Final Design Report

ME175B TTU-2

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FNL_DES-TTU-2

Toyota Tundra Assisted Unloading System for Bulk Materials

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Executive Summary

This document details the TTU-2 team's development of a rapid unloading system of bulk materials, with the Tarp Rollout System. The engineering process is described from the problem statement to the assembly and prototyping of the detailed design.

The project specifications and constraints require a system that can unload the Toyota Tundra SR-5 at payload capacity quickly. Group brainstorming was conducted to conceptualize each approach, using a Pugh chart to weigh each concept to one another until the best evaluated solution was decided upon. Once a concept was chosen, the idea was refined in order to ensure the best solution.

An overview of the chosen design solution will emphasize the key features of the system. Features included a sturdy four post mount system and a cross bar to stabilize and anchor the system, a chest height crank driven sprocket chain system for ease of use and repair and a hooked roller to roll in a tarp for ease of transportation.

Simulations were performed to determine the stresses and deformations of the system and its frame rigidity, with quantitative analysis conducted in the design and strengthening of the system throughout its development. A scaled physical prototype was constructed to prove the concept of how the material would be rolled out of the bed.

Lastly, how the project can be improved going forward is listed. Possible improvements would be a full scale model using a Toyota Tundra.

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Introduction

This report outlines the details for the rapid unloading system for the 2018 Toyota Tundra. The system must be able to help the user rapidly and safely unload non-building bulk materials off the truck bed. The system must also be lightweight and non intrusive, allowing the truck to keep its original functionality. The system consists of three main parts, an 8x6 foot tarp that will fit the 6.5x5.5 feet bed of the Toyota Tundra, a 72 inch roller mounted 30 inches above the bed walls, and a support structure for the roller to connect it to the bed. Other parts for the system include a crank handle, sprockets, and chain to provide the user with more leverage. The system will be able to unload the maximum payload of the Toyota Tundra which is 1600 pounds.

The problem statement will open the report detailing the specifications and constraints of the design process. An overview of the chosen design solution will emphasize the key features and operation of the system. Each component will be described in detail along with their specific function. The modeling and analysis of the Rapid Unloading System will describe the analysis that was used in the designing of the system. Quantitative results of the system will be discussed, justifying the design features and parameters of the system. The progression of the conceptual designs leading up to the chosen system will be shown, along with the methods that were used to generate the system. Lastly, the evaluation of the design will describe the prototype and simulations of the actual model, showing the test procedures and results that were obtained along with the strengths and weaknesses that were satisfied from the problem statement.

Problem Statement

The purpose of the Rapid Unloading System for the Toyota Tundra is to facilitate the unloading that is associated with landscaping jobs. The system will assist in unloading bulky free-form materials and bags of bulk items under 100 pounds from the truck bed, accelerating the unloading process while keeping our customers safe.

Current models that accomplish similar goals include a cargo slide, made by Realtruck, which extends out from the bed through a sliding deck, which circumvents climbing onto the vehicle and allows for easier access to larger items. The cargo slide has a maximum load of 1000 pounds at a price point of $899.00 [3]. Haul Master makes a roller and belt system where a crank turns the roller which reels in the belt. The belt rests on the bed of the truck and rolls loose items from the bed to the tailgate. The maximum load is 2000 pounds with a price point of $39.99 [4]. However, the tarp only stretches in between the wheel wells and is only attached to the tarp through duct tape and has issues with material being left in the bed as a result. As such, our system looks to improve upon these results. Our system is looking to be cheaper than the cargo slide, support a maximum load of 2000, and allow for the full use of the bed space rather than just a portion.

The system is meant to alleviate some of the physical energy that is required for unloading bulk materials. Providing a safe unloading system would mean less strenuous work and a decrease in work related injuries. Additionally, it will save time and improve efficiency of jobs.

The system will be lightweight, roughly around 75 pounds. The rapid unloading system will sit inside the bed dimensions and will meet current overhang and cargo height regulations [1]. The system will be able to handle loose flow bulk materials as well as bagged quantities under 100 pounds. This design will be manually operated. The loading mechanism will be dealing with loose materials that will need to be secured to keep the truck bed and system clean. Our system focuses on bulk, non-building materials. While it would most likely work for lumber, we are focusing on material such as dirt, sand, gravel and mulch.

The physical limitations will be based on the 2018 Toyota Tundra SR5 model. The truck has a 1600 pound payload, bed length of 6.5 feet, bed width of 66 inches and 50 inches between wheel wells, and bed depth of 22 inches [5]. The system should be lightweight to not interfere with the truck's payload capabilities and must account for the wheel wells of the truck bed. Movement of the system should not interfere with the dimensions of the truck bed to insure no damages to the vehicle or operator.

The system will be designed to be stable while driving over improved dirt and paved roads. Additionally, the system will have to be secure when unloading at slight angles. The system will be lightweight and easily assembled. Additionally, it will be designed with replaceable parts in mind allowing for easy repair. Lastly, the system will need to be constructed using non-specialized tools, allowing for easy self-repair. This ensures longevity of the product as well as the accessibility of the product.

Design Solution

The solution that best fit our problem definition features an elevated roller with increased diagonal and crossbeam support members. The materials would be placed on a tarp that would attach to the tailgate and the roller. The roller would then pull in the tarp and bulk materials until dumping the load off the tailgate. The final concept is pictured in Figure 1.

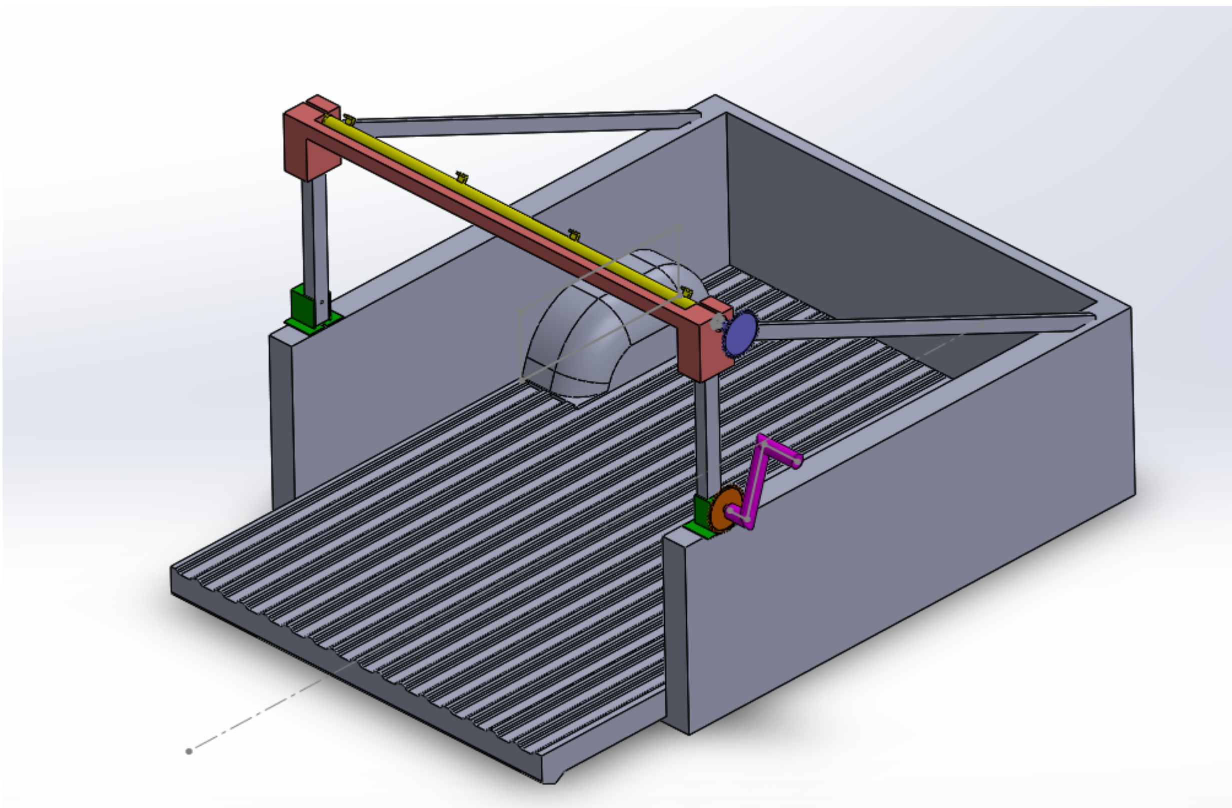

Figure 1. *Updated TTU-2 system design on a truck bed*

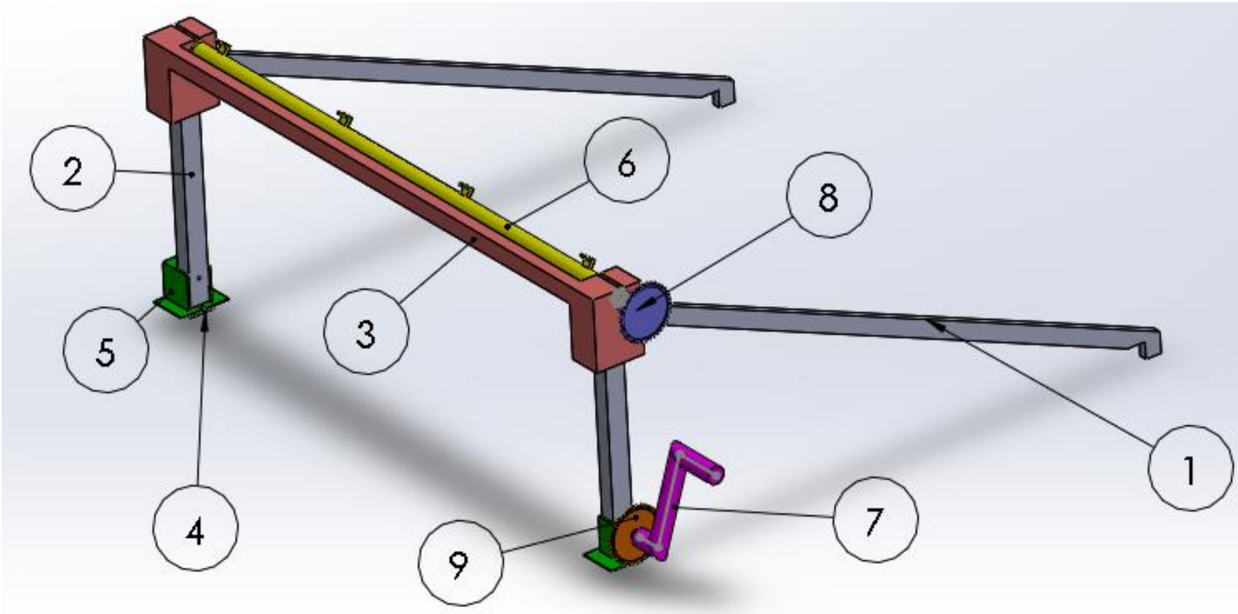

Figure 2. *Updated TTU-2 system design with bubbled callouts*

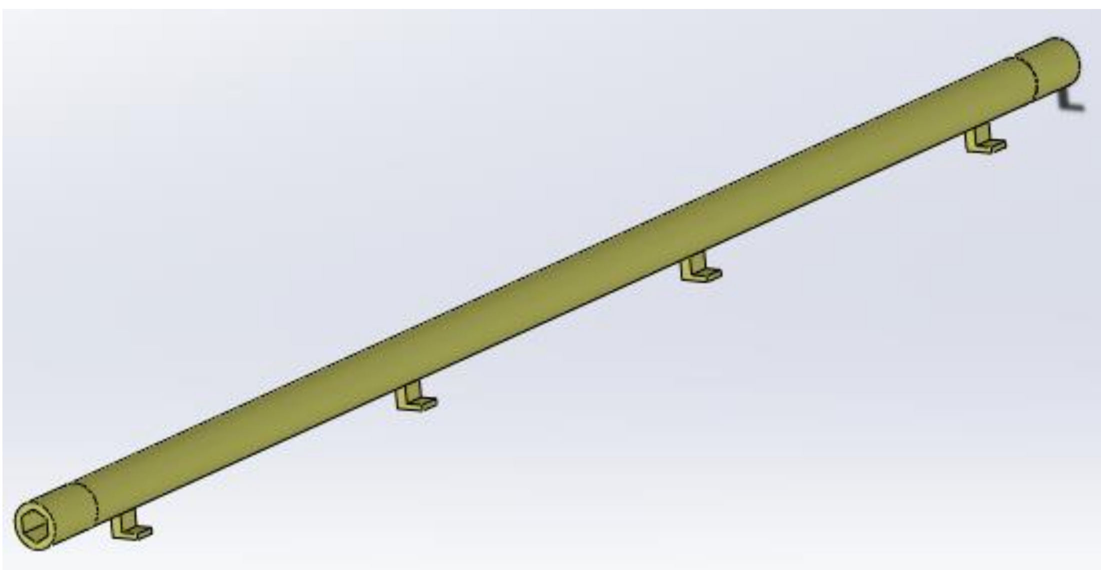

Figure 3. *Roller, Bubble 6*

The hooked roller is isolated in figure 3. The roller is 72" long with a diameter of 2" and is constructed out of 6061 T6 Aluminum. The hooked roller would have four equidistant hooks sitting at 20" apart and 6" from the ends. Additionally, a 3" deep hexagonal bore at each end for the crank to be inserted into. 3” on each side of the roller would be inside ball bearings on the supports. The hooks would be welded on before shipping.

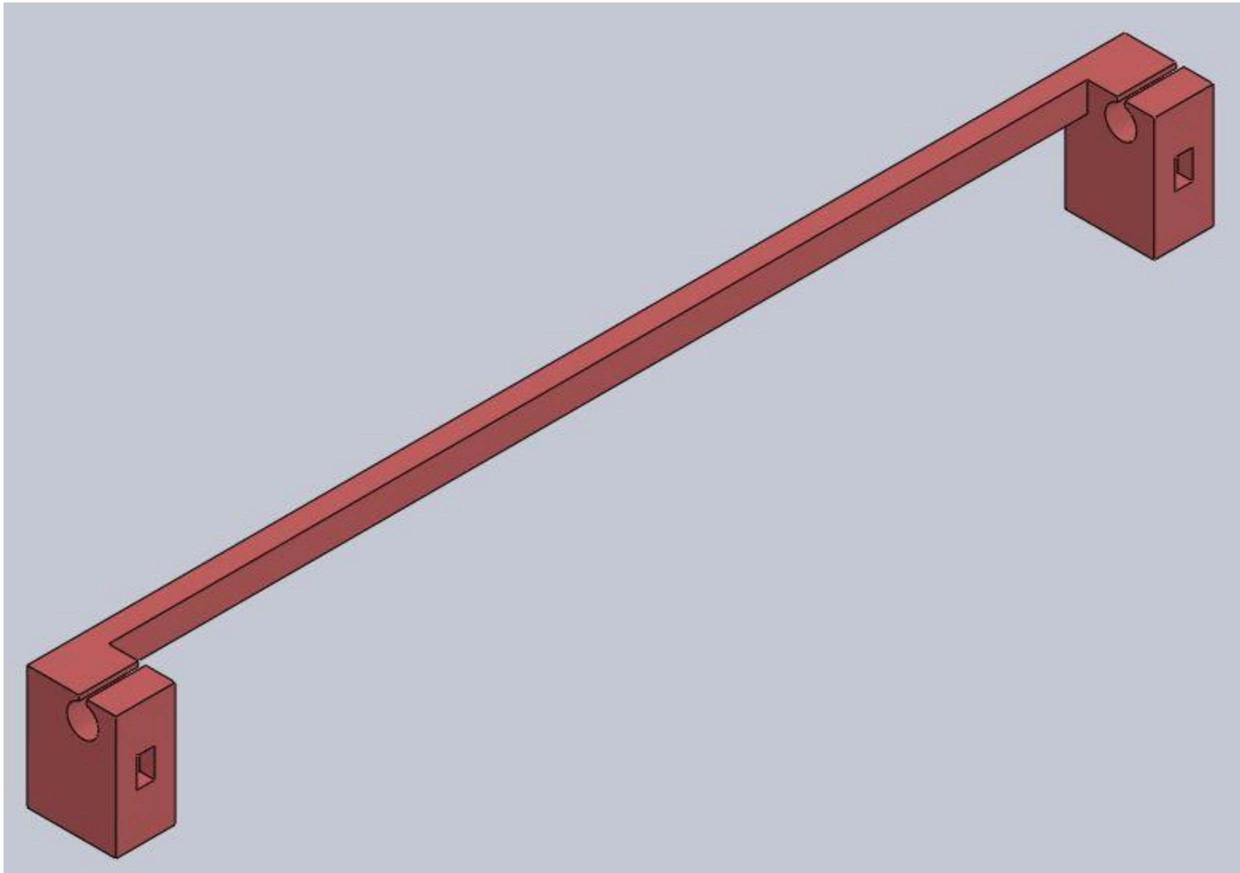

Figure 4. *Roller Mount, Bubble 3*

The roller mount is made of 6061 T6 Aluminum. The crossbar, 2”x2” cross-section, would be welded onto each of the roller brackets. Not pictured is the open ball bearings which would feature an opening allowing for the roller, bubble 6, to slide in without the hooks interfering. The crossbar helps resist deflection inward, easing the load on the roller and is placed 3 inches away from the roller. It attaches to the Upright Support, bubble 2, by means of a slot in the bottom. It attaches to the Diagonal Support, bubble 1, by means of a bored rectangular slot.

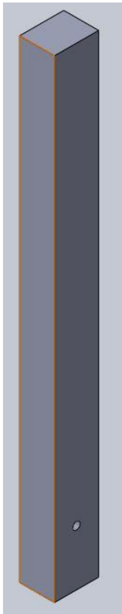

Figure 5. *Upright Support, Bubble 2*

The upright support would be made of 6061 T6 Aluminum. It features a .25” diameter hole near the base to interface with the Stake Pocket Mount, bubble 5. It would slide into the Roller Mount, bubble 3. The height is 30” and is explained in the Modeling and Analysis section. It has a cross-section of 2” x 2”.

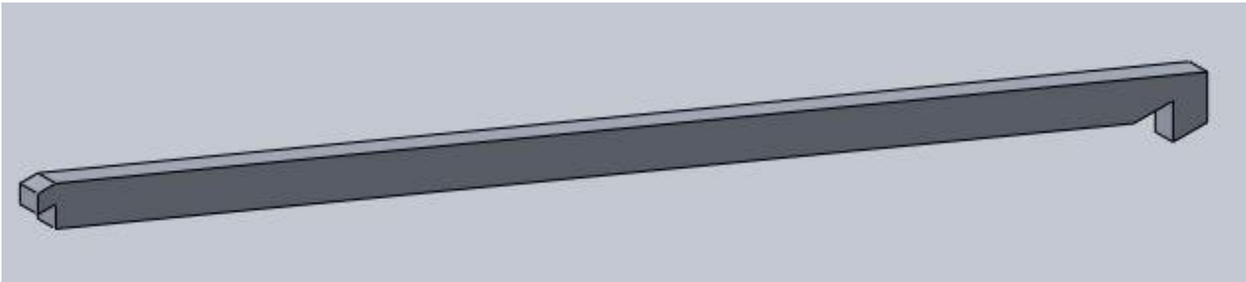

Figure 6. *Diagonal Support, Bubble 1*

The Diagonal Support is made of 6061 T6 Aluminum with cross-section 2”x2”. It has a length of 83”. It would attach to Roller Mount, bubble 3, by means of a slightly hooked end, pictured left in Figure 6. The right side in Figure 6 would attach to the stake pocket, 2”x3”. mount near the cabin.

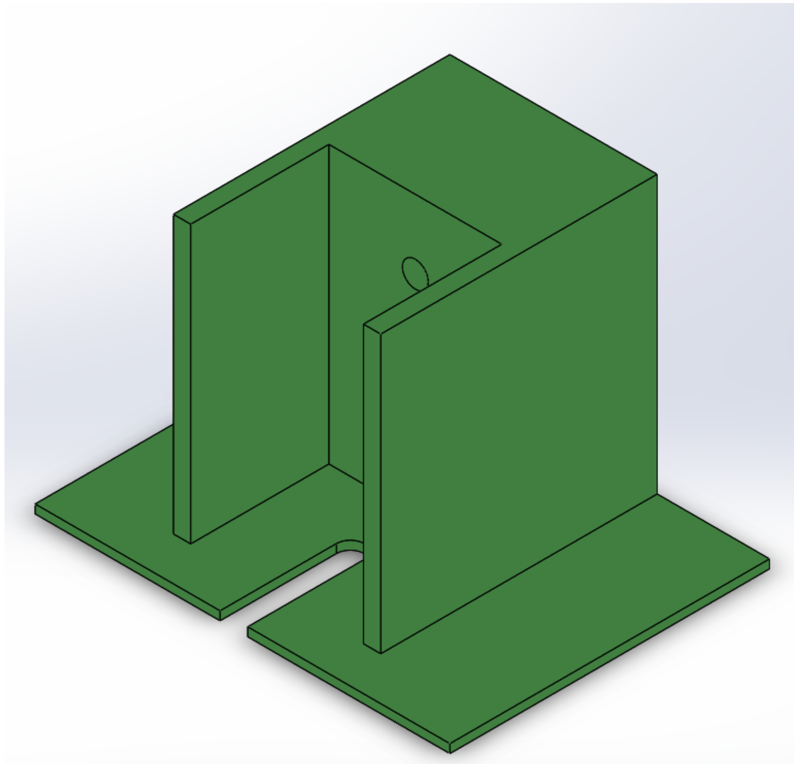

Figure 7. *Stake Pocket Mount, Bubble 5*

The Stake Pocket Mount allows the Upright Support, bubble 2, to slide into the slot. A screw of .25” diameter would fix the two together. The bottom slot allows for connection with the Stake Pocket Anchor, bubble 4. This connection would fix the system to the walls of the truck bed.

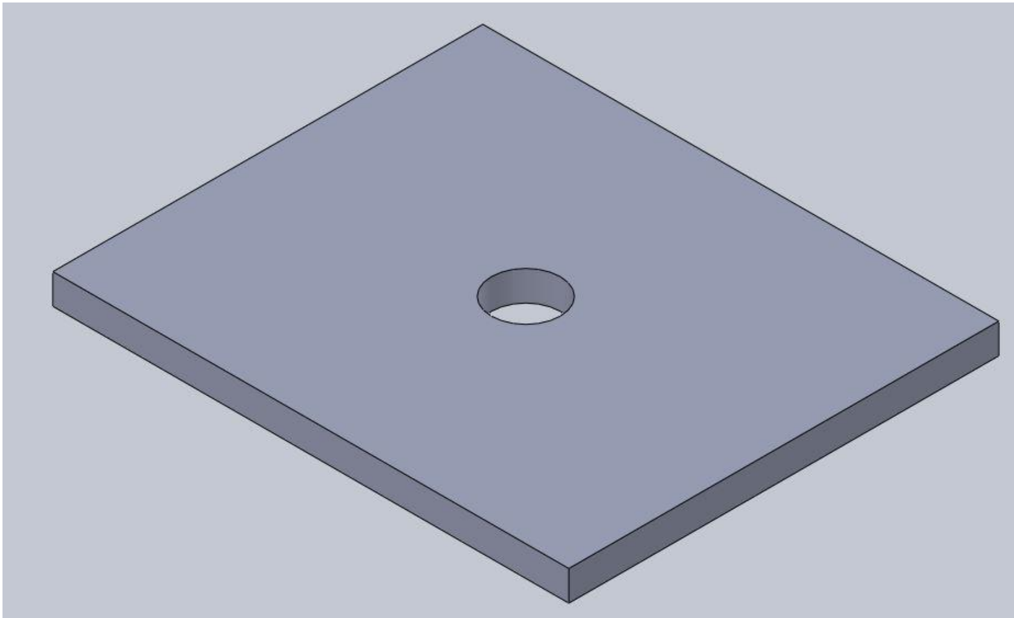

Figure 8. *Stake Pocket Anchor, Bubble 4*

The Stake Pocket Anchor is a 2.5” x 3.5” plate that would be inside of the stake pocket, 2” x 3”. It would then screw into Stake Pocket Mount, hole diameter .25”, and compress the plastic bed wall lining. This compression would secure the system to the truck itself. Figures 7 and 8 are based upon the design created and distributed by USRack, linked in Appendix B-11.

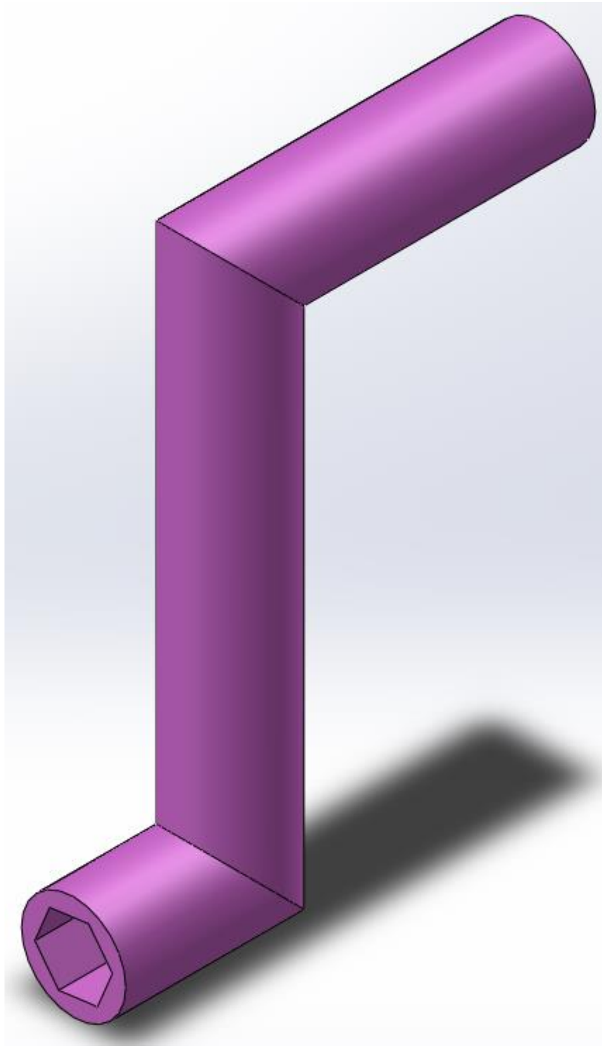

Figure 9. *Crank Handle, Bubble 7*

The Crank Handle has dimensions 2” long at the bottom, 10” high, and 6” long at the top. The 6” long handle is where the user would grip the crank. The 2” long extrusion at the bottom features a hexagon bore cut to interface with Crank Sprocket, bubble 9. The 10” height would allow the user to turn the roller with ten times less force due to the 10 to 1 radius ratio.

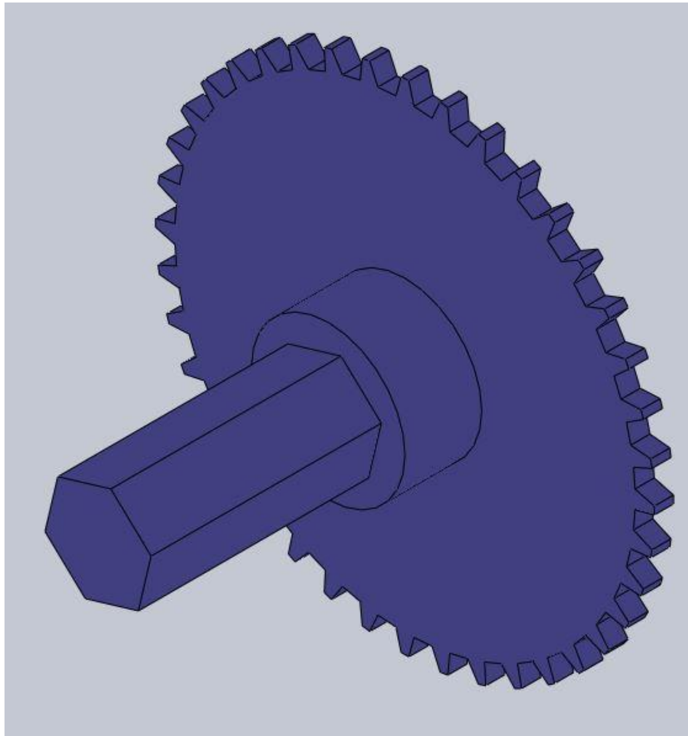

Figure 10. *Roller Sprocket, Bubble 8*

The Roller Sprocket features a 1” diagonal hexagonal extrusion 3” long. It would slide into the hexagonal bore in the roller, bubble 6. The Roller Sprocket would have a radius of 3” and would be manufactured for ANSI 60 Chain.

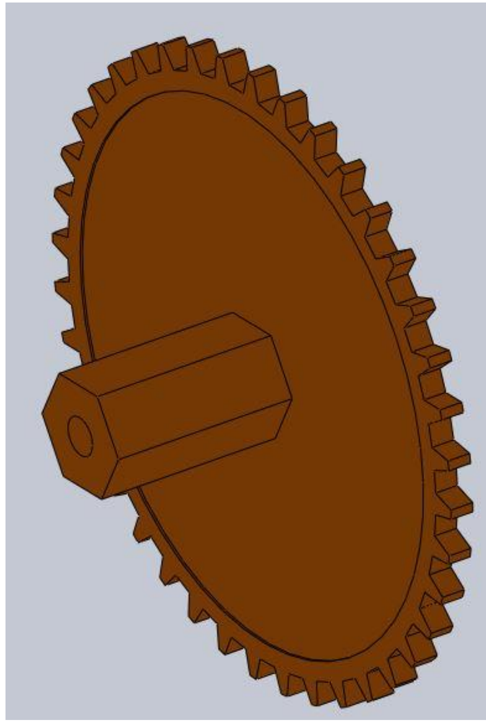

Figure 11. *Crank Sprocket, Bubble 9*

The Crank Sprocket features a 1” diagonal hexagonal extrusion 3” long. Additionally, a .25” bore hole through the center to fix it to the Vertical Support, bubble 2, and Stake Pocket Mount, bubble 5. The hexagonal extrusion would fit into the Crank Handle, bubble 7. The Crank Sprocket would have a radius of 3” and would be manufactured for ANSI 60 Chain. The Crank Sprocket and Roller Sprocket are currently intended to be the same radius, but it would be possible for them to be interchangeable with other sprockets. As such, the user could change out the sprockets if they want to increase speed at decreased leverage or decrease speed at increased leverage.

Not pictured are the ball bearings, chain, and the tarp. The open ball bearings would need to house a 2” diameter roller and would be fit into the Roller Mount. These ball bearings would allow the roller to be inserted onsite and would allow the roller to turn smoothly. An additional ball bearing would be placed in-between the Crank Sprocket and the Stake Pocket Mounts. This mounted ball bearing would allow the Crank Sprocket to turn. The ANSI 60 Chain would be fixed connecting the Crank Sprocket and Roller Sprocket. The length would be 70 inches to ensure a snug fit. Lastly, the tarp would be 66” and 205” long and would need to support 2000 pounds.

Modeling and Analysis

Since we are unable to accurately simulate the material and the interaction with the tarp, we used SolidWorks to virtually simulate the stresses and deformation in our solid members. We assumed that a maximum load of 2000 lbs. would be applied, overloading the truck capacity by 400 lbs. This is to ensure that the system does not break or excessively deform during use. Our simplifying assumptions were that the truck bed is uniform, so no ridges or wheel well arches. Additionally, the load is uniform and is ideally unloaded, so no clumping of materials.

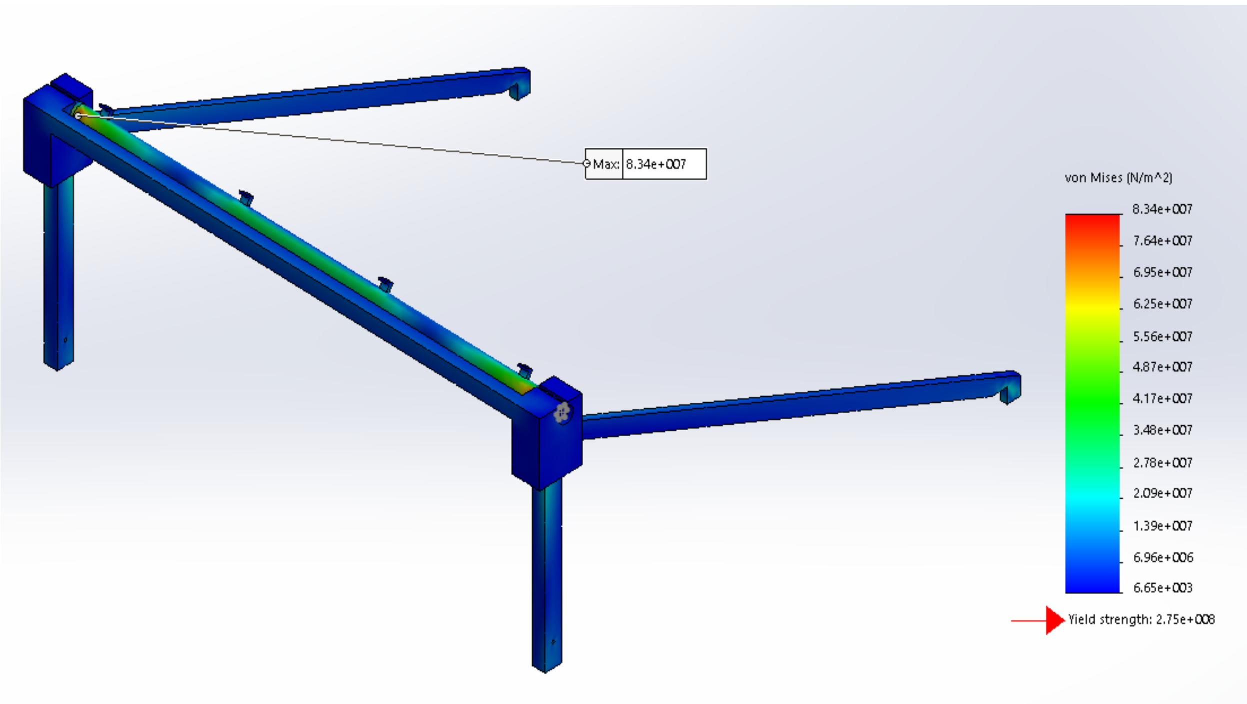

Figure 12: *Stress of Roller*

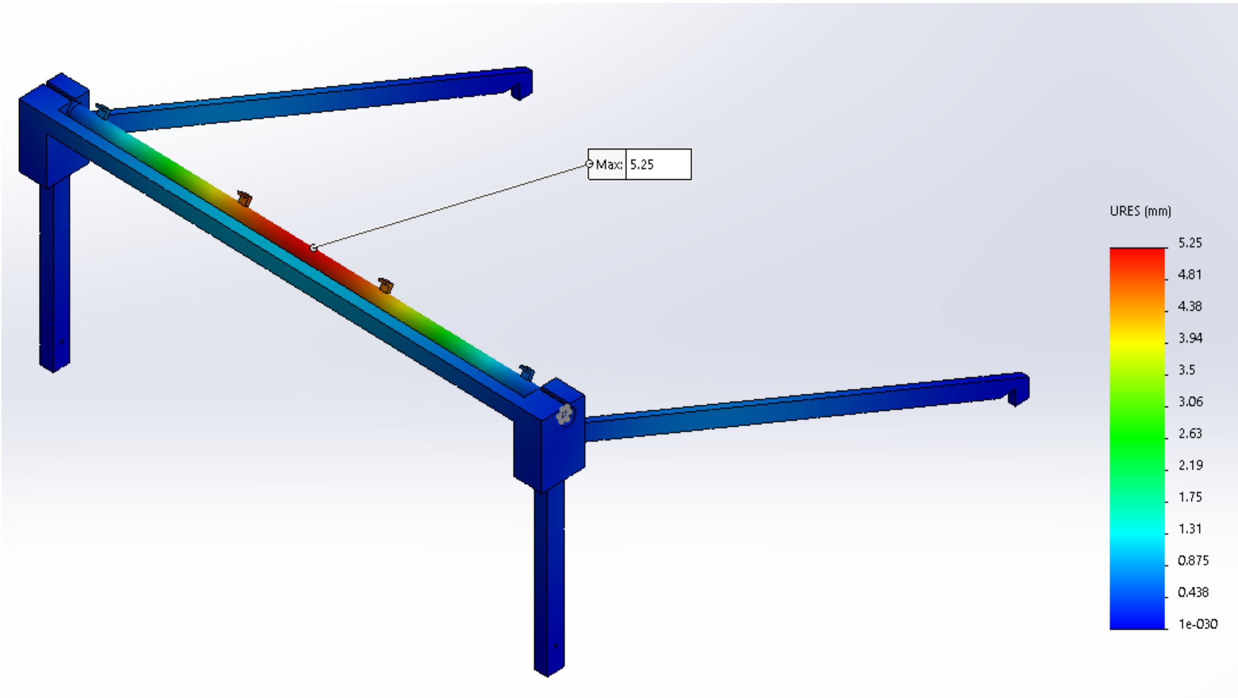

Figure 13: *Displacement of Roller*

The maximum stress the roller would be under is $83.4 * 10^6 \frac{N}{m^2}$. Since 6061 T6 Aluminum has a yield strength of $275 * 10^6 \frac{N}{m^2}$, the factor of safety for the roller is 3.31. Additionally, the center of the roller only deflects 5.25 mm or 0.2 inches.

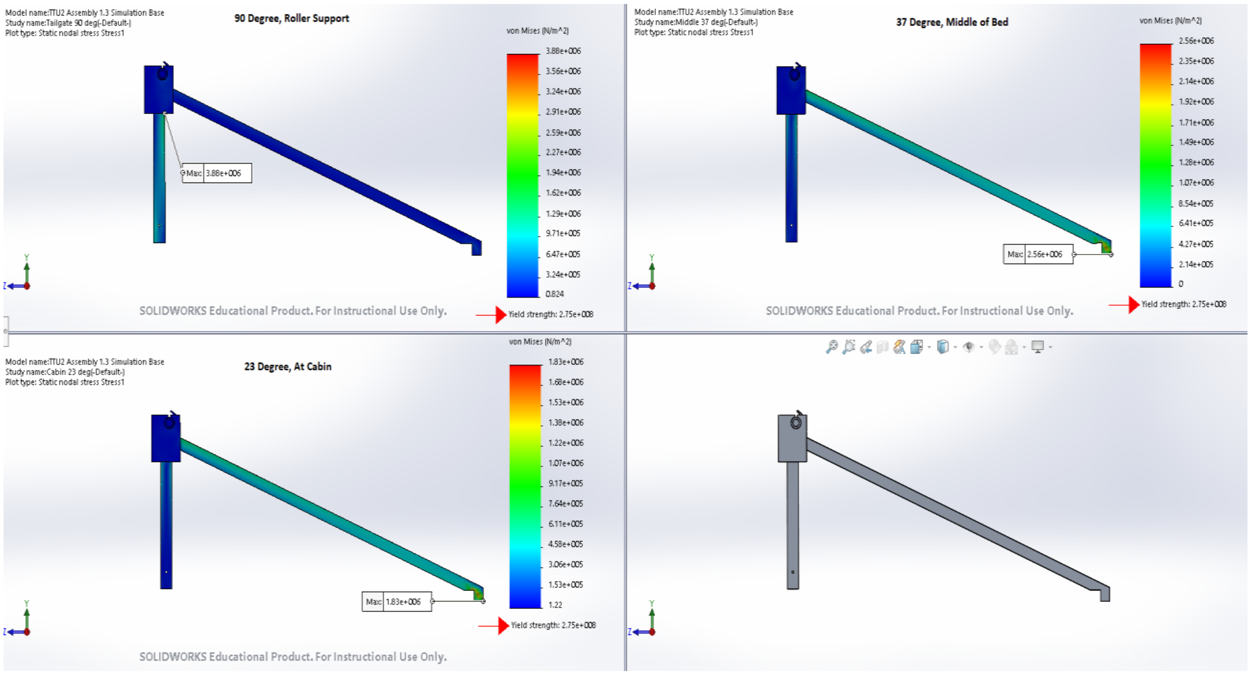

Figure 14: *Support Structure Von Mises stresses*

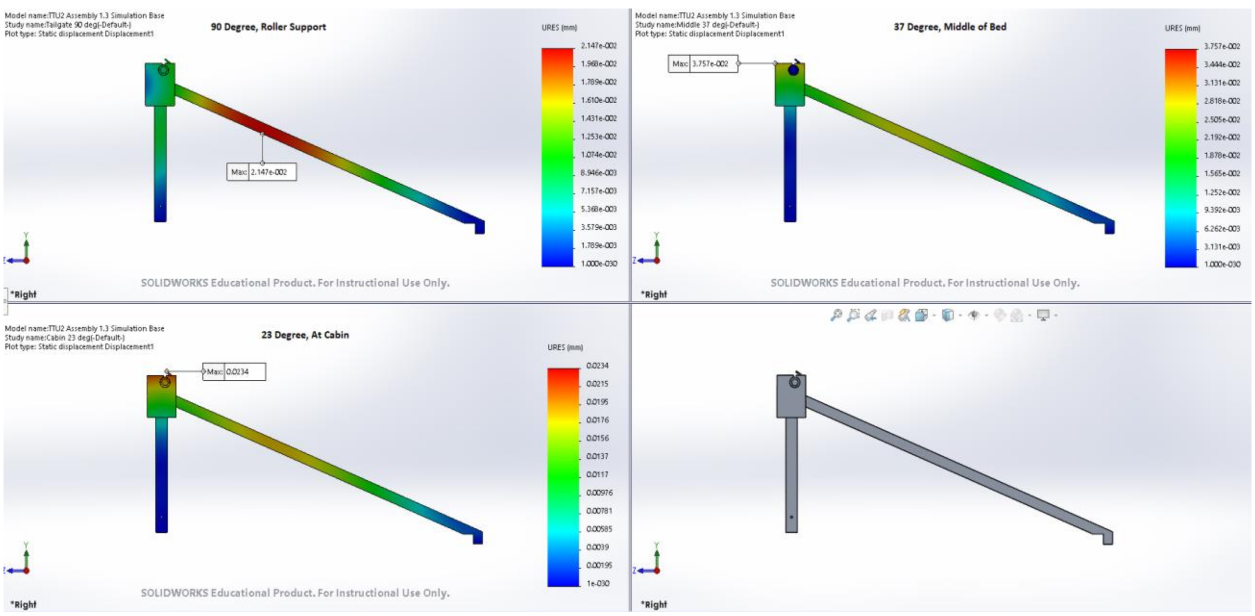

Figure 15: *Support Structure Displacements*

Figures 14 and 15 compare the stresses and displacements as the load moves throughout the truck. This is because as the load gets closer to the tailgate, more material is needed to be lifted at an increasing angle. The load lifted and angle correlates to the equations $\tan^{-1}\left(\frac{30}{X}\right)$ and $(78 - X)[in] * 25.6\ [\frac{lbs}{in}]$. Where X is the length of the bed. X is 0 directly underneath the support and 78 at the cabin end of the bed. The top left in both figures is when X=0 under the support. The top right is when X=39 in the center of the truck. The bottom left is when X=70 near the cabin.

Lastly, the height of the roller was determined by assuming that the load would be rolled into a perfect cylinder as it is unloaded. As such, we can take the volume of the bed and set it equal to the volume of a cylinder with the length of the bed. As such, the height of the theoretical cylinder is 46.75 inches, and the supports need to be at least 25 inches tall. The support height is 30 inches so that the roller sits well above our theoretical load.

Approach to Solution

The approach to our concept selection began with doing a brainstorming session generating 50 concepts for unloading bulk-materials. Feasibility screening narrowed down the concepts 30 and were placed in 6 different categories. Another brainstorming session was held to come up with a specific concept for each category. The designs generated for each category are shown in Figures 16 through 21.

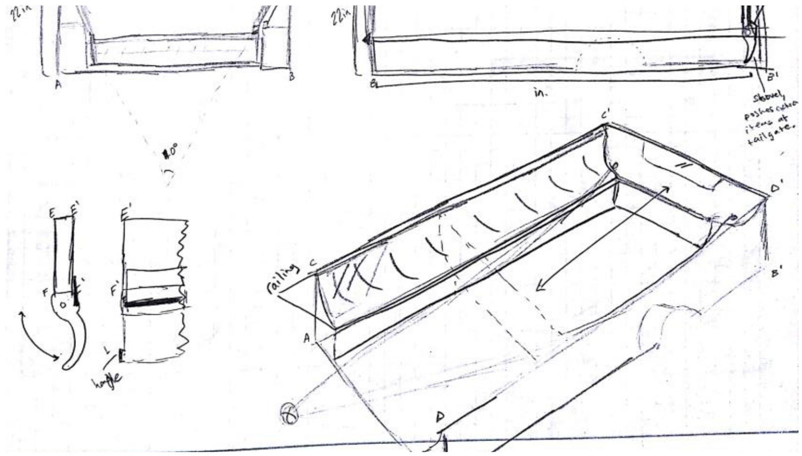

Figure 16. *Pull Out Shovel, PS, concept design sketch*

Figure 16 was based off the idea of having a system to pull the material out. The system would have a moveable wall in the back of the bed near the cabin. By pulling the wall to the tailgate, the load is pushed to the tailgate and subsequently onto the ground. To facilitate the process, a subsystem with rails would be mounted on the sides of the bed covering the wheel well arches at an angle. The rails would assist movement of the shovel wall to the tailgate from the cabin while allowing the wall to be flush with the side of the container. As a result, the pull-out shovel would be able to remove all the material from the back of the bed with no residue.

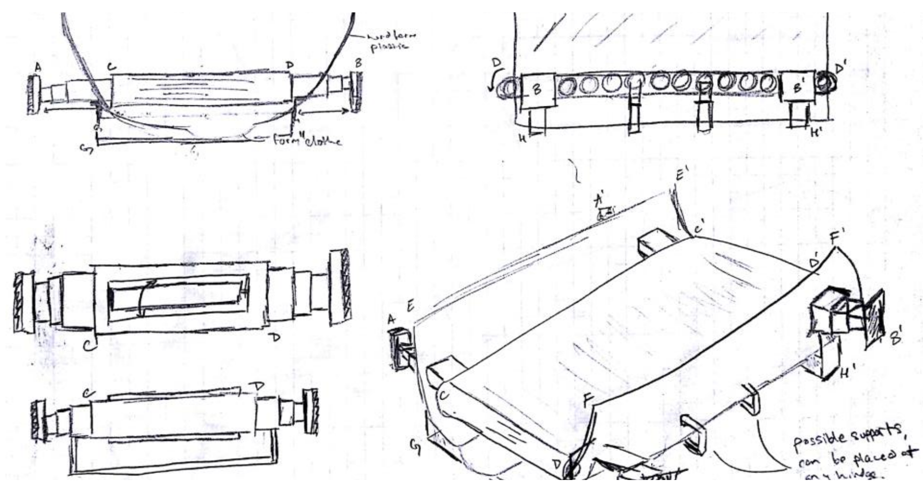

Figure 17. *Conveyor Belt Rollout, CBR, concept design sketch*

Figure 17 is a redesign of the current market conveyor belt system. The system would fit in the back of the bed and have walls going up the sides of the truck bed. The walls would ensure that all material is placed on the belt. By rotating a crank, the conveyor belt would move the material towards the tailgate and dump it. The system would be fixed to the tailgate by two arms that would lightly push against the sides of the bed. Additionally, several legs would keep the bottom of the conveyor belt off the bed to ensure that the conveyor belt moves smoothly.

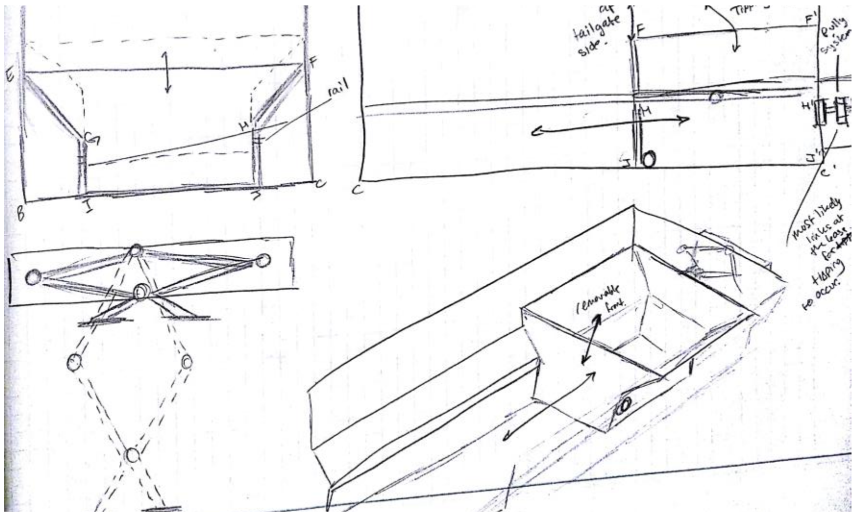

Figure 18. *Compartment Roll Out, CRO, concept design sketch*

Figure 18 is the compartmental unloading concept. It uses smaller containers where the dirt would be placed. As such when unloading only part of the load will be removed. While slower than unloading the full bed, this design makes it easier for the user to unload. The containers would have a wheel-rail system on the bottom to allow the containers to slider easier. Additionally, the containers would tilt at the tailgate to dump out the contents. The user would then remove the container and set it off to the side and repeat with the next container.

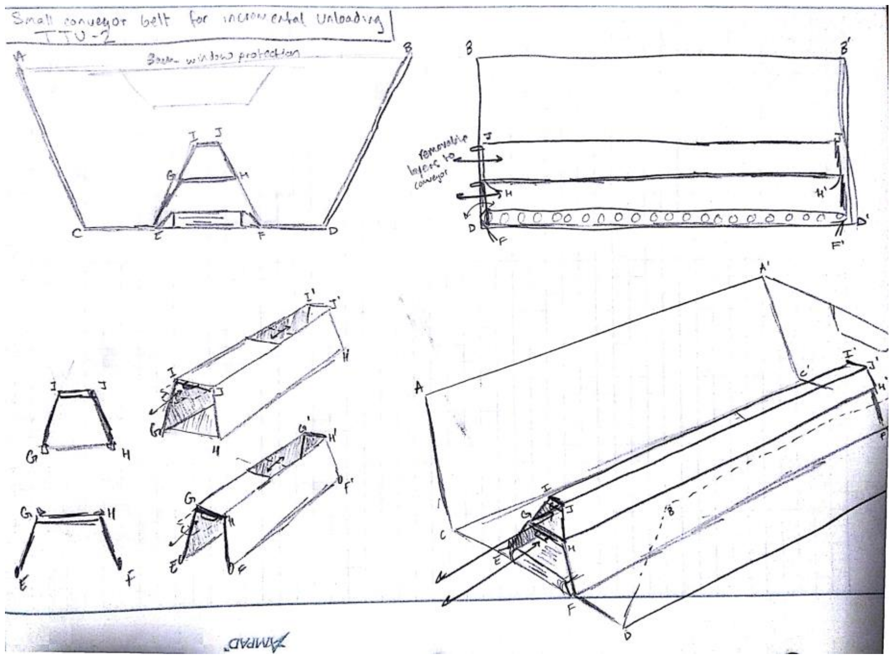

Figure 19. *Small Conveyor Belt for Incremental Unloading, SCBIU, design concept sketch*

Figure 19 is the small conveyor belt for incremental unloading. This design features a smaller conveyor belt that is housed in a metal trapezoidal shape that goes from the tailgate to the cabin. It combines the idea of constant unloading of a conveyor belt and the smaller load unloading of compartments. Dirt sitting on top and to the sides of the trapezoidal housing would fall into holes of the side and roof and onto the conveyor belt. The conveyor belt would be constantly moving, and dirt would be flowing out. Since the user is moving less dirt at a given time, they would not need to put in as much effort to remove the entire load.

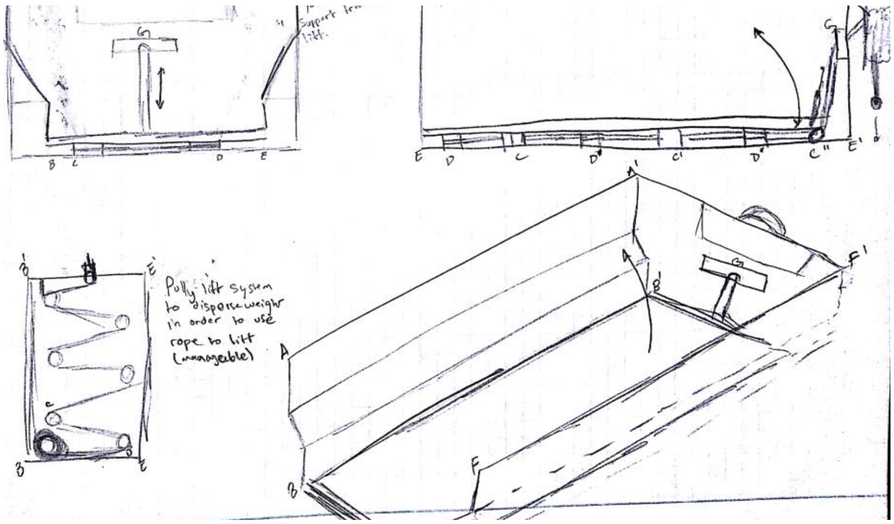

Figure 20. *Rope Tilt Lift Unloading, RTLU, design concept sketch*

Figure 20 is the tilt unloading concept idea. Dump trucks are common place but since the system will be manually operated with minimal bed tear, hydraulics can not be used. A solution to have a second container that would fit inside the bed, this container would have rope a pulley system attached to it. These ropes would connect to a vertical structure on the cabin end of the bed. Multiple pulleys would allow a weaker person to be able to tilt the container. The container would have a removable side on the tailgate end that would allow dirt to dump only when the operator wanted it to. Once some dirt was removed, the container could be lifted higher and repeat the process.

A Pugh chart was conducted, shown in Appendix A, to determine which concept design was the most feasible. The categories along with the respective weights are as follows: usability (10), safety (10), speed (8), load (9), durability (7), reparability (5), cost (5), cleanability (4), installation (6), weight (4), weather resistance (3), bed tear (8), and disposal (2). Usability was defined as ease of operation of the system for a single person. Safety was defined as a system that would not injure the customer during both installation and use. Speed was defined as how quickly the system can unload the materials placed upon it. Load was defined as the maximum load the system and truck could support. Durability was defined as the system's life span. Repairability was defined as how easy the parts of the system were to replace or fix in case of malfunction. Cost was defined as the price of parts and materials required for the system. Cleanability describes the system's ability to prevent spillage of the transported items onto the bed. Installation refers to ease of installation. Weight is how heavy the system is, with lighter system being better than heavier ones. Weather resistance refers to the system's ability to withstand weather conditions such as rain, hail, snow, high temperatures and low temperatures. Bed tear refers to the system's possible damage to the truck either through installation or continuous use. Disposal is the environmental impact of our system when it is retired from use.

For the Pugh chart, a plus meant that the system did the category better than the datum. A minus meant that the system did worse compared to the datum for that category with "s" being the same. For totaling, a plus added the weight, a minus subtracted the weight, and a "s" added zero, with a higher number total being better. Using the Pullout Shovel as the datum, the tarp rollout system ranked the highest. The process was repeated using the Tarp Rollout System as the new datum to ensure that no others ranked higher. The Rope Tilt Lift Unloading was concept was discarded due to being rated the worst consecutively. Additionally, the process was repeated one last time with the Small Conveyor Belt for Incremental Unloading as the new datum. This was due to it being very closely in point value to the Tarp Rollout System. Ultimately, we chose the Tarp Rollout System to continue designing with as it had proven to be the best using the values we set forth in the Pugh chart.

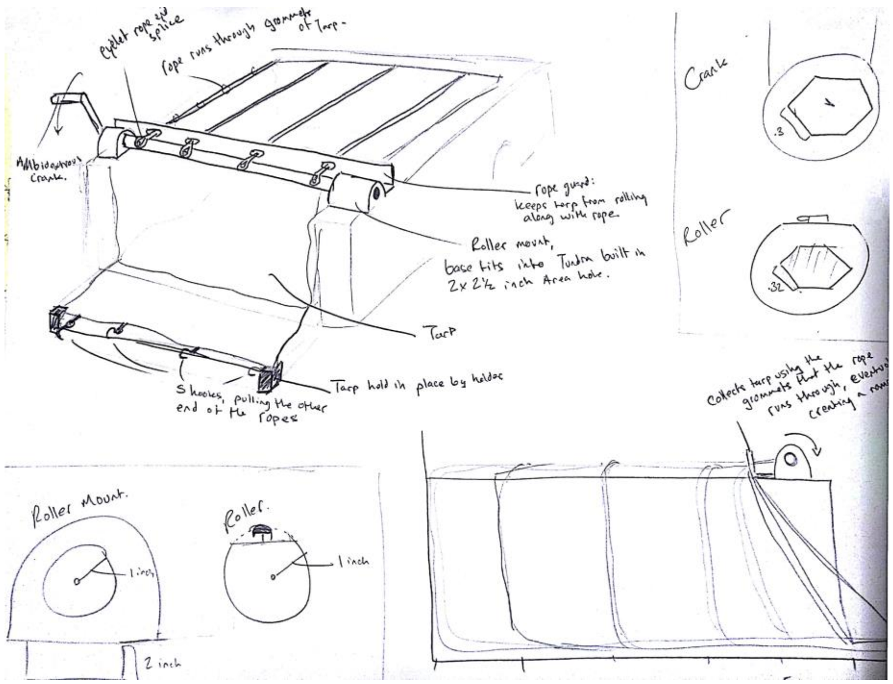

Figure 21. *Sketch of the Tarp Rollout System. This marks the final sketch for the preliminary design and marks the beginning of the modeling and analysis stage of the design process.*

The Tarp Rollout System worked by utilizing a roller that would roll in a series of ropes. These ropes would be attached to the tailgate of the truck and run under a tarp to the back of the bed near the cabin. They would then run back to the roller. These ropes would be fixed to the tarp using a series of grommets and d-rings, so as the ropes were rolled in, the tarp would begin to lift. As the tarp lifts, the material would begin to bunch up into a cylinder and roll out of the truck.

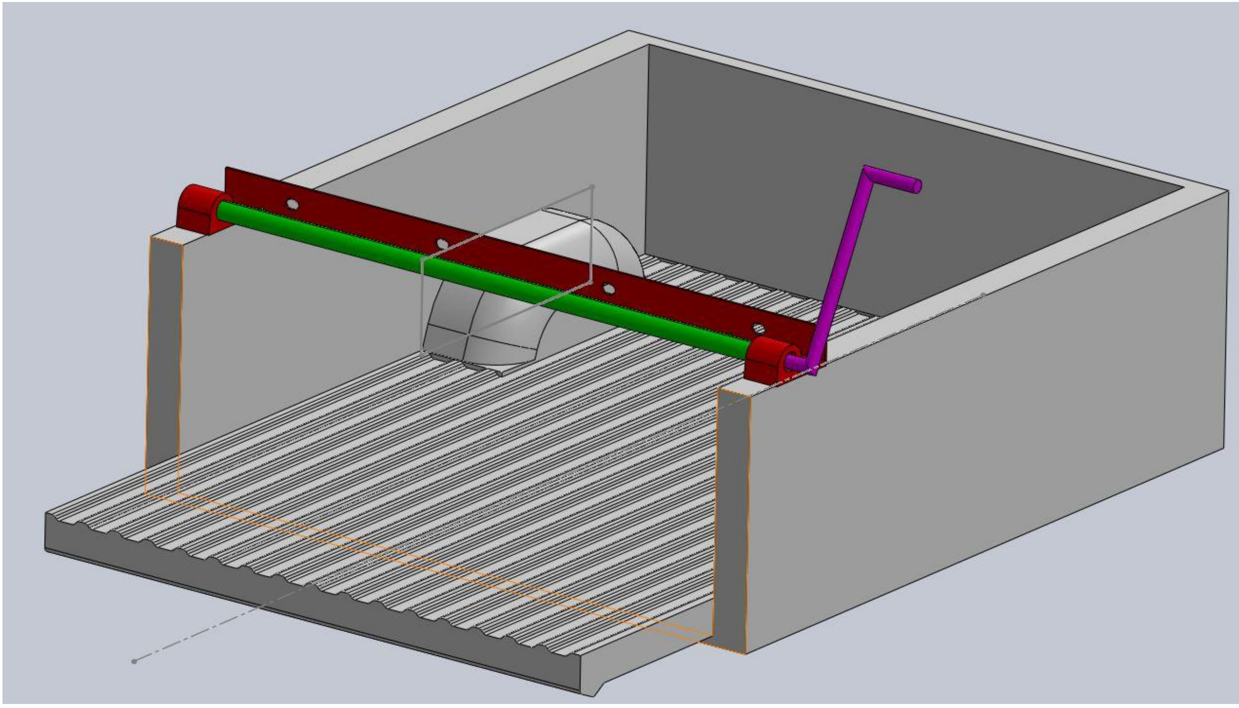

Figure 22. *Model of the Tarp Rollout System mounted onto the truck bed*

Figure 22 shows how our sketch turned into a 3d model. The red guard would prevent the tarp from contacting the roller and would provide some structural support to the roller, as well as allowing for the ropes to be guided onto the roller to be neatly rolled. Additionally, it housed the ball bearing mounds for the roller to be slid into. The roller, green, would connect to the crank by a matching bore and extrusion. The crank, purple, is how the user would turn the roller to operate the system.

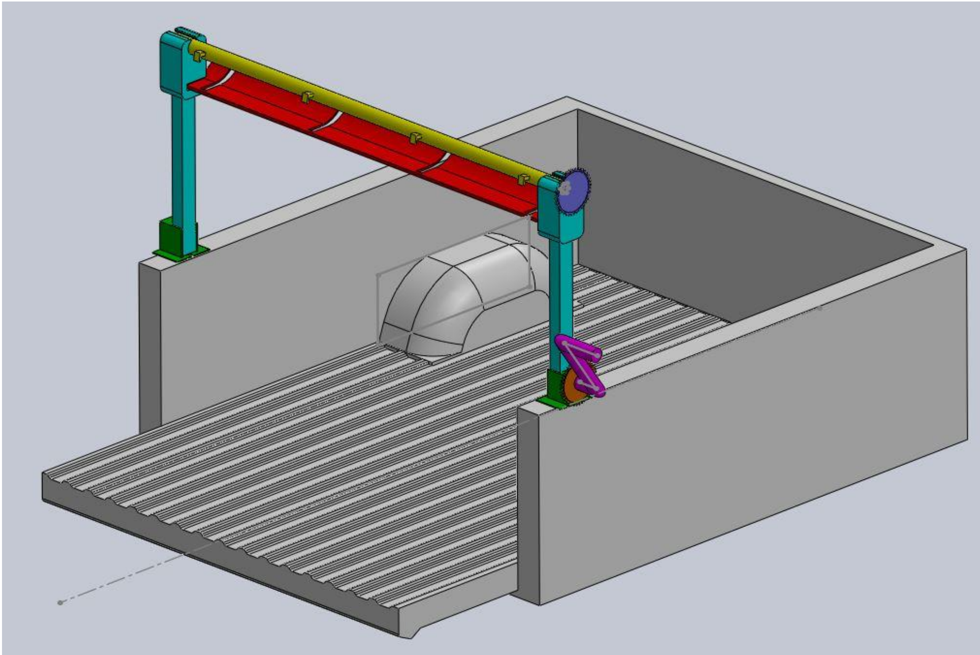

Figure 23. *Solid model of design Tarp Rollout System iteration 1.2.*

To ensure the material would not rise above the roller, the roller was raised up to its current height of 30”. Additionally, a series of sprockets were added to allow the user to crank from chest level rather than head level. Both changes made it into the final design. The rope guard was removed in the final design, due to a redesign that eliminated the need for ropes, leaving the tarp to roll off the bulk materials.

Evaluation of Results

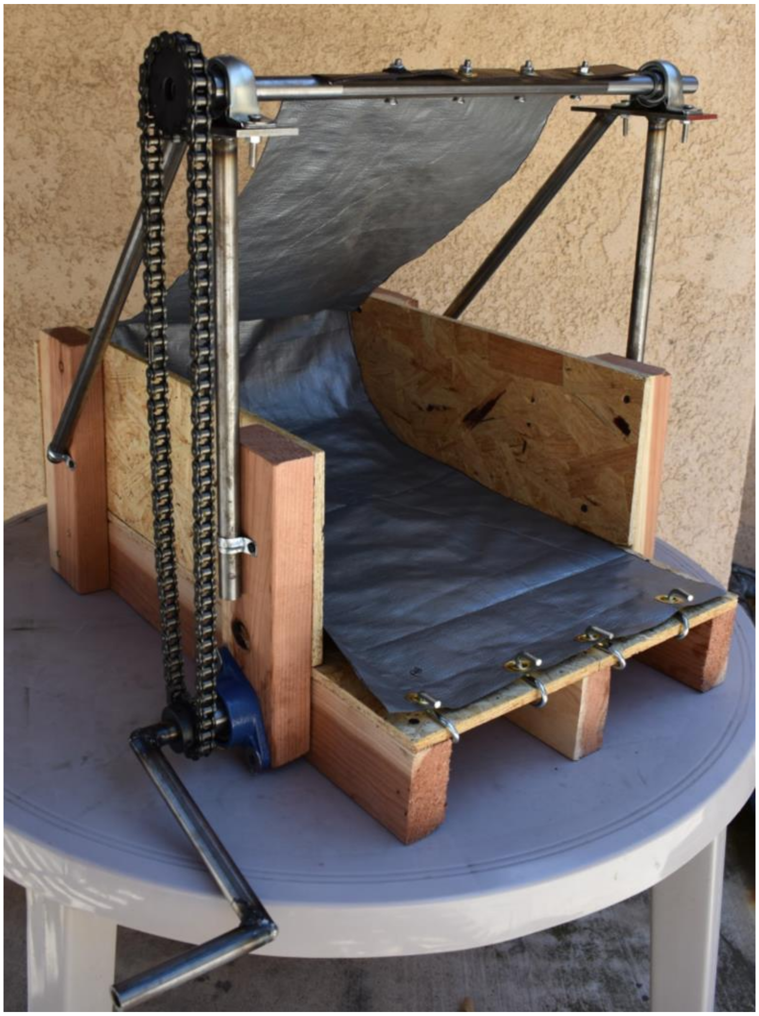

Figure 24. *Physical Prototype*

To prove the concept that the system would work correctly with material being rolled out, a physical prototype was constructed. The prototype was a scaled model, ¼ Length x ¼ Width x ⅓ Height. The height was scaled differently than the length and width to allow for more material being loaded while still accurately testing the unloading process. Specifically, this changed allowed us to load 42 pounds of material instead of 31 pounds. The system unloaded the material as expected with the material being lifted and then rolled onto itself. Upon reaching the tailgate, the tarp was rolled in until it formed a ramp for the remaining material to slide off.

Conclusion and Recommendations

The Tarp Rollout System exceeded our requirements set forth in both the full scale virtual simulations and the physical prototype. Bulk materials were easily unloaded in a quick manner while also being safe to operate. However, since we could only test with a scaled prototype the next step would be a full-scale model on a truck. Because we were unable to get the material and structure of the plastic that lines the bed walls and stake pockets, we ultimately cannot verify that the system would not warp the plastic.

While we have designed the system to have minimal shear using the diagonal supports, it is possible that the stake pocket mounts we have designed would be inadequate for the system. Additionally, a full-scale prototype would allow us to see the factor the wheel well arches are for our system. While our current system would not cover the arches, it may very well be possible that the material would be rolled onto the tarp regardless. Ultimately, we could not test both the plastic wall lining or the wheel well arches accurately without funding for a truck to test it on.

There is no current plan for further development of the Tarp Rollout System. A complete system Gantt chart has been included in Appendix D. This does not include the recommended additions and further research stated above.

References

[1] California, Caltrans State of. “Malcolm Dougherty.” California Department of Transportation (Overhang), www.dot.ca.gov/trafficops/trucks/overhang.html

[2] Aguilera, Antono. Personal interview. 26 January 2018.

[3]Harbor Freight, HaulMaster Truck Bed Cargo Unloader https://www.harborfreight.com/truck-bed-cargo-unloader-60800.html

[4]Real Truck, Bedslide S Truck Bed Cargo Slide https://www.realtruck.com/bedslide-s-truck-bed-cargo-slide/

[5]“2018 Toyota Tundra | In-Depth Model Review.” *Car and Driver,* www.caranddriver.com/reviews/2018-toyota-tundra-in-depth-model-review-2018

Appendices

A. Pugh Charts

Feature	Weight	PS (Datum)	CBR	CRO	SCBIU	RTLU	TRS
Usability	10	Datum	+	+	+	s	+
Safety (person and truck)	10	Datum	+	+	+	s	+
Speed	8	Datum	+	s	-	s	+
Load	9	Datum	s	-	s	-	-
Durability	7	Datum	+	-	s	-	-
Repairability	5	Datum	-	+	-	+	+
Cost	5	Datum	-	-	-	-	+
Cleanability	4	Datum	-	-	s	s	+
Installation	6	Datum	+	+	-	-	+
Weight	4	Datum	-	-	-	s	+
Weather Resistance	3	Datum	-	+	+	-	+
Bed Tear	8	Datum	+	+	+	+	-
Disposal	2	Datum	-	-	s	s	+
TOTAL			26	11	3	-17	33

Figure A-1. *Pugh chart comparing the Datum of PS to the other design ideas. As shown, CBR and TRS showed the strongest results, which decided what would serve as the next datum. RTLU seemed to be the weakest.*

Feature	Weight	PS	CBR	CRO	SCBIU	RTLU	TRS (Datum)
Usability	10	-	s	-	-	-	Datum
Safety (person and truck)	10	-	s	s	+	-	Datum
Speed	8	-	s	-	s	-	Datum
Load	9	+	+	+	+	+	Datum
Durability	7	s	+	s	+	-	Datum
Repairability	5	s	-	-	-	-	Datum
Cost	5	-	-	-	-	-	Datum
Cleanability	4	s	-	-	-	-	Datum
Installation	6	-	-	-	-	-	Datum
Weight	4	-	-	-	-	-	Datum
Weather Resistance	3	s	-	-	s	-	Datum
Bed Tear	8	+	+	+	+	+	Datum
Disposal	2	-	-	-	-	-	Datum
TOTAL		-28	-1	-30	-2	-43	

Figure A-2. *Pugh chart comparing the Datum of TRS to the other design ideas. This chart further implies that the TRS design is the best solution. Because SCBIU was consistently close to the TRS datum, the final comparison would be made using SCBIU as the datum. Additionally, RTLU was the worst in both, and was considered not viable.*

Feature	Weight	PS	CBR	CRO	SCBIU (Datum)	RTLU	TRS
Usability	10	-	s	-	Datum	X	s
Safety (person and truck)	10	s	s	-	Datum	X	s
Speed	8	+	+	-	Datum	X	+
Load	9	s	s	-	Datum	X	-
Durability	7	-	-	-	Datum	X	-
Repairability	5	+	+	-	Datum	X	+
Cost	5	+	-	-	Datum	X	+
Cleanability	4	+	+	-	Datum	X	+
Installation	6	+	s	s	Datum	X	+
Weight	4	+	-	-	Datum	X	+
Weather Resistance	3	-	+	-	Datum	X	+
Bed Tear	8	s	+	s	Datum	X	-
Disposal	2	-	-	-	Datum	X	+
TOTAL		10	10	-67		X	13

Figure A-3. *Pugh chart comparing the Datum of SCBIU to the other design ideas. Due to TRS being the largest score once again, it was agreed that the TRS design would be utilized.*

B. Small Scale Prototype Parts

Item Number	Item Name	Where
1	Roller	https://www.industrialmetalsupply.com/index.php
2	Support	https://www.industrialmetalsupply.com/index.php
3	Handle	https://www.industrialmetalsupply.com/index.php
4	Gear	https://www.industrialmetalsupply.com/index.php
6	S-Hook	Home Depot, 250 Pound
5	Tarp	Home Depot, Heavy Duty Tarp
6	Grommet	Home Depot, Grommet Kit
7	Chain	https://www.mcmaster.com, 6261K173
8	Flat Sprocket	https://www.mcmaster.com, 2299K24
9	Roller Sprocket	https://www.mcmaster.com, 6280K663
10	Mounted Ball Bearing	https://www.mcmaster.com, 5913K63, Quantity 2
11	Flange Mounted Ball Bearing	https://www.mcmaster.com, 5968K73

C. Part Drawings for Machining

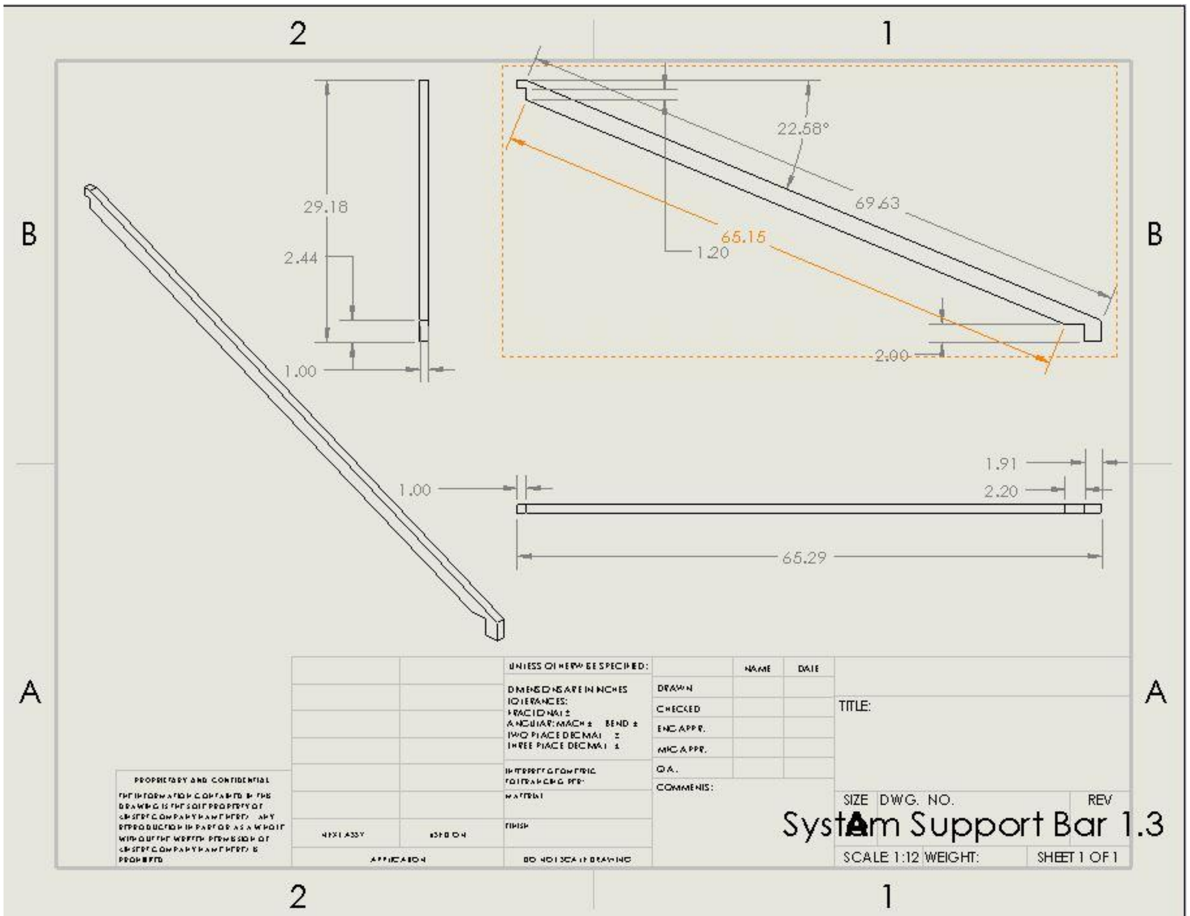

Figure C-1. *Diagonal System Support part drawing.*

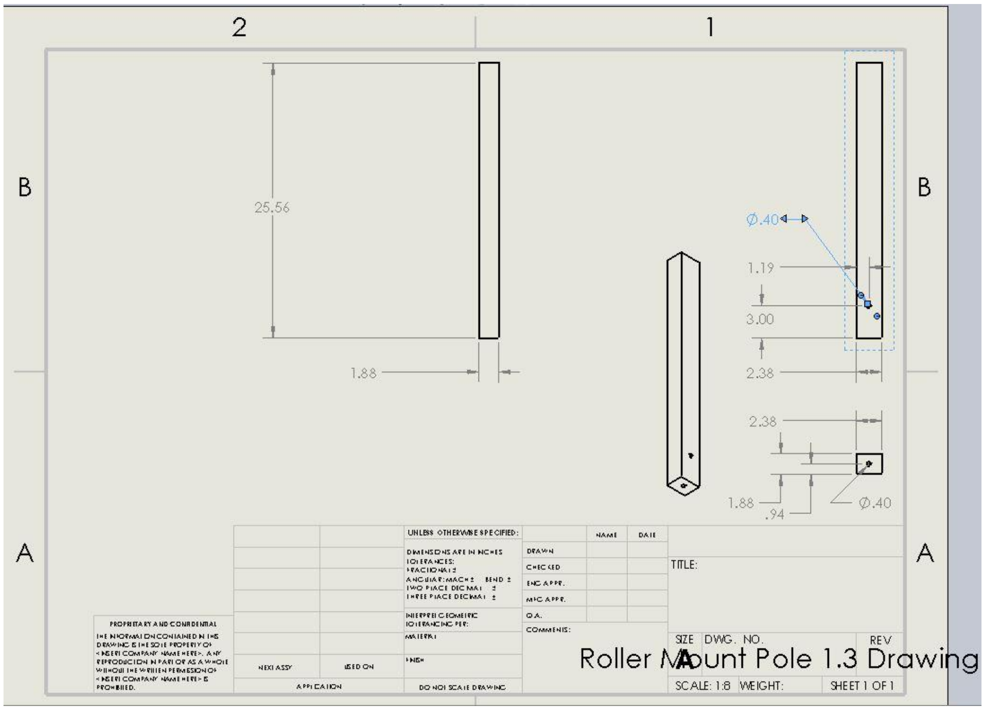

Figure C-2. *Roller Mount Pole part drawing*

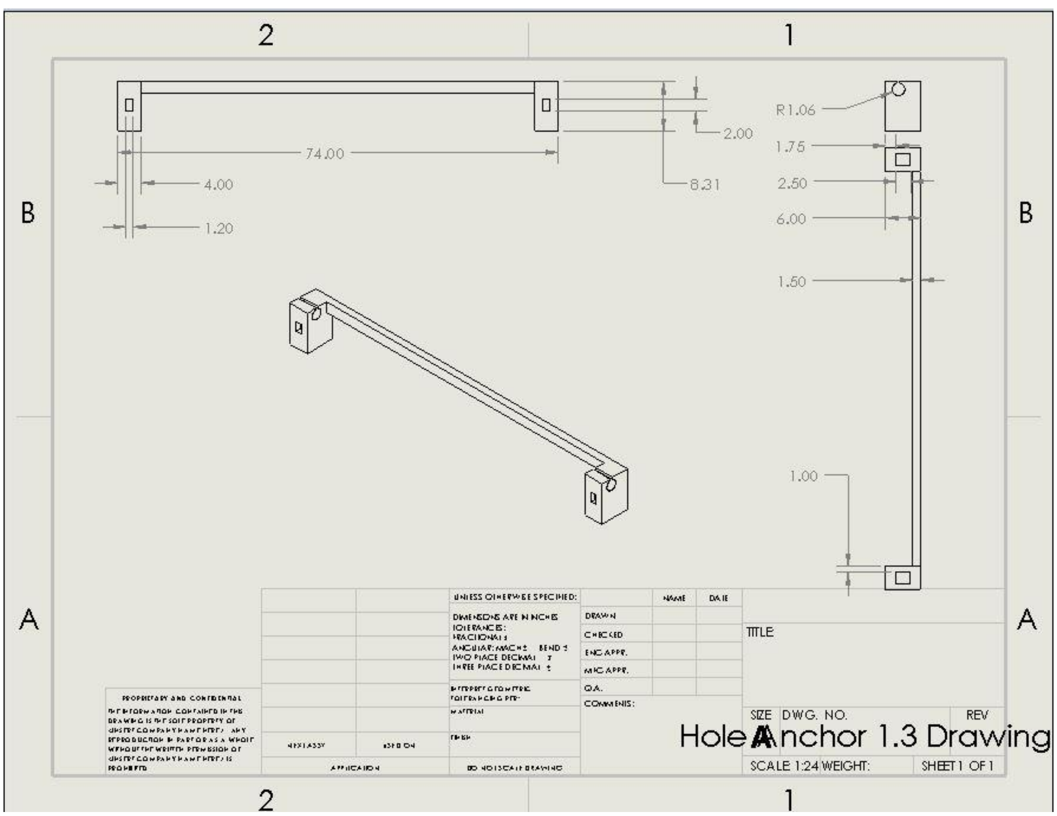

Figure C-3. *Hole Anchor part drawing.*

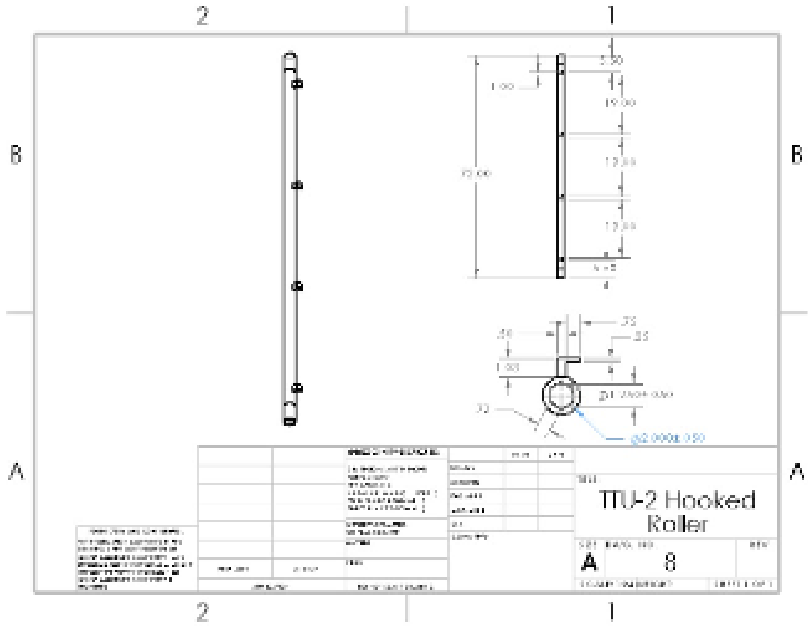

Figure C-6. *Roller part drawing.*

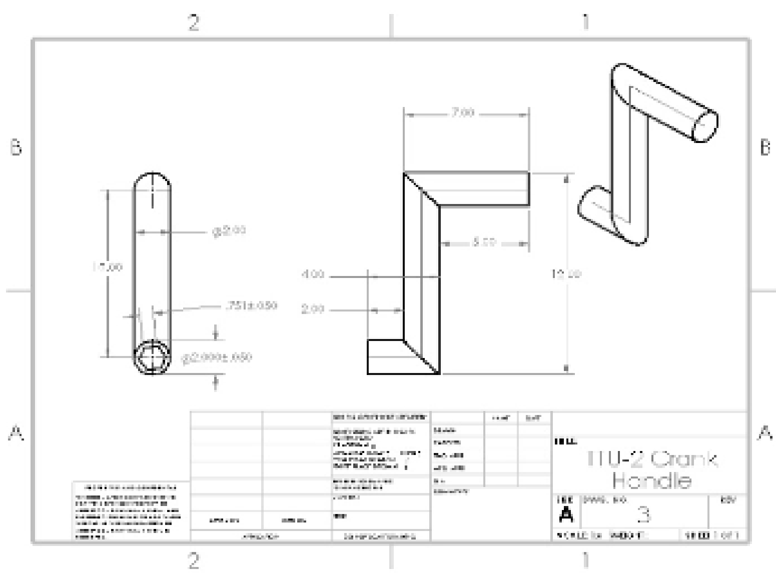

Figure C-7. *System Handle part drawing.*

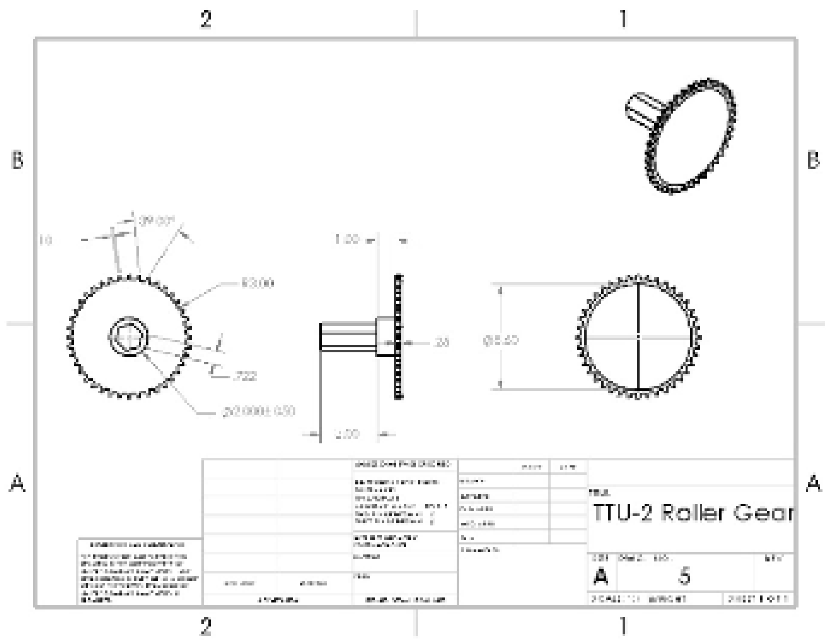

Figure C-8. *Roller Sprocket part drawing.*

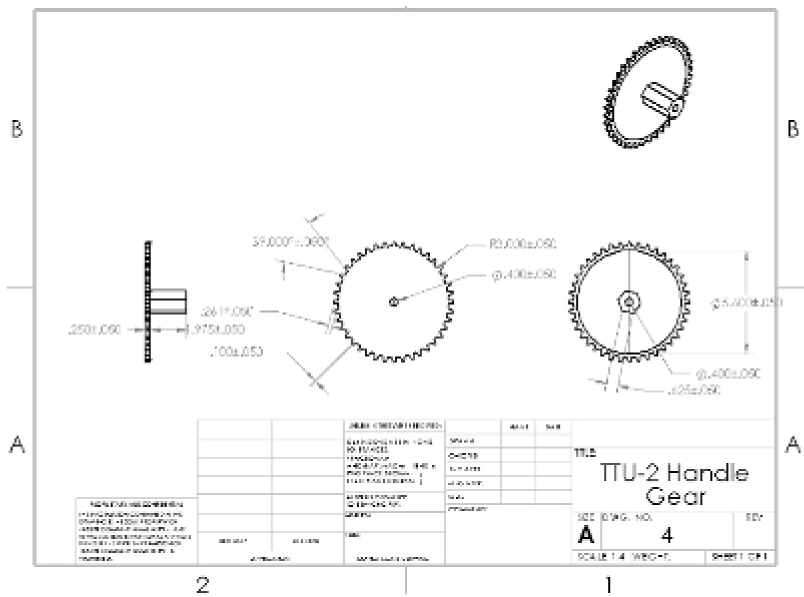

Figure C-9. *Handle Sprocket part drawing.*

D. Gantt Chart

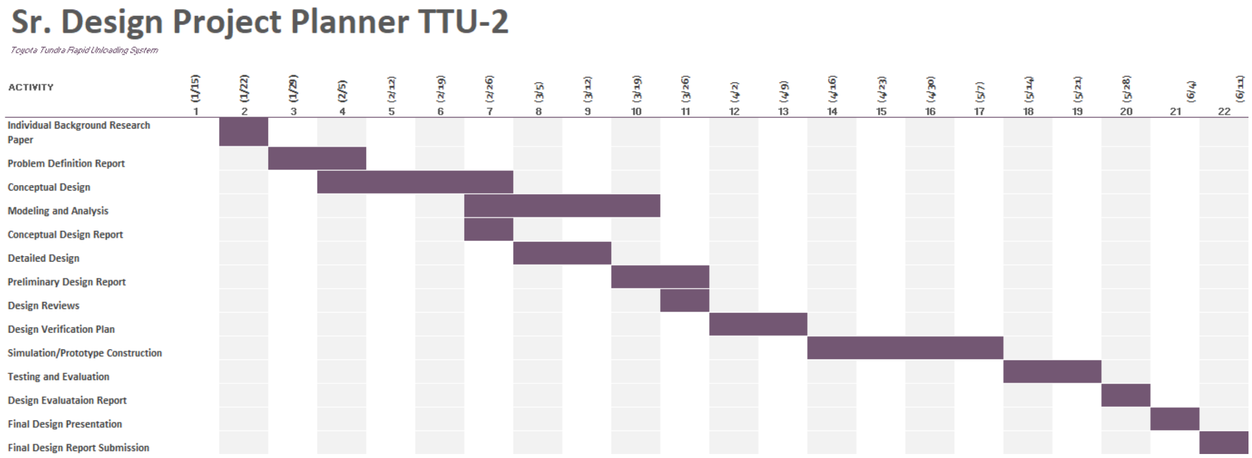

Figure D-1. *Final Gantt Chart for TTU-2 project plan, all deliverables completed*