Executive Summary

When a car runs into the back of a tractor-trailer outfitted with a weak underride guard, it poses an alarming danger to the passengers of the smaller vehicle. Mr. Jared Bryson from Virginia Tech Transportation Institute (VTTI) has come to our senior design team to study the causes of underride car accidents. Insurance Institute for Highway Safety (IIHS) have done crash tests on the underride guards from the eight largest underride guard manufacturers. All trailer bumpers passed the 100 percent overlap test, all but 1 passed the 50 percent overlap test, and all but 1 failed the 30 percent overlap test. Their studies have shown that the underride guards are not sufficient enough to prevent a car from going under the tractor-trailer, especially on a 30 percent overlap test.

Our team's goal is to work together to effectively design, develop, and build the next generation Interstate Commerce Commission (ICC) rear underride guard that meets the National Highway Traffic Safety Administration (NHTSA) standards and pass all IIHS overlap tests of 100, 50, and 30 percent. The main purpose behind this project is to design a bumper that will prevent a car from under-riding a tractor trailer bumper upon impact. The main motivation behind this project is to prevent fatalities when impacting the rear of a tractor trailer underride guard.

Throughout the semester, our team generated various concepts and designs for an underride guard that will fulfill our objective. We performed analysis to be able to down-select these concepts and lead us to our final design. These analysis were done through calculations, generating computer aided design (CAD) models, and Finite Element Analysis (FEA). We also consulted with Mr. Jared Bryson and Professor Robin Ott for their constructive feedback towards the goal of this project.

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I. Introduction

Every year, underride accidents account for fatalities in traffic accidents. Rear underride accidents occur when a passenger vehicle runs under the rear of a straight truck or semi-trailer. This brings an alarming issue that the current standards for underride guards are not sufficient enough to prevent these accidents. Shown in Figure 1 is how a car looks after a rear-end crash with a weak underride guard. This type of crash can result in serious injuries in the head and chest, or even death due to decapitation to the passengers of the vehicle.

Figure 1. A case of underride from a weak underride guard.

National Highway Traffic Safety Administration (NHTSA) has worked with Trucks Involved in Fatal Crashes (TIFA) to determine the severity of these crashes. For the 539 vehicles that struck the rear of the trucks, 532 were fatal. Of those fatalities, 312 of them were due to underride. The death toll on this type of accident is alarming. Associations such as Truck Safety Coalition and AnnaLeah and Mary for Truck Safety are bringing awareness to this case [1].

New crash tests and analysis by the Insurance Institute for Highway Safety (IIHS) demonstrates that underride guards on semi-trailers can fail in relatively low speed crashes. They have conducted tests with eight semitrailers including Great Dane, Hyundai, Manac, Stoughton, Strick, Utility, Vanguard and Wabash. Each of these were tested in various percent overlap cases. Overlap is the amount of the front bumper that is in contact with the object.

Shown in Figure 2 is an example of a crash test with a 50% overlap. This means that half of the vehicle bumper is in contact with the underride guard of the trailer. From the tests, all eight semi-trailers passed the 100% full width test. Seven of them passed the 50% overlap test and only one passed the 30% overlap test [2].

Table 1: Summary of the IIHS Semitrailer bumper tests results.

Crash test results for 8 top-selling trailers

	Full-width	50% overlap	30% overlap
Great Dane	pass	pass	fail
Hyundai	pass	pass	fail
Manac	pass	pass	pass
Stoughton	pass	pass	fail
Strick	pass	pass	fail
Utility	pass	pass	fail
Vanguard	pass	fail	n/a
Wabash	pass	pass	fail

Figure 2. A 50% overlap test using a 2010 Chevrolet Malibu.

Virginia Tech Transportation Institute took interest in this case to work towards real life solutions to this problem. The objective of this project is to develop and design a semi-trailer bumper that will prevent underride cases during rear end accidents. Based on the crash tests done by IIHS, our team would like to develop and design a semi-trailer bumper that will stand up against 30, 50, and 100% overlap. We will focus on addressing the cases for 30 and 50% overlap since most of the fatalities occur in those scenarios. The design team will come up with several concepts, down select the concepts addressed, and aim to narrow down to one final design. The goal by March 21, 2016 is to have our final design manufactured. From there, our team will be conducting tests and evaluate our final product from March 28, 2016 until April 28, 2016. We will then be presenting our final product to Mr. Jared Bryson on May 4, 2016. On May 5, 2016, our team will be attending an Underride Roundtable discussion hosted by IIHS in Charlottesville, Virginia to present our final design as well.

II. Target Specifications and Requirements

To begin the project, our team had a face to face meeting with our sponsor, Mr. Jared Bryson, to discuss a list of customer needs. These customer needs gave the project a direction and told our team where our client's needs were focused. As seen in the table below, our client offered 12 preliminary needs that our team used to direct our focus throughout the project.

Table 2: Refined customer needs according to our sponsor's design.

No.	Original Customer Need	Refined Customer Need	Engineering Characteristic	Importance (1-5 Important)
1	Does Not Affect Payload	Weight Conscious Design	Weight, kg	3
2	Aerodynamic	Does not Affect Current MPG Values	Change in MPG	3
3	Low Production Cost	Cost Conscious Design Process and Final Product	Production Cost, US Dollars	2
4	Durable	Does not Fail in Rear End Collision Scenarios	Adequate Factor of Safety	5
5	Weather Resistant	Rust and Corrosion resistant	Reactive Resistant Coating / Steel	1
6	Detachable	Easily Replaceable	Low Assembly Time	1
7	Repairable	Can be weld-repaired	Modularity	2
8	Fits Current Trailers	Bolts in/Welds on the Same Way Current Designs Do	Modularity	2
9	Meet/Exceed Current Performance Standards	Design for Rear End Collisions	Adequate Factor of Safety	5
10	Axle Mobility	Application does not limit adjustability/mobility of axles	% Mobility Lost	4
11	Allows for Common Trailer Use	Does not Interfere with Loading and Unloading	Gap Between Trailer and Loading Dock, cm	4
12	Disperses Load More Efficiently	Crumple Zone	Damping / Deceleration Zone	4

The sole purpose of this design project is vehicle passenger safety. Therefore, safety concerns were one of the most significant customer needs discussed, as seen above. The topic of safety was broken down into two basic needs: the prevention of under-ride and the creation of a deceleration zone to ensure the passengers in the car did not experience severe G-loads. Prevention of underride was the founding need for this design that could not be overlooked. The creation of a deceleration zone ensured passenger safety beyond the prevention of underride. The added safety value of a deceleration zone would aid in the acceptance of the final design in the trucking industry.

The other general customer need that was stressed by Mr. Bryson was maintaining trailer functionality. The new design could not impede the basic performance requirements of tractor trailers. Our team broke this general customer need down into three individual needs. The first was trailer axle mobility. Trailer axles can be moved in order to accommodate different loads in the trailer, and this range of mobility could not be drastically limited by our design. The second need focused on the function of loading and unloading trailers. The customer's request was that the final design did not cause a severe gap between the trailer and trailer loading docks. A gap would cause extra steps the driver would need to take to unload and load the cargo, creating cause for the industry to ignore the design altogether. The final general customer need derived from maintaining trailer functionality was durability. If the bumper design were not durable, it would require constant maintenance and extra time for care and attention that modern bumpers do not. Maintenance of basic trailer functionality would help ensure our design was seriously considered for implementation in the trucking industry.

In the customer needs table, our team generated a set of engineering characteristics based on the customer needs presented by our client, Mr. Bryson. In Table 3 below, our team created target specifications based on these engineering characteristics. The first column of the target specifications table, needs, displays which customer needs each engineering characteristic affects. The final two columns, threshold value and target value, are determined from both research and estimation. Our team researched approximate values based on current products and estimated values from engineering experience and basic calculation. The target value column presents the optimal values we are trying to achieve based on the best values from current tractor trailer bumpers in production. For example, in the first row, in an ideal design our team would create a bumper with a weight near 90.7 kilograms (200 lb). 90.7 kilograms is the approximate weight of the lightest bumpers on the road today, such as the Utility bumper. Meanwhile, the threshold value is essentially the pass/fail mark for the design. From the first row, if the weight of the trailer bumper is above 226.8 kilograms (500 lb), the design is considered a failure and our team must redesign the bumper. Each value discussed above can be seen in Table 3.

Table 3: Target Specifications table derived from the Customer Needs and Engineering Characteristics.

Need(s)	Engineering Characteristic	Importance	Units	Threshold Value (Needed to Pass)	Target Value (What we're shooting for)
1, 2, 3, 6	Weight	3	kg	226.8	90.7
1, 2	% Change in MPG	3	%	5	0
3,7	Production Cost	2	$(US)	2000	500
4, 9	Factor of Safety	5	Ratio	3*	4*
4, 5	Non-Reactive	1	List	Low Grade Steel	Non-Reactive Coating & Low Grade Steel
1,6, 7, 8	Assembly Time	1	Minutes	45	15
8,10,11	Modularity	2	# of Trailers Design Fits	1	Translatable to Several Trailers
10	% Mobility Lost	4	%	10	0
11	Gap Between Trailer and Loading Dock	4	cm	5	0
4, 9,12	Damping/ Deceleration Zone	4	cm	0	45
*Factor of Safety based on current U.S standards. For this spec, the current top performing production bumper has a factor of safety of 3					

From the table above, it is clear that the general customer needs of vehicle passenger safety and trailer functionality remained the issues of highest importance. With our sponsor in mind, our team therefore set the target values to achieve high standards of performance with the threshold values still surpassing modern designs' standards.

The target specifications were useful in generating numerical goals for our design to meet while also providing a stepping stone in the creation of the project requirements, as seen in Table 4.

Table 4: The requirements based off of the specifications of Table 3.

Requirement	Category	Specification	Threshold Value (Needed to Pass)	Target Value (What we're shooting for)
Payload shall not be affected	Design	Weight	226.8 kg	90.7 kg
Gas mileage shall not be affected	Functionality	% Change in MPG	5	0
Part shall meet current budget for trucking industry	Manufacturing	Production Cost	$2000 US	$500 US
Part shall meet and exceed the maximum allowable load based on material properties	Design	Factor of Safety	3	4
Part shall not corrode or react to road salt/sea air	Design	Non-Reactive	Low Grade Steel	Non-Reactive Coating & Low Grade Steel
Part shall not cause a waiting period for production	Manufacturing	Assembly Time	45 mins	15 mins
Part shall be applicable to several trailers with minor attachment point design variations	Functionality	Modularity	Fits 1 Trailer	Translatable to Several Trailers
Part shall not interfere with trailer axle functionality	Functionality	% Mobility Lost	10	0
Loading ability shall not be impeded	Functionality	Gap Between Trailer and Loading Dock	5 cm	0
Part shall absorb at least 20 kJ within the first 125 mm of deflection	Functionality	Damping/ Deceleration Zone	0 cm	45 cm

Table 4 displays the relationship between each specification and the requirement associated with that specification. Essentially, a requirement is a definition of each specification in the form of a command. For example, in row one, the specification is weight; the accompanying requirement for weight is that the payload shall not be affected by the weight of the bumper. The requirement clearly explains the specification and is worded as a goal that the team must achieve.

One characteristic of the requirements that is worth noting is that each requirement is written to achieve the target value as opposed to the threshold value. For example, in row two, the requirement states that gas mileage shall not be affected. Our team's target value for percent change in miles per gallon is 0% change. If gas mileage is not affected by the installation of the new bumper, then the percent change in miles per gallon of fuel must be 0%. The reason each requirement is written to achieve the target value is that our team must strive to achieve the optimal design with respect to each specification, ensuring the absolute best final product.

Before we could complete the requirements table, though, our team needed to make one final adjustment. The category column is usually determined by the mechanical sub-category each requirement addresses. For example, in an airplane, if the requirement stated that the plane shall produce a certain amount of thrust, the category for that requirement would be the engine, a mechanical sub-category of the airplane. For this project, however, the mechanical sub-category of each requirement was simply the tractor trailer bumper and further categorization could not be achieved. As a team, we decided to sort each requirement into one of three new categories: Functionality, Manufacturing, or Design. Although this is not how the category column was originally designed, our team and client both agree that this is the best way to address the issue.

III. Concept Generation and Selection

Concept Generation: The concept development process performed by this group was extensive. We accounted for all possibilities and designed alterations that could affect the final design using the target specifications created previously from the customer needs and engineering requirements. A series of structured methods were performed to generate ideas towards our final concept.

Initially, a series of brainstorming activities were performed. A 6-3-5 brainstorming method was used to generate the initial ideas. This allowed for all members to have an equal opportunity in the process. This structured brainstorming method led into a more free-for-all brainstorming session where each team member contributed ideas to the group discussion. Once an idea was proposed, team members would build upon it, or discuss it to create more ideas that branched off from the original.

The next brainstorming activity performed was a morphological analysis. The design team considered the overarching functions of the underride guard as well as the target specifications. These functions and specifications were then used to generate sub functions to define the purpose of the design. The sub functions helped in creating concepts specific to each aspect of our design and covering specific functions rather than an overarching goal.

Concept Selection: From these concept generation methods, a total of 32 concepts were determined. To down select these concepts into a final concept, a series of selection methods were used. First, a concept screening matrix was used to narrow down the possibilities. Each concept was compared using the engineering characteristics from our customer needs. A datum was chosen as the base. Each concept was then compared to that datum with regard to each engineering characteristic. If the concept performed better than the datum in that category, the concept was given a 1. If it was similar, it was given a 0. If it was inferior in that engineering characteristic, it was given a -1. These totals were added up and each concept was given a rank. This process was repeated for several different datums to allow for accurate rankings and down selection results. After these initial iterations, 11 concepts were selected from the original 32. These 11 concepts can be seen in Table 5. The final concepts below are the highest ranking concepts involved.

Table 5: Concept screening matrix

	Concepts										
	"+1" support beam	Dampener Support Bumper	Leaf Springs Bumper	Sine/Triangular Support Beam Bumper	Night Rider	Curved Bumper w/ Honeycomb	Retractable Bumper with Shear Webbing	Airbags	Wrap Around Bumper	"+2" Support Beam	Soft/Hard Wall Bumper
Cost	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
% Change MPG	0	0	0	0	0	0	0	0	0	0	0
Weight	0	-1	-1	0	-1	0	-1	0	-1	-1	-1
Factor of Safety	0	1	1	1	1	1	1	-1	1	1	1
Non-Reactive	0	-1	0	0	-1	-1	-1	0	0	0	0
Assembly Time	0	0	-1	0	-1	0	-1	-1	-1	0	-1
Modularity	0	-1	-1	0	0	1	-1	0	-1	0	-1
% Axle Mobility Loss	0	0	0	0	0	0	-1	0	0	0	-1
Gap Between Trailer and Loading Dock	0	0	0	0	0	0	0	0	0	0	0
Deceleration Zone / Damping	0	1	1	1	1	1	1	1	0	0	1
TOTAL	*0*	*-2*	*-2*	*1*	*-2*	*1*	*-4*	*-2*	*-3*	*-1*	*-3*

After this round of concept selection, the above 11 concept designs were considered. The next series of iterations using the concept screening matrix brought the final number of concepts down to six. Shown below, our team used the final concept screening matrix once more in order to generate four final concepts. These four final concepts would be examined later in a weighted down selection matrix.

Table 6: Refined concept screening matrix

	Concepts					
	Curved Bumper with Honeycomb	Dampener Support Bumper	Sine/Triangular Support Beam Bumper	Night Rider	Wrap Around Bumper	"+2" Support Beam
Cost	0	-1	-1	-1	-1	-1
% Change MPG	0	0	0	0	0	0
Weight	0	-1	0	-1	-1	-1
Factor of Safety	0	1	1	1	1	1
Non-Reactive	0	-1	0	-1	0	0
Assembly Time	0	0	0	-1	-1	0
Modularity	0	-1	0	0	-1	0
% Axle Mobility Loss	0	0	0	0	0	0
Gap Between Trailer and Loading Dock	0	0	0	0	0	0
Deceleration Zone / Damping	0	1	1	1	0	0
TOTAL	*0*	*-2*	*1*	*-2*	*-3*	*-1*

After several iterations with our team's final concept selection matrix using many different datums, our team selected 4 final concepts. The Honeycomb concept, Knight Rider concept, Wrap Around concept, and "+2" Support concept were chosen as our final four design concepts. The sine/triangular support beam concept was considered more of a facet that could be implemented in any of our designs, therefore eliminating it as an individual concept. Although the dampener support concept did not finish last in several of the concept screening matrix iterations, our team eliminated this design for feasibility purposes. The required diameter of the dampeners that would be used to absorb the force of impact was calculated to be roughly 0.5 meters. This was simply too large to implement in a bumper design, rendering the concept useless.

With the final four concepts decided, we organized them into two categories. The first category represented the concepts that served as a better brick wall. They are simply designed to stop the car without absorbing impact or trying to reduce the forces upon the car. The second category was the energy absorbing category. This category focused on increasing the stopping distance of the car to reduce the load felt by the driver and car.

The first design of the energy absorbing concepts is the Honeycomb bumper concept. As shown in Figure 3, this design absorbs energy by including an energy absorbing material on the outside face of the bumper. In this design, our team uses a metallic Honeycomb material to provide uniform damping with a known crumple distance of the material (70% of the original Honeycomb depth). This would increase the stopping distance of the car, thus creating less load on the vehicle's occupants and the trailer bumper.

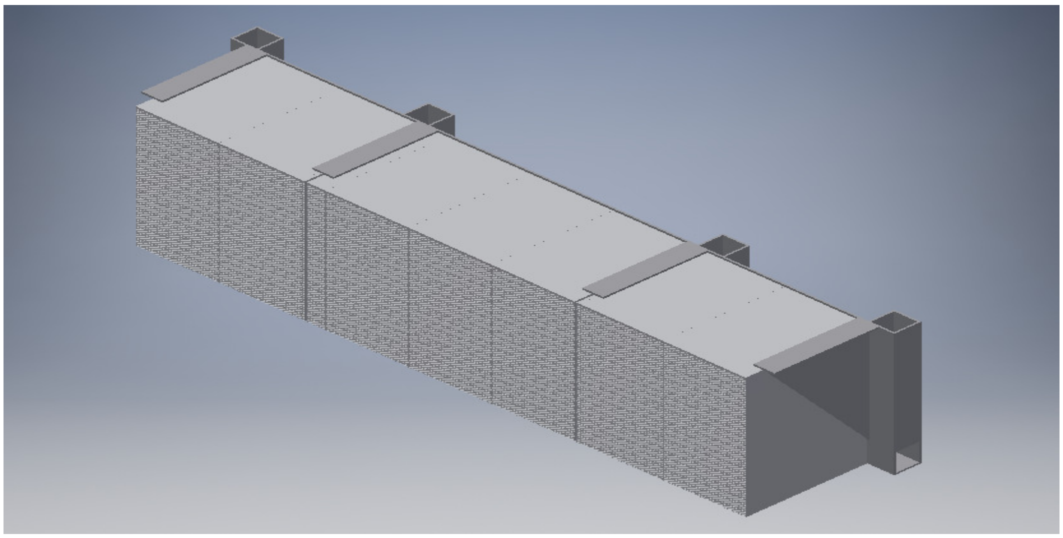


Figure 3. This image shows the CAD model of the Honeycomb bumper.

Figure 4 below shows the other concept included in the energy absorption category which is the Knight Rider design. This concept consists of a bottom plate that is mounted underneath the trailer. This serves as a functional catcher's mitt that wedges the car into place. The plate is pulled upward in the vertical direction by a series of chains or cables attached to both the plate and the bottom of the trailer. When the car pushes against these cables, the plate is pulled upward, resulting in the wedging of the car between the plate and the bottom of the trailer.

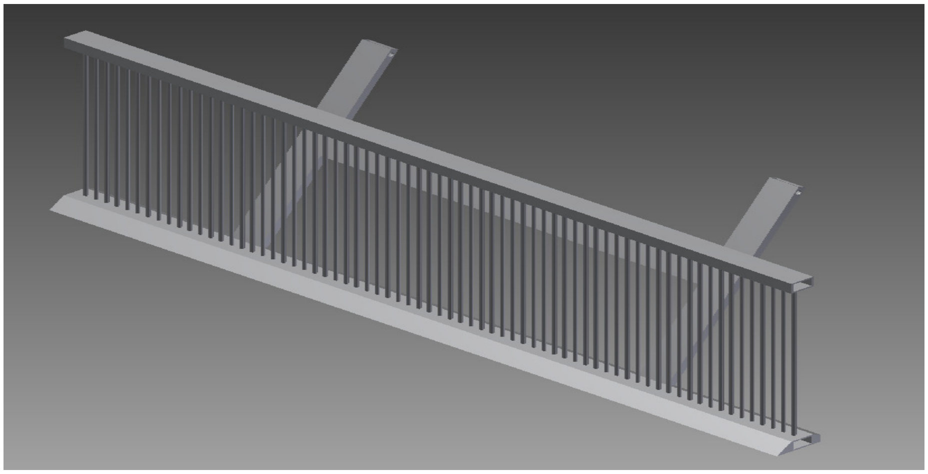


Figure 4. This is an image of the Knight Rider concept shown in an orthographic view.

The next series of concepts are part of the category of better brick walls. This set of designs prevent underride, but do not attempt to decrease the force seen on the car through damping mechanisms. The first design can be seen in Figure 5. The center Wabash support beams provides a brick wall and that is supported by an additional 2 gussets to increase strength.

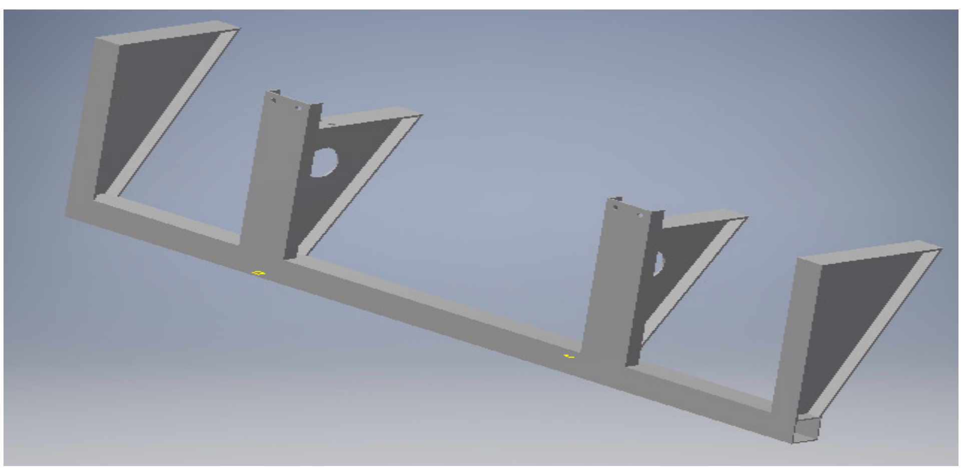


Figure 5. Image showing the design of the underride guard with 2 additional support beams.

The design shown above is a very rigid design that is highly simplistic and offers no new features from current production designs; it is simply an improved brick wall bumper. This concept is based on the Wabash which currently has four vertical supports along the rear of the bumper. The "+2" Support Beam design, however, improves the structure of the support beams on the ends of the bumper to accommodate for the 50% and 30% overlap scenarios.

The second design in this category is the Wrap Around Bumper as shown in Figure 6. This design consists of the “+2” Bumper design to prevent rear underride while including a side bumper that wraps around the trailer toward the tires. This design serves as an underride guard in the instance of either rear or side collision. The side panels not only provide protection from a side impact but also offer structural support for rear collisions with less than 100% overlap.

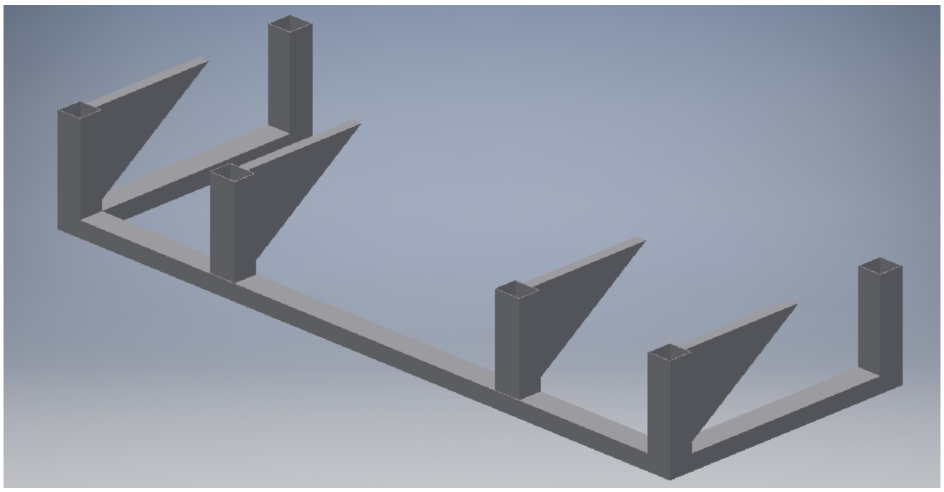


Figure 6. This image is a depiction of both the orthographic view of the Wrap Around Bumper.

With our four final concepts chosen, our team moved on to the final form of down selection: The weighted down selection matrix. As seen in the table below, the weighted down selection applies weight to each of the engineering characteristics based on their importance from the target specifications table.

Table 7: Weighted concept down selection matrix

Constraints		Honeycomb		Knight Rider		Wrap Around Bumper		"+2" Support Beam	
Meets NHTSA standards		Y		Y		Y		Y	
Increases Passenger Safety		Y		Y		Y		Y	
Objectives	**Weight (%)**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Weight	13.00	0.00	0.00	0.19	2.50	0.64	8.30	0.98	12.76
Cost (US$)	17.00	0.06	1.00	0.99	16.88	0.98	16.63	1.00	17.00
Factor of Safety	18.00	0.52	9.36	0.00	0.00	0.71	12.86	0.98	17.68
Non-Reactive	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Assembly Time	2.00	0.00	0.00	0.74	1.47	0.36	0.72	1.00	2.00
Modularity	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
% Axle Mobility Loss	8.00	1.00	8.00	1.00	8.00	1.00	8.00	1.00	8.00
Gap Between Trailer and Loading Dock	16.00	1.00	16.00	1.00	16.00	1.00	16.00	1.00	16.00
Damping / Deceleration Zone	17.00	1.00	17.00	0.00	0.00	0.20	3.40	0.00	0.00
Total	**100.00**		**52.36**		**45.85**		**66.90**		**74.44**

The total scores of each design are in bold along the bottom row of the table. From this weighted down selection, it is clear the “+2” Support Beam concept won with the second best design nearly eight total points behind. The Honeycomb simply weighed too much and the cost of the Honeycomb material was $3000-$4000 based on a quote from Plascore, making the design too expensive to produce for our $3,000 budget. The Knight Rider was too heavy and the group had feasibility concerns overall. The concept had to be feasible both in functionality and our ability to produce a working product by the end of the spring. Our engineering team was too concerned that even if we could produce it by the end of spring, we were not certain it would perform as desired. Our team also knew that we had two other designs that were both feasible and proved to rank higher in the weighted down selection matrix.

The Wrap Around Bumper and “+2” Support Bumper have essentially the same rear face while the Wrap Around concept adds safety in the side impact scenario. Because of the added material and minor design alterations, the Wrap Around Bumper suffered in cost, weight, and assembly time in comparison to the “+2” Support concept. These were the main reasons the Wrap Around fell short in the total value row. However, because the Wrap Around design offered improved safety not only in a rear end collision, but also in a side collision, our team decided to choose the Wrap Around Bumper. Our team felt the added safety benefits of the Wrap Around outweighed losses in cost, material weight, and assembly time when compared to the down-selection-matrix-winning “+2” Support design.

By the time our team had chosen the Wrap Around concept, more developed CAD models had been produced. When comparing Figure 7 below to Figure 6 of the original Wrap Around design, the team generated a much more realistic rendering of our winning concept.

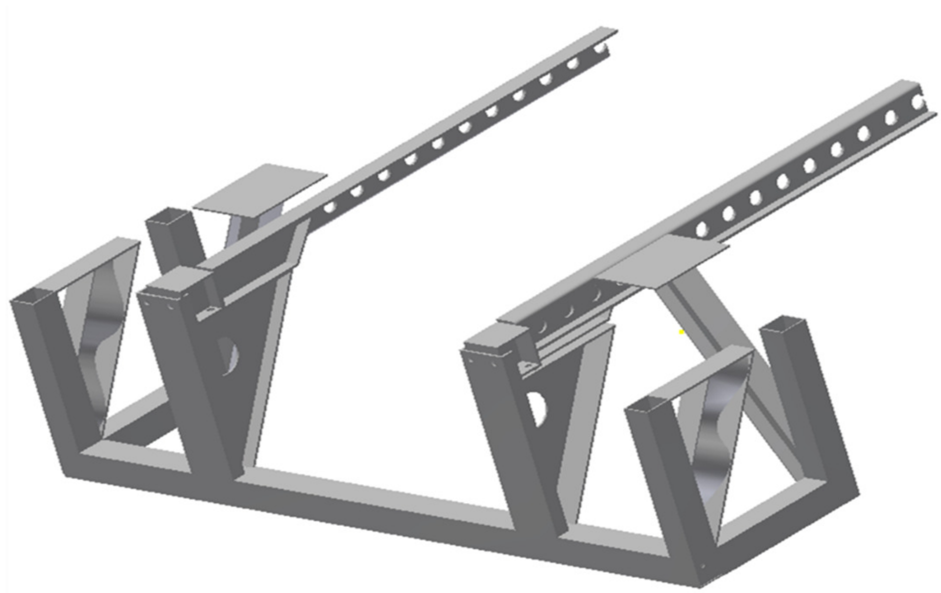


Figure 7. The image above displays the winning, Wrap Around Bumper concept.

IV. Analysis, Prototyping and Test Results

Initial Analysis: The first major simulation that was performed for this project was an analysis to determine the initial loading of a vehicle at the point of impact. In an effort to do this the, team created a CAD model of the underride guard of a 2016 Wabash bumper. The accuracy of this model was then tested using test data from an IIHS study performed on a trailer of the same type. The procedure for this testing follows the Federal Motor Vehicles Safety Standard 223. [3] This dictates three separate points on which a trailer may be loaded, and are named P1, P2, and P3. The location of these points may be found in Figure 8.

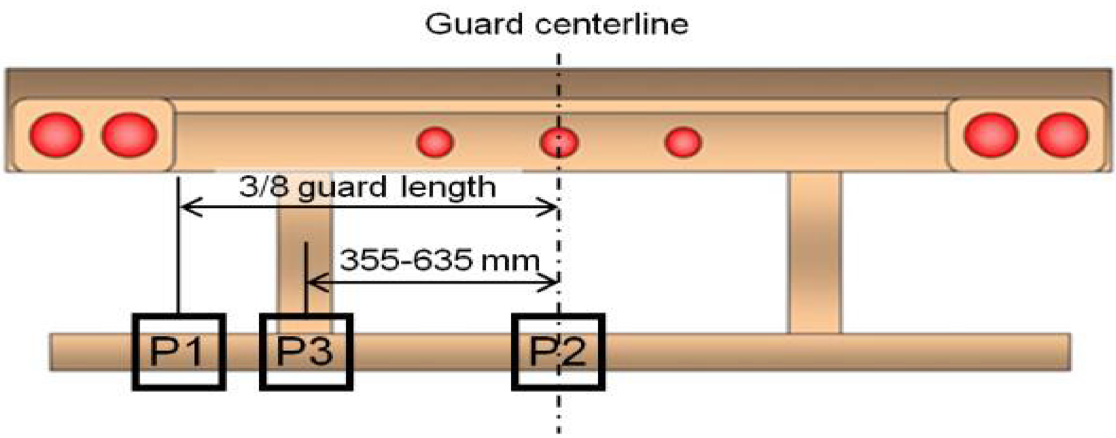


Figure 8. P1, P2, and P3 identify the 3 locations the test load can be applied.

FMVSS standard 223 also lays out the testing procedure. This says that the guard must be loaded quasi-statically with a force application device that has a feed rate of between 2 and 9 cm/min.[3] The device that applies the force must measure 203 x 203 x 25 mm and be made of steel.[3] In order to satisfy these requirements an extrusion was created on the guard as shown in Figure 9. The extrusion is placed in the location described as P3 in the FMVSS standard.

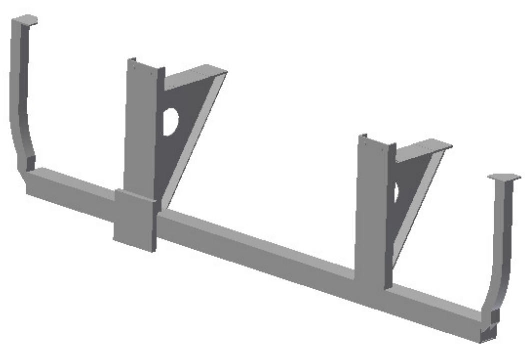


Figure 9. The loading device is centered on the horizontal bar at the P3 location.

Previous IIHS test were conducted on three production tractor trailer bumpers.[4] The team used the results from this test as a baseline for our Finite Element Analysis(FEA). The results from the IIHS test are shown by Figure 10. By changing the constraints in our CAD model the team found a set of constraints that was able to accurately depict the test data. These constraints included the four main bolt connections on the vertical members and the main bolt connections on the side support arms.

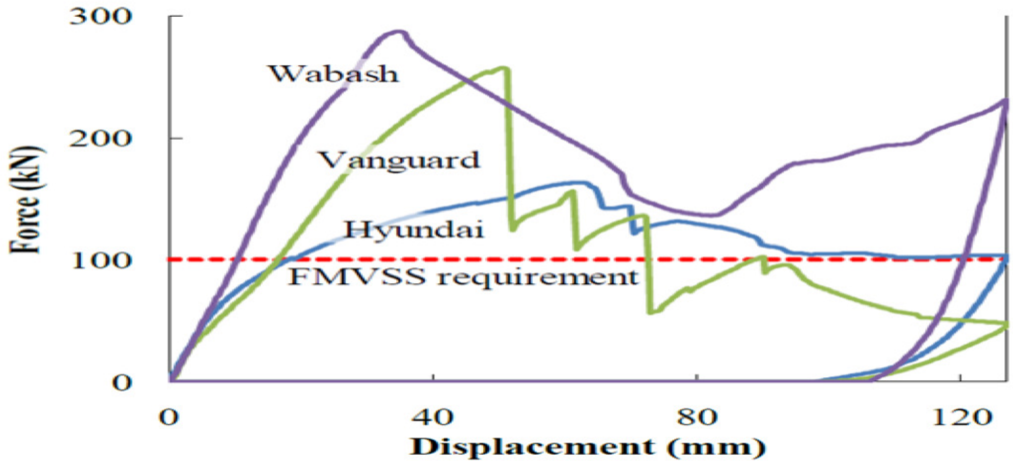


Figure 10. Shown are test results of three production trailers when applying a P3 load. The figure also shows the minimum amount of force required to pass the test. [4]

Although these connections gave accurate results, upon closer inspection of the model's FEA simulation, the lack of constraints near the rear of the model concerned us. As seen in Figure 11, the initial analysis showed deformation that would be impossible in the actual trailer due to a bump stop that is mounted behind the member.

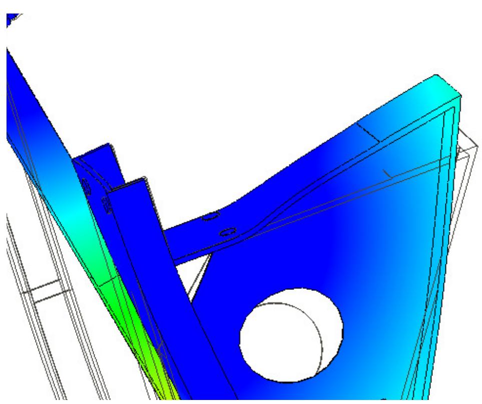


Figure 11. Shown is the deformation of the Wabash model that would have been impossible in a real-life scenario.

With this realization the team decided that a closer look at the constraints must be performed before moving forward with the analysis.

Constraint Analysis: In order to get accurate results we varied the constraints in our model to achieve the same displacement as the Wabash Trailer. As stated earlier, our previous analysis used a model with improper constraints. The team took a trip to VTTI and determined the proper constraints to use on our CAD/FEA model based off visual inspection of the actual bumper. The bumper is attached to the trailer by four ¾ inch bolts and the gussets in the rear are welded to the main support rails. The main issue with our original model was that we under-constrained our model. When running new test we did not want to over-constrain our model, so we applied various combinations of constraint to our CAD model. Figure 12 shows the different combinations of constraints we applied to our model.

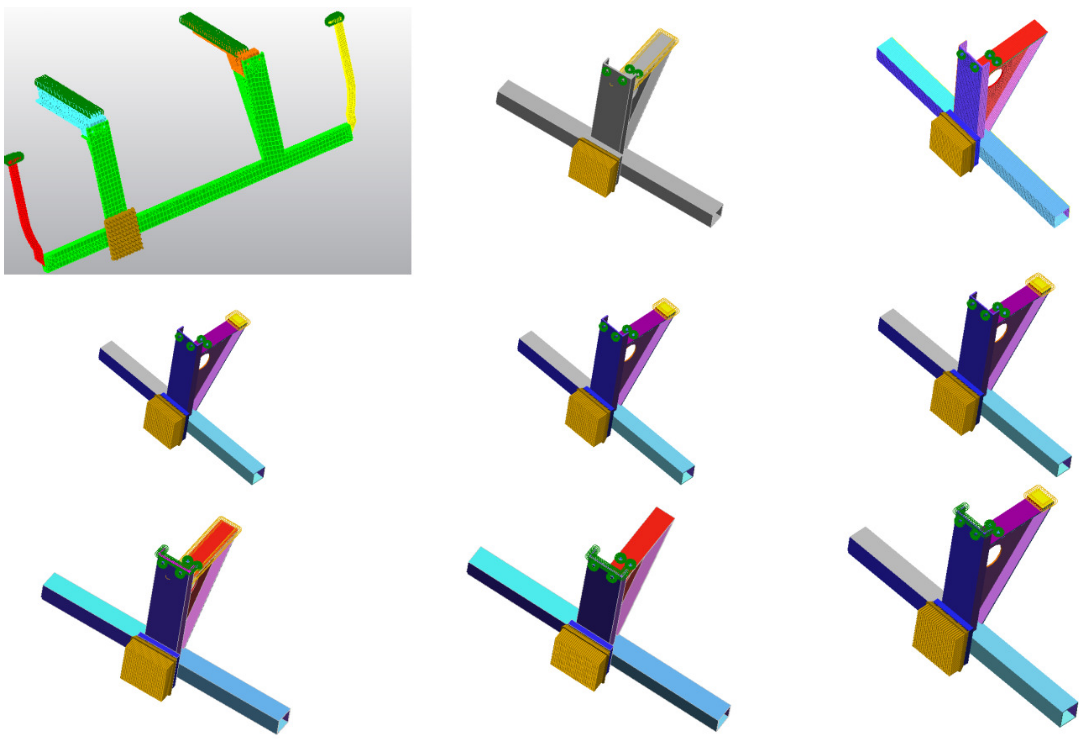


Figure 12. Shown are the different combinations of constraints applied the CAD model.

The cases for our constraints analysis are labeled as follows; starting from the top row, going left to right: Full model, Case 1 with edges and Case 1. Starting from the middle row, going left to right: Case 2, Case 3, and Case 3 with edges. Starting from the bottom row going, going left to right: Case 4 just bolts, Case 4 just bolts and edges, and Case 5.

For some of the cases we removed the bolt holes (Case 3) and extruded a cylinder that would simulate the bending of bolts (Case 1 and 4). In other cases we allowed the gussets to flex by adding an extrusion to the rear end of the model (Case 3 and 5) and then applied the constraints to the extrusion. For all cases we set our constraints to have no translation in the x, y, and z directions.

With the different combinations of constraints established we applied the same P3 loads as the IIHS test to each case and ran the finite element analysis. Figure 13 shows the results from the constraint analysis performed.

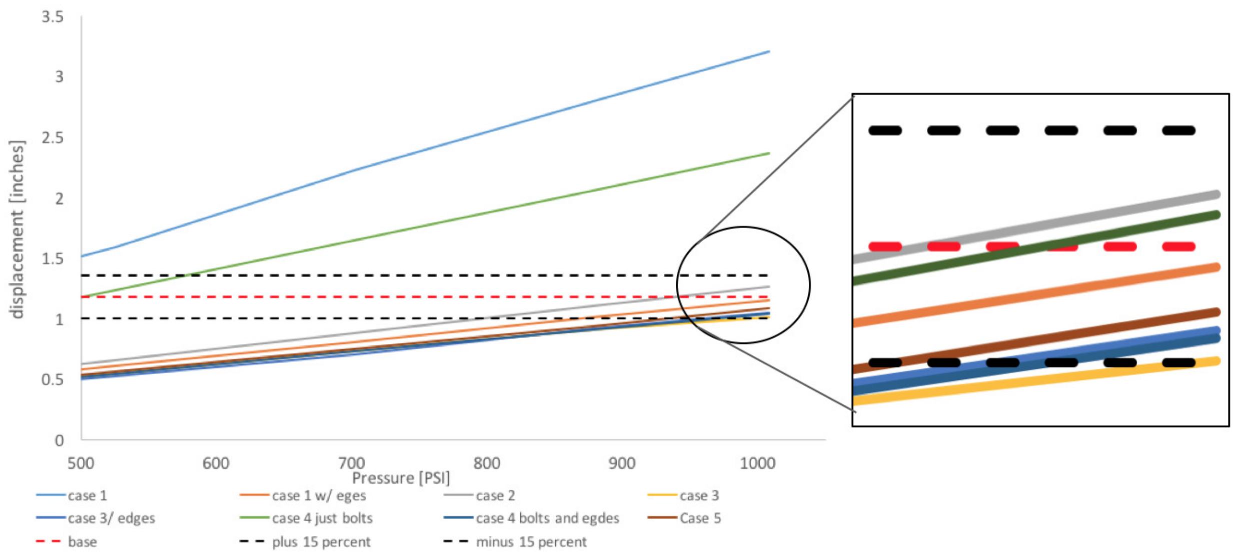


Figure 13. Results from the constraint analysis performed on our cad model. The results from our analysis were compared to the test results at 1080 PSI.

As shown in Figure 13, most of the constraint combinations fell within plus or minus 15 percent of the final deformation in the test results as indicated by the dashed red line. With these results we felt confident that any additional finite element analysis performed will provide the team accurate results.

Analysis of Final Four Concepts: With the constraints properly defined the team was able to analyze the final concepts as an aid to the down-selection to a final concept. These final concepts included the wrap around bumper, the nightrider, the honeycomb, and the plus two support bumper. Due to the structure of the honeycomb it was not feasible for the team to analyze the design by solely using Finite Element Analysis. The first step in its evaluation was to determine the decrease in velocity that implementing the honeycomb will provide. This was done by using conservation of energy as shown in equation (1):

(1)

Where m is the weight of a 2014 Chevrolet Malibu in kg, is an assumed initial velocity of 15.5 m/s, is the energy absorbed by the honeycomb from the Crush Force data for a PACL-XR1-3.7-⅜-0.0025-5052 honeycomb over a crush distance of 12.5 m, and is the final velocity in m/s.

This calculation resulted in a final velocity of 11.1 m/s or a decrease of 29%. This allowed us to implement the corresponding change in force to our model. As discussed earlier however, the tremendous cost of the honeycomb was a major hindrance to the concept.

The nightrider concept was perhaps the most difficult model to analyze due to the bending of the cables. It's because of this that the team performed this analysis primarily through hand calculations. The most critical of these calculations was determined to be whether the cables had enough tensile strength to withstand the impact of a vehicle. To study the feasibility of this, the tension in the cable was found at various angles from the vertical. This study was then compared to the the maximum tensile strength of a steel cable. The results of this study found that the minimum angle for the cables to be effective was 45 degrees. This is assuming the vehicle is able to contact 10 steel cables with a ½" diameter. This raises a couple of concerns for the team as in the overlap scenarios it will be impossible for the necessary contact area to be created without the spacing being incredibly small. In addition by the time the necessary angle of the cable is reached, the car will be partially under riding the trailer.

The wrap around and the plus two support bumpers were considered very similar for the purposes of this analysis. Both models were evaluated using FEA as the primary tool. Since both of these designs were very similar to the original Wabash model, the first thing that our team wanted to do is to make sure that the addition of the side supports does not deteriorate the success of the 100 percent overlap scenario. To test this, the team added a force application device to the bar that represented the main contact between the vehicle and the underride guard. This was found to be the bumper bar that is shown in a light blue color in Figure 14.

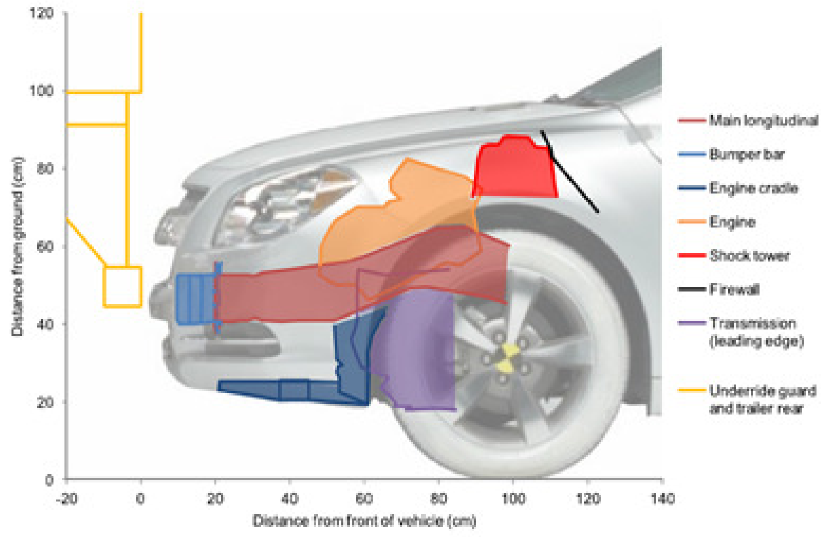


Figure 14. The car pictured above is a 2014 Chevrolet Malibu. The part shaded in light blue is considered the main point of contact between the car and the underride guard.

When implementing these factors into the model, as shown in Figure 15, the team is able to see that the total displacement in the model changed by 2.27%. From this the team predicts that there should be no major setbacks in the 100 percent overlap scenario by adding the side supports. The next study the team performed is the 50 and 30 percent overlap scenarios. This was done by simply adjusting the location of the bumper bar along the horizontal member. In doing this the team noticed a pattern that became clearer as the bar approached the end of the member. This pattern is that the the increased strength in the bumper causes the vehicle to bounce away from the bumper upon impact. An example of this is shown in Figure 16 as there is obvious deflection away from the bumper as the guard is impacted. This leads the team to believe that when the car hits the rigid structure that is seen in the wrap around and plus two bumpers it will bounce out of its current lane of travel. The solution to this problem is to soften the rigidity of the corner so that the distance the vehicle is deflected from the bumper is decreased.

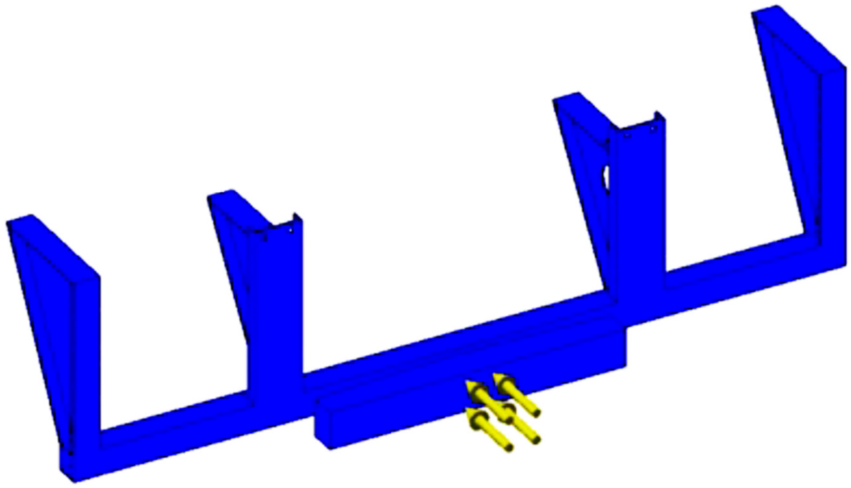


Figure 15. The 100 percent overlap scenario of the plus two support bumper. In the 100 percent overlap scenario the centerline of the trailer and the vehicle are aligned.

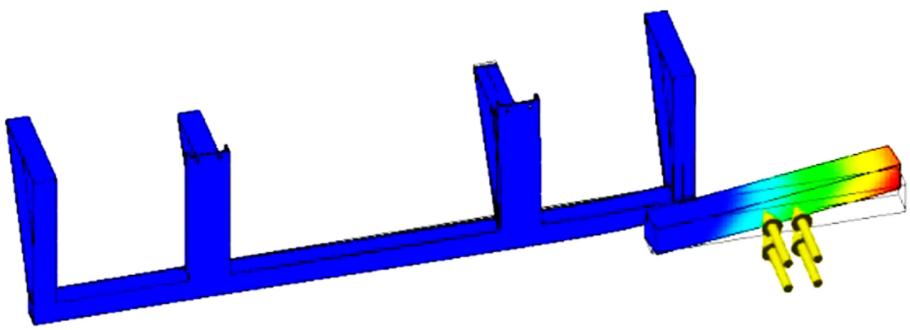


Figure 16. The 30 percent overlap scenario of the plus two bumper. The largest deflection is seen at the far right of the figure which illustrates a vehicle being pushed outwards during a collision.

FMEA and Risk assessment: To ensure the team maintained our current schedule, the team evaluated different risks our project could come across during the fall and spring semesters. These risks can include any of the following: Technical, Schedule, or Program risks. To determine the risk, we sat down and brainstormed ideas. In total, the team came up with 10 potential risks that need to be addressed. With each risk, we identified the likelihood and consequence of each risk. The team also determined the cause of the risk, the impact of the risk, and developed a mitigation plan for each risk. Table 1 shows an example of one risk the team identified.

Table 8. Schedule Risk identified by the team.

Risk Item No.:	7	Risk Identifier:	Daniel Carrasco
Project Name:			
Project number:	10		
Risk Title:	Getting Material/fabrication on Time	Ratings:	
Description:	Team not being able to build the bumper on time and meet the schedule.	Likelihood	1
		Consequence	5
Basic Cause:	Ordering parts late and not giving suppliers enough time to fabricate our bumper.	Risk Level	Mod
		Risk Type:	S
Impact:	Not having the material will prevent us from building our tractor trailer bumper. This will prevent us from providing a final product to our client.	Potential Cost	
Mitigation:	We will order parts ahead of time and we will give our supplier enough time to fabricate/ship our parts.	Potential $ for Mitigation Items:	

With risk identified we can implement a mitigation plan that will prevent the team from straying off schedule. These risk were also helpful in the design process because if risk was too high and had no mitigation plan then the design with that risk was not considered. In total we identified 10 risks and a summary table of all risk are shown in Appendix B.

Design for Manufacturing and Assembly: After the team selected its final design, we were left with a couple of manufacturability concerns. The largest concern was the corner support that protects against the side and 30 percent overlap impact scenarios. As shown in Figure 17, there are three components that seem to be serving almost the same purposes. To correct this problem the team considered several design options, and eventually came up with the design shown in Figure 18. This improves the manufacturability because it improves the two main aspects of DFM: reduction of parts, and improving ease of handling, insertion and fastening. The former is displayed by the reduction of one of the vertical members, or as seen in Figure 17 as a slanted vertical member. The latter is improved due to the realignment of the sine beam so that the edges now stop at 90 degree angles. This allows the beam’s axis of rotation for insertion to be increased.

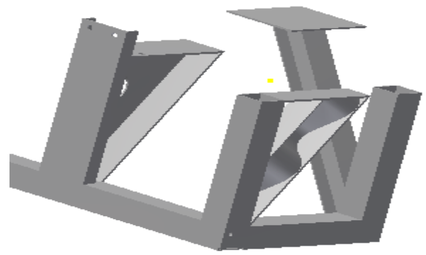


Figure 17. Shown is the original design of the corner structure after the concept selection process was completed.

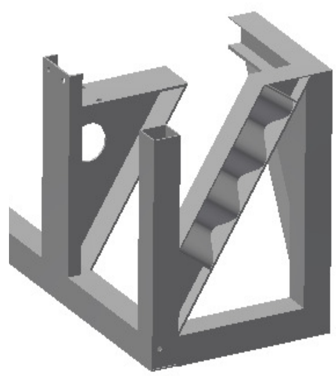


Figure 18. Shown is the updated design of the corner structure with design for manufacturing and assembly in mind.

Prototyping: One of the key features we want to implement in our design is a sine beam. A sine beam is a unique part that is not commonly sold by metal suppliers. Because of this, we had to contact multiple metal fabricators and determine if they have the capability to manufacture a sine beam. One supplier, Custom Metal Fabricator Inc, said they could produce a sine beam but proposed a unique way of making the beam. The supplier would laser-cut sine curves out of sheets of steel. They would then stack the pieces together, and weld the ends. While this is a novel approach to our solution, we'd prefer a non-laminated beam. The team decided to build a prototype sine beam in the APPLIED lab using the same methods the supplier would use. Using a CNC router we cut out the sine curves, and using wood glue we welded the pieces together. Shown in Figure 19 is the prototype sine beam built in lab.

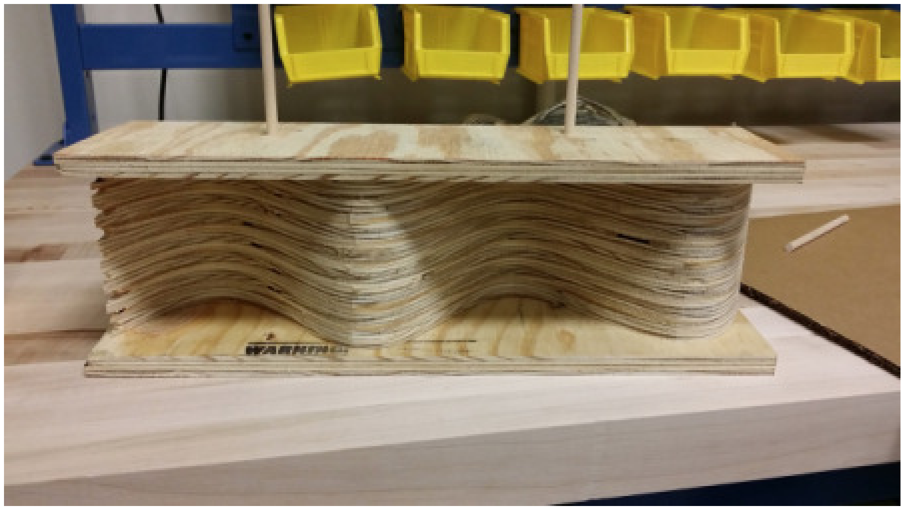


Figure 19. Prototype sine beam built in the Applied Lab using a CNC router.

With this prototype built we noticed how weak the beam would be when using pins to stack the pieces together. The supplier would be using pins as well to stack the metal sheets together, which may compromise the functionality of a sine beam. The team's idea of using a sine beam was based off of a research paper that used a non-laminated sine beam in their finite element analysis.[5] We are currently working on a CAD/FEA model of a sine beam using laminated pieces, which will be compared to the finite element analysis done using a non-laminated sine beam. In addition, we are working with our current supplier to figure out how we can avoid using pins or find a way to implement the pins without compromising the sine beam. While we conduct new finite element analysis, we will continue to contact more metal fabricators to see if anyone else is capable of manufacturing a sine beam.

V. Design

With analysis, prototyping, and test results performed, the final design was determined. As seen in Figure 20, the final design utilized a combination of concepts and features to accumulate the optimal design.

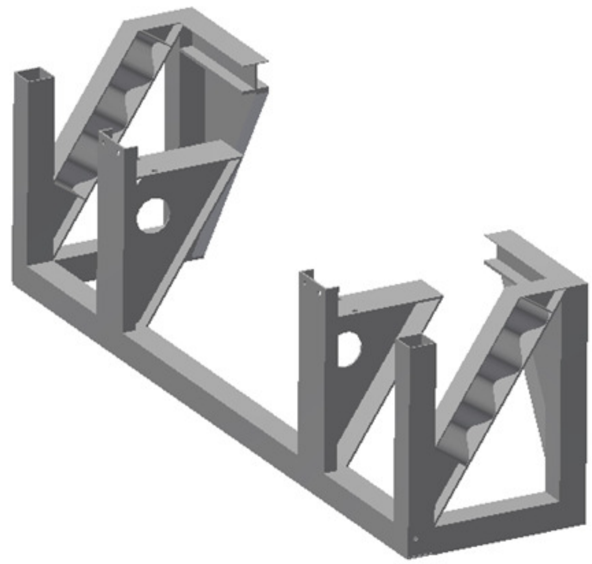


Figure 20. The complete final design of the final bumper

The first feature of the design was the inclusion of the existing Wabash support structure. This maintains the 100% overlap underride prevention and provides a working base. The Wabash design has been tested extensively and the connection points to the bottom of the trailer are standardized as well as the whole design.

The next feature included in our final design is the side support. A horizontal base bar is included that acts similarly to the front horizontal bar and provides a catching point for the car. Attached to the horizontal side support is a gusset and I-beam bump stop. The bump stop is used to maintain the correct attachment height while still maintaining the functionality of the side gusset by not making it extend too far up. If the gusset were extended at the same angle to the attachment point, then the structural integrity would be lost and would not function correctly. The gusset is to be manufactured with sheet metal and bent into the appropriate shape. This reduces both manufacturing cost and difficulty.

The final feature is the sine beam. This beam provides a controlled deformation that is known through sampling tests of the specified amplitude and thickness. This can then be used to optimize the displacement seen for 30% and 50% overlap. It gives more of a deceleration zone for these smaller overlaps and thus decreases underride. As mentioned before, the manufacture of this sine beam has multiple possibilities. One of the ones being explored is the possibility of laminating laser cut sections of the beam together. They would be welded and held in place with a rod running through the middle of them.

Progression of design: The progression of our design project has continued nicely. We are approximately 75% completed with our detailed design, as seen in Appendix A. We have completely completed our preliminary design. The final concept has been chosen using down selection matrices and other methods. The individual features of this design have been determined and the dimensioning of them has begun. This progress allows the team to begin the next stage of our project. We are able to start ordering specific parts for the construction of our design. Because some aspects of our design will take longer to manufacture due to the specialty of them, a longer lead time will be needed. One of these parts is the sine beam. Because of the long lead time, we will be ordering it well in advance to ensure a timely delivery. Other steps that can be completed at this time are to finalize the connection points and ensure our model is accurate.

VI. Project Team and Resource Allocation

The structure of our team is broken down into 3 subgroups: CAD, Testing & Analysis, and Manufacturing as shown in Figure 21.

Figure 21. Group is broken down into 3 sub-teams, shown are the team members within each sub-team.

The CAD team is responsible for the creation of drawings, determining constraints and CAD models. The Testing & Analysis team is responsible for any finite element analysis, data processing, hand calculations, and does any research that the team may need. The Testing & Analysis group will also be responsible for test preparation, test support, and test execution for any tests the team may execute. The Manufacturing group is responsible for the assembly and fabrication of the tractor-trailer bumper. The Manufacturing group is also in charge of the following: getting quotes from suppliers, obtaining metal or part materials, creating prototypes, requesting funds or sponsorships, project scheduling and finance. The team will also have a Team Facilitator whose main responsibilities are the following: keep all the sub-teams on schedule, directly communicate with the project sponsor and advisor, submit any team assignments, create a supportive environment for all meetings and group interactions, will ensure all team members are held accountable for their task, evenly distribute work, and attend weekly facilitator meetings. The Team Facilitator will have access to all ME 4006 professors, the project sponsor, and the project advisor. The Team Facilitator for this team is Wayne Carter.

The CAD team has access to the following resources: CAD room in Randolph, Abaqus and Autodesk Inventor. The team will use Autodesk Inventor to create all drawings and formal sketches. The team will use Autodesk Inventor & Abaqus to create all 3D CAD models. All drawings and CAD models will follow the standard GD&T practices learned in ME 4006.

The Testing and Analysis team will have access to the following resources: Abaqus, MATLAB, Simulation Mechanical, Microsoft Excel, Microsoft PowerPoint, Virginia Tech Transportation Institute (VTTI), Virginia Tech Mechanical Engineering Staff (VTME) and Jared Bryson (our sponsor). The team will use Simulation Mechanical to create finite element models, execute analysis, and post process the results. The team will use MATLAB, LabVIEW, Microsoft Excel, Microsoft PowerPoint to post process data and present results. The team will utilize VTTI, VTME, and Mr. Jared Bryson for advice and suggestions for analysis set up and execution.

The Manufacturing team will have access to the following resources: Ware Lab, Applied Lab, Suppliers, on-campus welders, VTTI, Microsoft Project and Microsoft PowerPoint. The team will use the Ware Lab, Applied Lab, On-campus welders and Suppliers to fabricate the tractor trailer bumper. The team can do mocks up and assemble the tractor-trailer bumper at

VTTI or at the Applied Lab. The team will use Microsoft Project and Microsoft PowerPoint to convey Project schedule and progress to our project sponsor and advisor.

All team members will have access to their personal computer and to other sub-team resources. Each team member can obtain additional roles and responsibilities in other teams if their workload has decreased. Members in other sub-teams can provide assistance to other sub-team members if the help is needed. The distribution of team members within each sub-team may change based upon project schedule, project demand, and team member interests.

The team will have the following test plan and strategy for this project. The CAD team will develop CAD models and drawings of our final concepts. The Testing and Analysis group will take those CAD models and convert them to finite element models. The Testing and Analysis group will then apply appropriate boundary conditions and execute the analysis. After the Testing and Analysis group determines a feasible solution to our problem, the Manufacturing team will create prototypes of our design. Then from the prototypes the team will create final product designs. The goal of our team is to use our final design in an IIHS test facility. The finite element analysis and the real world testing will determine if our product meets all of our target specifications and requirements.

VII. Schedule

The Senior Design project encompasses a full year. In order to easily visualize what is due throughout the year a Gantt Chart was developed. The Gantt Chart shows the start date of a task and the end date. It also allows us to schedule tasks in parallel to complete objectives on time. Located in the Appendix C is the full detailed schedule. The major milestones to be completed during the year are shown in the Gantt Chart below.

Table 9. The table represents the major milestones that should be completed this academic year. The expected duration of each event is listed. The predecessor column means that to start the listed task the previous task has to be completed.

Task Name	Duration	Start	Finish
Receive Project	1 day	Thu 8/28/15	Thu 8/28/15
Customer Needs, Engineering Characteristics, Target Specifications (1st Draft)	6 days	Tue 9/1/15	Tue 9/8/15
Measurements of VTTI Trailer Bumper	4 days	Mon 9/14/15	Thu 9/17/15
Engineering Requirements	2 days	Fri 9/18/15	Mon 9/21/15
Develop CAD Model of Current Design	5 days	Fri 9/18/15	Thu 9/24/15
Concept Generation	4 days	Wed 9/23/15	Mon 9/28/15
Concept Review	1 day	Tue 9/29/15	Tue 9/29/15
Midterm Design Review	3 days	Tue 10/13/15	Thu 10/15/15
Risk Assessment	2 days	Fri 10/16/15	Mon 10/19/15
CAD Models of Concepts	5 days	Thu 10/22/15	Wed 10/28/15
FEA Analysis of Models	5 days	Mon 11/2/15	Fri 11/6/15
Downselection Matrix	2 days	Fri 11/6/15	Mon 11/9/15
Preliminary Design Review	1 day	Tue 11/10/15	Tue 11/10/15
Design Modifications	4 days	Wed 12/2/15	Sat 12/5/15
FEA of Design	3 days	Sat 12/5/15	Tue 12/8/15
Contact Suppliers	5 days	Mon 12/14/15	Fri 12/18/15
Final Fall Review ~50% Detailed Design	1 day	Wed 12/9/15	Wed 12/9/15
Specification of Tolerances	5 days	Mon 1/25/16	Fri 1/29/16
Critical Design Review	4 days	Thu 2/4/16	Tue 2/9/16
Product Launch (Presentation Only)	4 days	Thu 3/17/16	Tue 3/22/16
Product Test and Eval	24 days	Mon 3/28/16	Thu 4/28/16
Expo and Poster Session	1 day	Fri 4/29/16	Fri 4/29/16
Final Design Presentation and Report	2 days	Mon 5/2/16	Tue 5/3/16
Final Product Realization Demo	2 days	Mon 5/2/16	Tue 5/3/16

The team was assigned the project on August 28, 2015. We have until April 14, 2016 to fully complete the task of designing a trailer bumper that prevents underride. Along the way there will be three checkpoints in terms of midterm presentations and a winter report. Before each midterm we are scheduled to turn in necessary details to keep our project running smoothly. The main tasks of each subsection before a midterm are as follows: concept generation before October 19, 2015, concept selection before Winter Break, and then a built design by the fourth week of March 2016.

In the month of September we researched our project in depth. We visited the Virginia Tech Transportation Institute to help us further understand the scope of our project and to measure the dimensions of underride guards used in industry today. The data we collected allowed the team to begin generating concepts for a more improved design. While brainstorming concepts, our CAD sub team worked on making a CAD model of the current bumper design used in industry.

During the month of October we worked diligently to begin testing our own ideas. In order to test our concepts, we modeled them in Autodesk Inventor. It was also necessary to perform Finite Element Analysis on the current bumper design as we were trying to match IIHS test results with our own FEA. Once we were able to achieve the same values we knew we could then test our ideas to see if they surpassed the current industry standard. Also, during this time we did hand calculations and used common sense to determine which of our designs were feasible.

To select a final design for our preliminary design review we did Finite Element Analysis on all our concepts. This allowed for a down selection matrix to be done early November. Our final design, the Wrap Around was chosen before Thanksgiving break.

Once returning from break we need to assemble all the work we done during the semester for our winter presentation. The use of a 3D model was also needed for the presentation. This is when the team prototyped the sine beam. The team is looking to complete a large chunk of dimensioning before winter break in order to buy the metal we need to build our concept. If we get our order in now, then we can expect it once we return in the spring. With a successful presentation and report we feel confident going into the spring semester.

The spring semester's main focus will be on building our design. Once we return from winter break we have to finalize the specifications and tolerances of the design. The material purchased at the end of fall semester should be arriving. Once the material arrives we will ship the material and plan of fabrication to the certified student welder on campus. The plan of fabrication is our CAD model and how all the pieces are connected to one another. While our official design is being fabricated, the team will look to 3D print a full model at a 1:12scale down of the Wrap Around. We will also begin gathering all the information from the project and compiling it into a report.

Test Schedule: Once our design has been fully manufactured we will begin testing. In order to properly test our design we would have to attach it to a semi-trailer and run a vehicle into it. However we do not have the means nor the resources, so we will be submitting our design to IIHS in hopes that they accept our project for testing. We are looking to submit our design after we finalize our specifications and tolerances, which should be February 1^{st}. If selected our concept will be tested in their test facility in Charlottesville. We would be at the mercy of the facility as to when they could bring us in for a test. We would know instantly if our design carries it weight though after the test. However if we are not selected for the test, then we will perform further finite element analysis and other simulations on the model to show its credibility.

VIII. Budget

Submission of the Senior Design Grant Proposal in October granted us $3,000 for the school year. The following table shows the budget for the 2015-2016 academic school year.

Table 10. Semitrailer Bumper Budget for 2015-2016 Year

Costs			**Cost/EA**	**Quantity**		**Total**
3D Prototyping						
Pine Wood 24x24x0.5"			5.67	2		$11.34
Router Bit (1/4")			21.03	1		$21.03
Material for Design						
Horizontal Beam - 3.5x3.5x94.72"			108.56	1		$108.56
Front Side Vertical Beams - 19(1/8)x3.5x3.5x(3/16)"			30.75	2		$61.50
Middle Support Beam - 8.75 x 23"			34.96	2		$69.92
Top Connecting Piece Front-Back - 3.5 x 16.5 x 0.5"			50.12	2		$100.24
Top Piece For Middle Support - 5.5 x 15.75 x (1/4)"			26.94	2		$53.88
Middle Slanted Piece - 5.5 x 22.75 x (1/4)"			29.98	2		$59.96
Middle Plate w/ Circle - 18.75 x 15.25 x (1/4)"			41.98	2		$83.96
Front-Back Horizontal Beam - 3.5 x 20 x (3/16)"			30.75	2		$61.50
Back Vertical Support - 3.5 x 19 x (3/16)"			29.71	2		$59.42
Sheet Metal Covering Back Support - 25.75 x 18 x 10 GA "			31.94	2		$63.88
Sine Beam Supports Bottom - 3.5 x 25(1/8) x (1/4)"			27.52	2		$55.04
Sine Beam Supports Top - 3.5 x 13(5/8) x (1/4)"			24.05	2		$48.10
Sine Beam Side Supports - 3.5 x 4(7/8) x (1/4)"			21.45	4		$85.80
Sine Bump Stomps - 8.5 x 9.75 x (1/4)"			26.51	2		$53.02
Sine Beam			495	2		$990.00
Build Cost (Estimate)						
Welder (15 hours)			50	15		$750.00
Subtotal						**$2,737.15**
Assets						
Senior Design Starting Income		$3,000.00				$3,000.00
Total						**$262.85**

Table 10 gives a detailed design of the cost breakdown for the year. 3D prototyping is the only cost we've taken on so far. As detailed in an early section we developed a Sine Beam from pine wood. The total cost for this 3D prototyping was $32.

The largest chunk of our budget will be going towards material for our Wrap Around Underride Guard. The expected total amount will be $1,954. This was found by using www.metalsdepot.com to determine the cost for each individual piece of metal. The CAD model of the Wrap Around Bumper was broken down into pieces and dimensioned to give an accurate measurement of the size that would be needed. Then the matching piece of metal was found on the website or was custom fit to our specifications. If the piece did not exist however then the closest relating piece was subbed in its place. This also helps to standardize our part so that if it is accepted by industry then manufactures can easily get the materials needed. The sine beams presented a unique problem as they are not readily made. After contacting a few suppliers, some returned our plea with a solution. A steel plate would be laser cut into the shape of a sine wave. Then that piece would be stacked on top of the next then finally welded together. The quote from one supplier believes that this will cost $495 per sine beam. The unique facet of the sine beam proves to be our most expensive part of the guard. We look to start buying materials toward the end of the semester once the main dimensions are clarified.

Lastly the cost of the welder is taken into account. The team does not have a certified welder, so we will have to outsource to a graduate student welder. We believe that this may cost $50/hour. We expect a fully welded part will take around 15 hours of work time. Any leftover money will be used to help cushion the cost of a trip to Charlottesville where we were invited to the Underride Roundtable Discussion hosted by IIHS.

References

[1] "Heavy-Vehicle Crash Data Collection and Analysis to Characterize Rear and Side Underride and Front Override in Fatal Truck Crashes." DOT HS 811 725, March 2013. http://www.nhtsa.gov/DOT/NHTSA/NVS/Crashworthiness/Truck%20Underride/811725.pdf

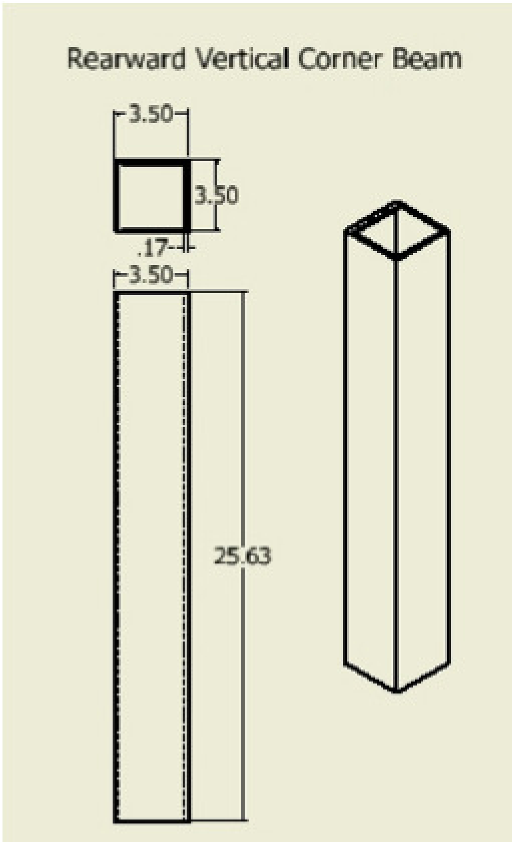
[2 "Not good enough: Underride guards on big rigs can be lifesavers, but most leave passenger vehicle occupants at risk in certain crashes." IIHS Status Report, Vol. 48, No. 2. Insurance Institute for Highway Safety.

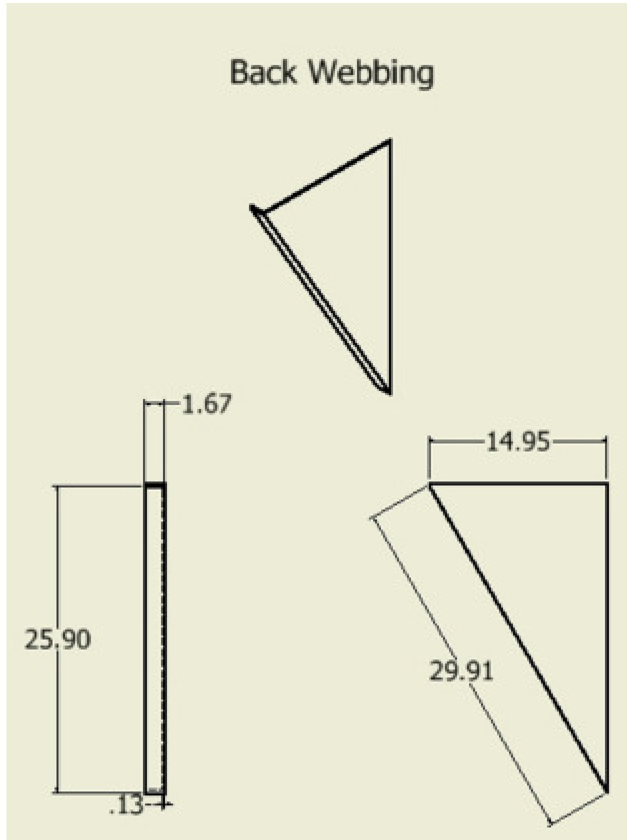
[3] Federal Motor Vehicle Safety Standards, 1998, "Rear Impact Guards," 223. Accessed at www.ecfr.gov.

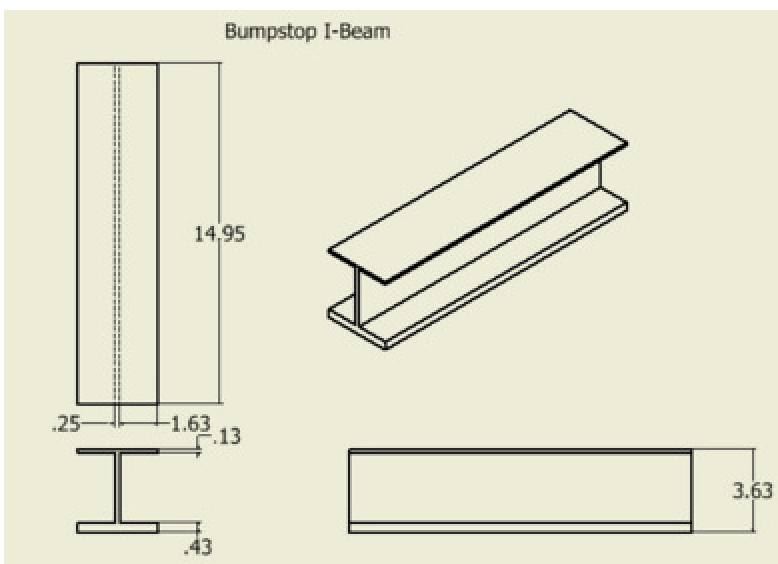
[4] Brumbelow, M., 2012, "Crash Test Performance of Large Truck Underride Guards," Paper No. 11-0074, Insurance Institute for Highway Safety. United States.

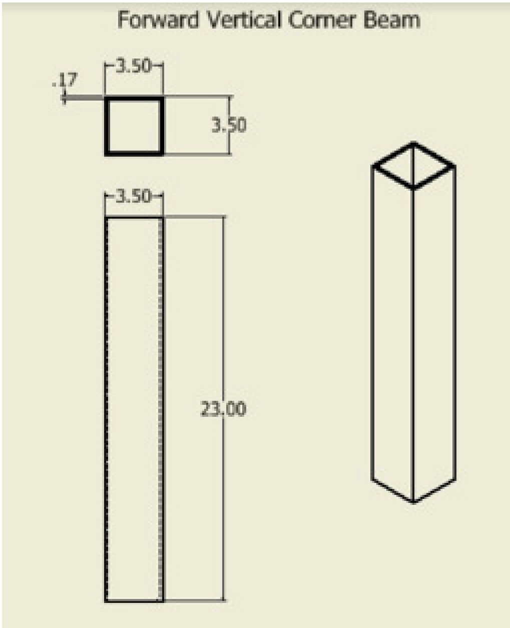
[5] Smith, Robert, "Energy Absorption of Sine Wave Beams Subjected to Axial Impact Loading" (2007). All Theses. Paper 75.

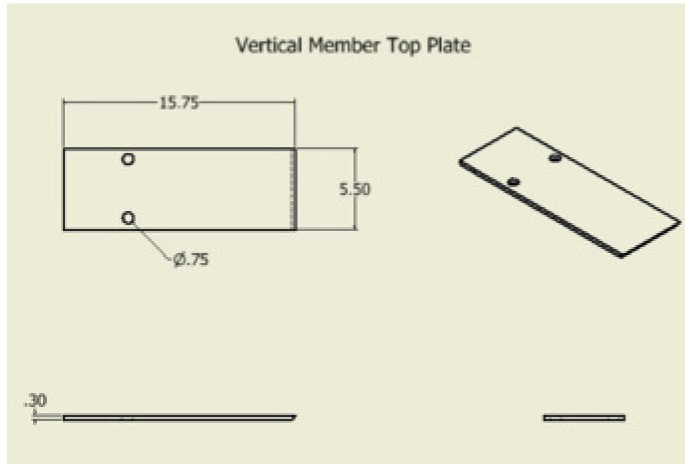
Appendix A: Part Drawings with Dimensions

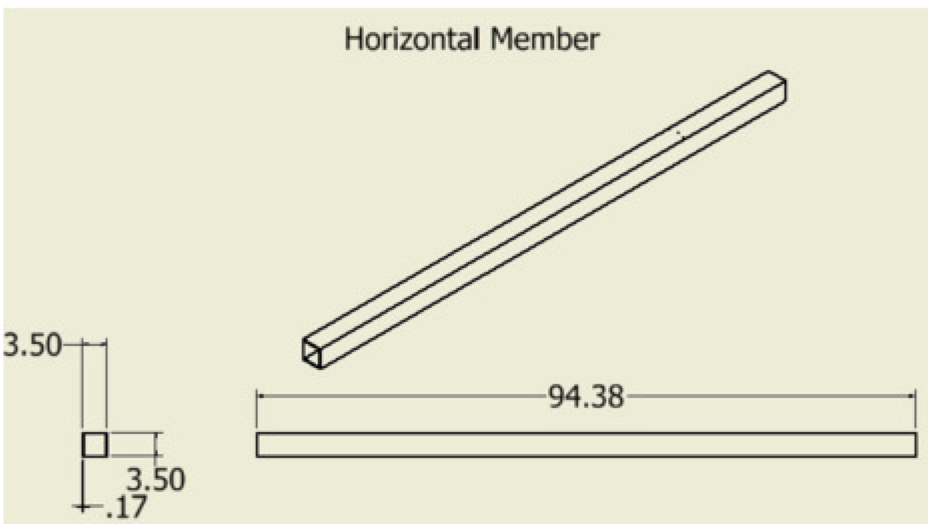


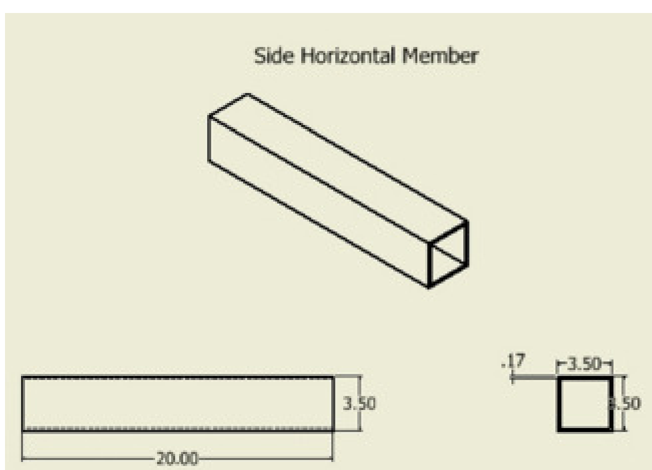


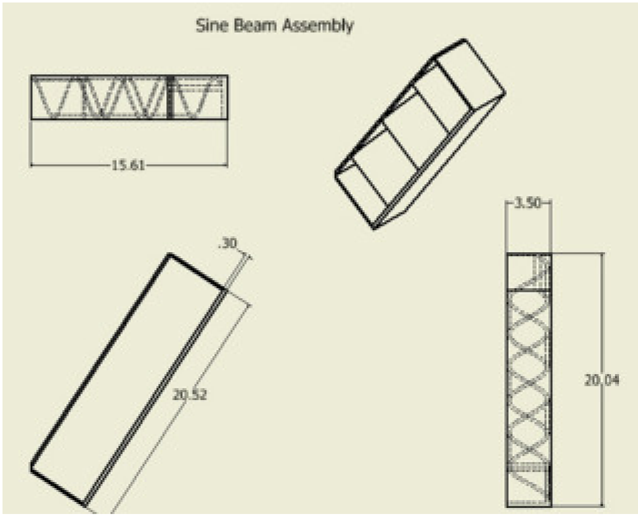


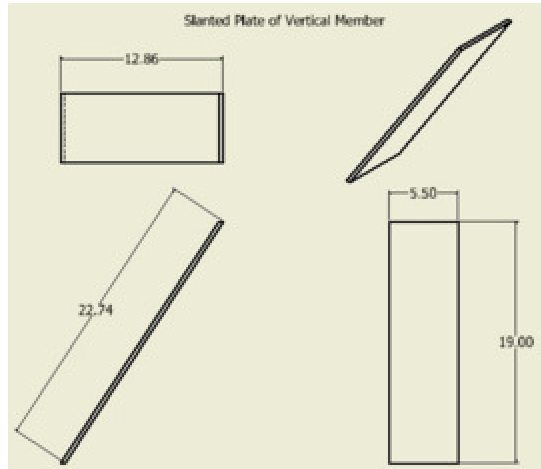

Forward Vertical Corner Beam
.17
3.50
3.50
3.50
23.00

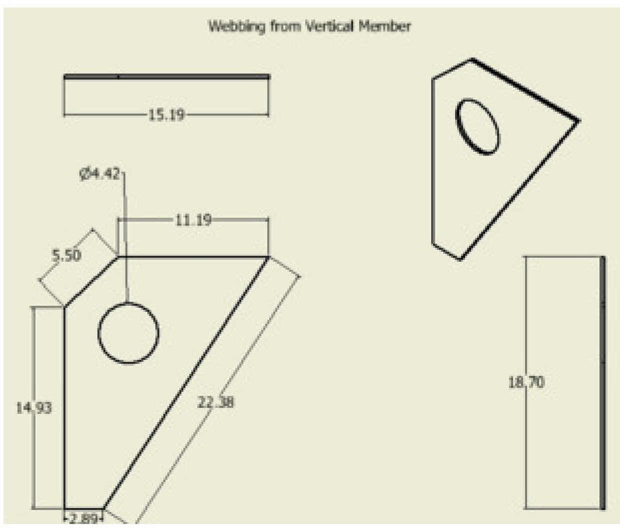

Vertical Member Top Plate
15.75
5.50
Ø.75
.30

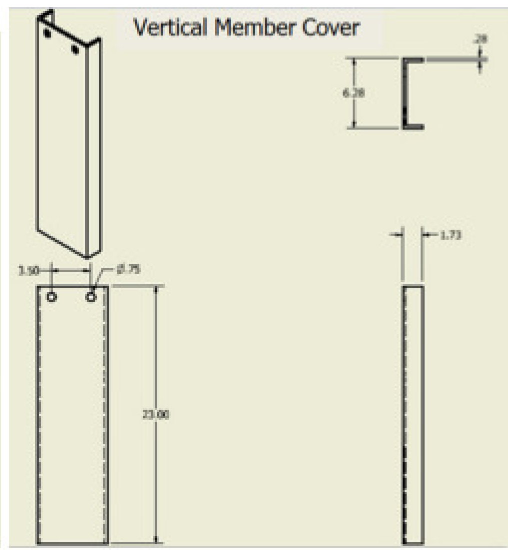

Horizontal Member
3.50
3.50
.17
94.38


Side Horizontal Member
3.50
20.00
.17
3.50


Sine Beam Assembly
15.61
.30
20.52
3.50
20.04


Slanted Plate of Vertical Member
12.86
22.74
5.50
19.00


Webbing from Vertical Member
15.19
Ø4.42
11.19
5.50
14.93
22.38
2.89
18.70


Vertical Member Cover
.28
6.28
1.73
3.50
Ø.75
23.00

Appendix B: Summary of Risk

Risk ID #	Risk Description	Risk Category	Likelihood	Consequence	Risk Level	Owner	Mitigation Plan	Mitigated Probability	Mitigated Consequence	Mitigated Risk Level
1	Air dampeners can be used to slow down the acceleration of the car when impacting the trailer. The air dampener will absorb the kinetic energy of the vehicle	Technical	5	3	8	Carrasco	Avoid the use of air dampeners as an energy absorber. Look at hydrualic/spring shock abosrbers as an alternatic	1	3	4
2	Cannot perform Dynamic Finite Element Analysis on our tractor trailer bumper designs	Technical	4	1	5	Carrasco	The team can use static FEA analysis to predict the crash test results. We can do simple hand calulcations to calclate the dynamic force and then use that force for our analysis. The team can also spend fall and spring semester to learn how to do simple dynamic FEA analysis	3	1	4
3	Team not being able to build the bumper on time and meet the schedule	Schedule	1	5	6	Carrasco	We will order parts ahead of time and we will give our supplier enough time to fabricate/ship our parts	1	2	3
4	The sine wave beam will require tools that we don't have direct access too. These tools must be able to shape the web to look like a sine wave beams. Thus if don't have the tools we can't properly create the web of the beam	Technical	4	2	6	Carrasco	The team can outsource the process of making the sine wave shape web to supplier outside of Virginia Tech. The team can also fabricated custom tools that we allow us to fabricate the sine wave web	2	3	5
5	Designs require CAD modeling so finite element analysis can be performed	Program	5	5	10	Smith	Model cables as thin beams with similar properties to what the cables would have	3	3	6
6	Two current concepts are basic constructions of a bumper that will entirely prevent underride without providing a deceleration zone. The risk here lies in the event of an accident at moderate to high speed where the vehicle driver experiences severe deceleration due to the lack of a crumple zone in the bumper design	Technical	1	5	6	Carter	Crumple zones or energy absorbing materials can be implemented with these two designs to slow the deceleration experienced by the passengers in the vehicle impacting the rear of the trailer	1	3	4
7	The steel cables for the nightrider design has to hold the steel plate and maintain connection with the trailer. Upon impact the connection points of the cable to the frame has to hold and not tear away	Technical	3	5	8	Smith	Ensure that cables are attached correctly by welding a tube of metal to the back end of the trailer and then run the steel cables through in interlocking fashion to have a proper fasten	1	3	4
8	There is a potential for welds to fail in the design. The weld could fail when the design is loaded to its maxium load	Technical	2	5	7	Gardner	We will do adequate research to ensure our welder is experienced and is certified in welding	1	4	5
9	The exact force from the intial collsion is difficult to obtain as the calculation that are being used give the average force during the collision, but there is going to be an initial spike in the data	Technical	2	4	6	Pitt	Research similar scenarios for more data so that our analysis may be refined	1	4	5
10	The current design for the honeycomb material attached on the curved bumper accounts for direct impact from the rear. When impacted on the side or in other direction, the honeycomb will not serve its purpose as a crumple zone	Technical	1	2	3	Adriano	Design the honeycomb in various orientations to account for direct impact in the rear end as well as from other possible directions	1	3	4

Appendix C: Detailed Gantt Chart