system has already called for help when a fault in the system may have occurred. This could cause emergency responders to be delayed in arriving at a scene as compared to not having the system at all (i.e. other drivers would know to call immediately).

The other reliance issue could come on the maintenance side. For example, if a maintenance crew begins to rely solely on the system's alerts for when to perform maintenance, then if the system has a fault, the maintenance crew will not know how to perform the necessary repairs.

The last major societal impact the team considered was the impact on the environment. This system could be harmful to the environment at many different stages in its life. While in operation the batteries used to power the nodes could begin to leak and allow acids to leak into the environment. At the end of their lifespan when the nodes are to be removed or replaced, they could contain chemicals that are not safe to leave in a landfill and would require additional costs to properly dispose of.

Future Work

Future areas of work can be seen in **Table 5** below:

Table 5: Future Work.

System or Sub-System	Area of Work	Need	Comment
Node	Electrical Engineering	Need to implement a Radio Transmitter	This radio transmitter should communicate with the hub unit
Hub Unit	Electrical Engineering / Computer Science	Need to set up a hub to receive radio transmissions and send MQTT signal	The development of the hub unit is what will allow the node to communicate with the server.
Server Subsystem	Computer Science	Development of the server subsystem.	This should receive MQTT signals and process them to send the required alerts.
Node	Electrical Engineering	Need a low-cost power supply solution	Development of a low-cost power supply that can reliably power the nodes.

As seen in **Table 5**, future work that needs to be done to this project to have it fully operational begins with the implementation of a radio transmitter onto the node. This will allow the node to properly communicate with the hub so a detected impact can be relayed to the appropriate entities. The next area that was identified by the team as needing future work is the development of the hub unit. This will require mostly a computer science background for interpreting the signals that are transmitted by the node and relaying them to the server. This leads to the next area of future work, which is the development of the server subsystem. This area will be purely a computer science area and will be processing the information from the hub and displaying it in an organized manner to the client. Another piece of future work that the team has identified would be to find a low-cost solution for supplying electrical power to the node. This would help the reliability of the overall system.

Team and Project Organization, Planning, and Execution

Ella Edwards, our team leader, was responsible for not only coordinating all of the team members but also being in charge of the UX design. Jo Flores was responsible for much of the circuit and electrical design but was assisted by both Ella and Connor. Pryce Hundley was responsible for much of the mathematics and computation that went into the design. Connor Roddy took the role of being in charge of the analysis and documentation. Jared Yost took the lead for modeling that was associated with the design.

The Gantt chart depicted below gives the general flow that the group adhered to over this semester. Some sectors of this chart are more volatile than others when it comes to the expected times of completion or the order in which the events occur, so what is shown below only illustrates our best prediction of how the semester would pan out. Now that the semester is over, our team was able to stick pretty well to the timeline provided.

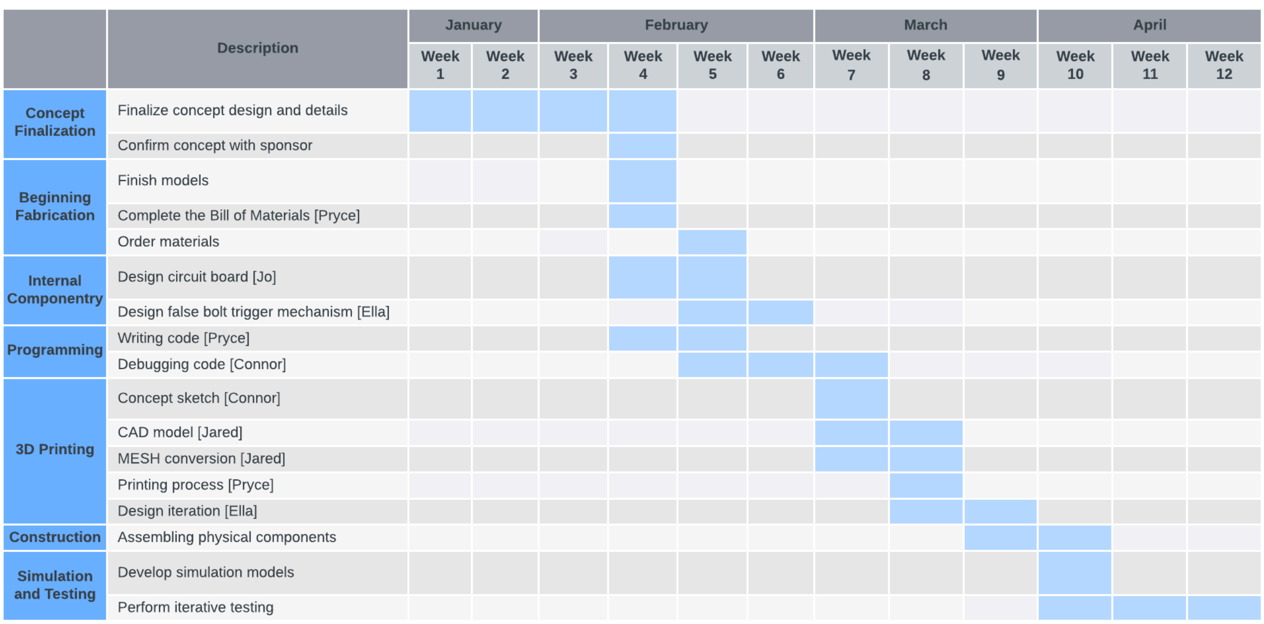


Figure 11. The Gantt chart for the Spring 2024 Semester.

This chart was used to help guide the group's weekly objectives to ensure that we had a timely completion of the project. Each week, the group would meet during studio time and begin working on the tasks for that week. By the end of studio time on Mondays, each group member was given various tasks to complete either individually or with a partner (if it was a challenging or more demanding task).

Summary

The goal of this project was to design, build, and validate an impact detection system for TxDOT that integrates with highway median cable barriers which broadcasts severity estimation and location information, providing alerts for emergency response and maintenance teams. This need statement has served to guide the team's engineering efforts this semester—all steps in the design process have been per this need statement. The team also adopted TxDOT's number one priority of the safety of Texas drivers in the engineering design process.

During the previous semester, the team used many concept selection techniques including a quality function diagram and down selection to land on the most suitable design. The concept that was decided on is the trigger device system. This system is composed of a modular binary detection system that is attached to the cable barrier posts and reacts to displacements in the cable following a disruption by detecting the removal of the connecting U-bolts. Despite this binary nature, severity can still be classified to a resolution that is within tolerances of TxDOT's standards for safety.

This semester, the team has modified the design in a few notable ways. The most notable alteration is that the modular body that mounts to the highway cable barrier post has been extended such that multiple U-bolts may be mounted directly to the body. This extension of the body also ensures that any wires are enclosed and protected as well as provides more space for the internal circuitry. This semester, the team furthered the design by developing the internal circuitry and further refining the 3D CAD model. Once these tasks were completed, the team began running through the testing and validation procedures outlined above. The team was able to test and validate the response of the node with great levels of accuracy.

With great pleasure, the team would like to thank Dr. Andrew Conkey for his ongoing support and consultation. His input has allowed the team to progress further than what had originally been planned for. In addition, the design team would also like to thank Arleene Garcia for her support and information relating to the mission of TxDOT.

Appendix

A. List of Abbreviations and Terminology

CAD — Computer Aided Design

CBAS — Cable Barrier Alert System

COTS — Commercial off-the-shelf

COTS-M — Commercial off the Shelf with Modifications

FEDC — Fischer Engineering Design Center

FMEA — Failure Mode and Effect Analysis

LED — Light Emitting Diode

M — Manufactured

MQTT — Message Queueing Telemetry Transport

NAND — NOT-AND

PLA — Polylactic Acid

QFD — Quality Functional Diagram

SWOT — Strength, Weakness, Opportunity, Threat

TxDOT — Texas Department of Transportation

USB — Universal Serial Bus

WBS — Work Breakdown Structure

B. References

No references were directly used for this report.

C. Order of Magnitude and Detailed Calculations

Objective of Analysis:

The objectives of these analyses are to examine both the minimum amount of force that will be exerted on a U bolt (normal to the post) when a vehicle collides with the cable barrier and the minimum tension force that is added to the cable when a vehicle collides with the cable barrier. These will relate to the functions of the system in the way that the force values exerted on the U bolt and the added tension force will be used to determine the magnitude of the collision.

Essentially this is presenting the problem statement. The statement needs to tie the analysis to a function and present the constraints of the analysis. The inclusion of a figure with labels is required. This work would end up in the appendix, but the initial setup and results would be included in the body of the report. This is pointed out as the content needs to agree with each other. That is, sections need to support and deliver the same message.

Engineering Principles to Apply:

Engineering principles that will be applied are the conservation of energy and work (physics)

State the engineering science, or principles, that will be applied and show how it ties into function.

- Conservation of Energy → Determine the amount of kinetic energy in a vehicle that must be absorbed by the system.
- Work → Determine how much force must be exerted on the vehicle by the cable to stop it.

Assumptions Applied:

Explicit Assumptions: a) the force applied by the cable onto the vehicle is constant, b) the cable is displaced laterally a distance of x, c) the vehicle is hitting between 2 posts separated 20 ft, and d) the force exerted on the “U” bolts is the same between the 2 posts.

The reason the force is assumed to be constant is because this will find the minimum possible force values that are exerted on the system. This is desirable because the team can compare the minimum force exerted to actual force values to determine magnitude thresholds for crashes.

Parameters: define the variables that will be used in the analysis. Good time to define a) parameters that are fixed, b) a range of parameters, and c) the known and unknown parameters.

$P_1 = P_2 = P$ = force applied to the “U” bolt on the post

F_1 = Force the cable exerts on the vehicle

F_t = Added Tension Force in Cable

X = displacement of cable from its straight position

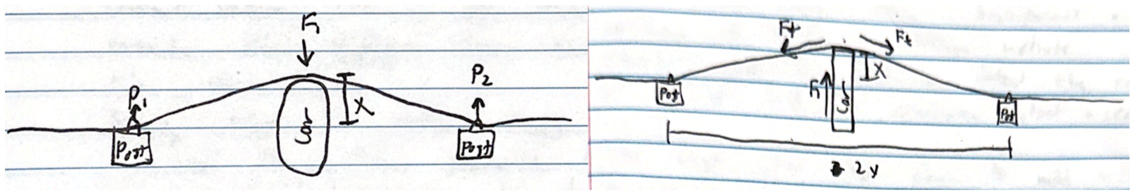
Y = distance from one post to the vehicle

Z = car weight (in Kg)

V = car velocity (in m/s)

W = Vehicle's Energy

θ = angle of cable deflection



Governing Relations:

$$F_1 = P_1 + P_2$$ ***Equation C1***

$$W = 0.5 \cdot z \cdot v^2$$ ***Equation C2***

$$W = F_1 \cdot x$$ ***Equation C3***

$$\theta = tan^{-1}\left(\frac{x}{y}\right)$$ ***Equation C4***

$$F_1 = 2F_t sin\theta$$ ***Equation C5***

<u>Analysis:</u>

The first step of the analysis is to set *Equations C2 & C3* equal to each other since the kinetic energy in the vehicle (*Equation C2*) must be equal to the work done by the car (*Equation C3*). After that, the x can be divided by both sides to result in the following:

$$F_1 = \frac{z \cdot v^2}{2x}$$ ***Equation C6***

Here, one can simply divide both sides by 2 to get the minimum force exerted on the U bolt, P. That result appears as follows:

$$P = \frac{z \cdot v^2}{4x}$$ ***Equation C7***

The next step is to combine *Equations C4 & C5*, then solve for F_t. After that, F_1 from the result above can be inputted to result in the following:

$$F_t = \frac{z \cdot v^2}{4x \cdot sin\left(tan^{-1}\left(\frac{x}{y}\right)\right)}$$ ***Equation C8***

E. Detailed working drawings/models/assembly

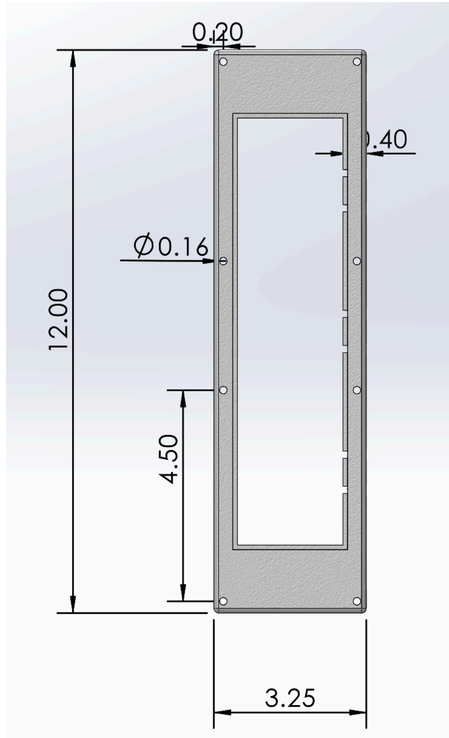


Figure 18. Front view of the node with dimensions in inches.

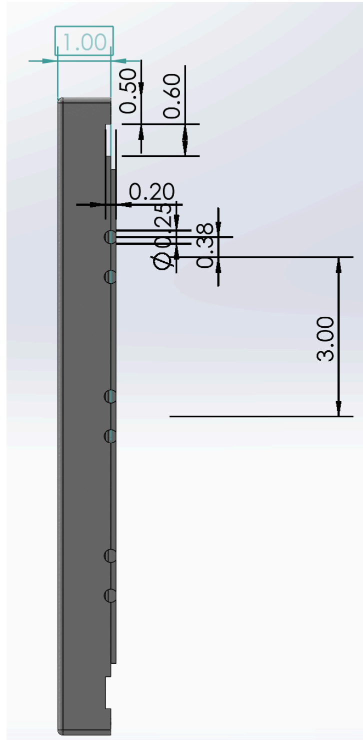


Figure 19. Profile view of half of the node with dimensions in inches.

F. Testing/Validating/Verification/Experimentation

The testing process for the circuit ensured functionality aligned with the intended design through systematic trial. The responsiveness of the LED display was confirmed to correspond to the removal of U-bolts in random order. This provides a clear visual indication of the severity level.

Additionally, assessments were conducted on the mechanical functionality of the node. By creating a false cable barrier system, the team was able to authenticate false U-bolt removal when an impact occurred– this ensures that the U-bolt removal would happen correctly in a real-world scenario.

Overall, the successful outcomes of these tests gave the team confidence in the CBAS's ability to function as intended in various conditions both electronically and mechanically.