UNIVERSITY OF MANITOBA

MECH 4860 ENGINEERING DESIGN

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Redesign of Vidir Bicycle Merchandising System Skyhook Final Design Report

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Executive Summary

The Engineering Design course at the University of Manitoba Faculty of Engineering provides an opportunity for students to take on industry design problems and apply engineering skills and principles learned throughout their program. Team 24 consists of Jason Ward, Evan Jackson, Fabian Faller and Gil Patriarca and they have been grouped with Vidir Machine Inc. for their design project. Vidir Machine Inc. manufactures a three tier Bike Merchandising System, or BMS, which can be found in Wal-Mart stores across North America. Vidir Machine Inc. has presented a design project of analysing and redesigning the Skyhook component of their BMS. The Skyhook is a system of linkages and a shock which allows bikes from the top tier of the BMS to be lowered such that a consumer may access the product.

The concept development performed by the team explored various alternatives for which considered the limitations and constraints of the scope. To evaluate the alternatives, a cost breakdown analysis was performed, along with advantages and disadvantages of each design. A scoring matrix and house of quality were used to select the main three designs. The exploration for alternatives to the current gas shock demonstrated that the gas shock is the lowest cost, from all the considered alternatives. The alternatives for the linkage arms assembly concepts had to be compatible with the gas shock, this eliminated many of the explored concepts.

Eventually 3 main concepts were chosen: Two Arm Scissor with gas shock Design, Single Sliding Arm with gas shock Design, Manufacturing redesign of the current skyhook. The main three designs were presented to the customer whom chose which of these three designs was to proceed to detailed design stage.

Vidir and the team chose to proceed with a improved manufacturing methodology of their current skyhook design. The team identified the main beam where the most manufacturing improvements can be made. The current Vidir design is comprised of a U-channel, square tube, several plates, and arms that are all welded together. Through our re-design of the main beam we have eliminated the need for the square tube and many of the plates. Our design uses a smaller U-channel that now runs the full length of the beam and the rear hole locations for the guide track is now part of the main beam eliminating the need for welding. The cost analysis showed we can fit four more main beams in a five by ten foot piece of sheet metal, and the design decreases manufacturing time to save costs. This cuts down the cost per main beam by 6.56 dollars and decreases the overall cost of the skyhook form 38 dollars to 31.44 dollars.

Throughout the design project, the team has accomplished the objectives Vidir set out for the team. Manufacturing costs have been reduced, manufacturing time has been reduced, and the construction of the skyhook is significantly simpler. Overall, we can conclude this project a success.

1 Introduction

The University of Manitoba engineering design team 24 was contracted by Vidir Machine Inc. to review their Bike Merchandises System (BMS) Skyhook component. The BMS is found throughout stores in North America to display bicycles to their customers for purchase. Vidir has presented this design project for analyzing and the redesign for the skyhook component, the project must comply with the customers needs and objectives, such that the proposed preliminary redesign can be evaluated for adoption by the customer.

1.1 Purpose

The purpose of this project is to explore alternatives designs, components and manufacturing processes for Vidir Machine Inc. skyhook component for the Bike Merchandising System. The Bike Merchandising System or BMS is a storage and display system for bicycles that have three levels. At the top level, there is a component called a Skyhook that lowers the bicycles from the top level to ground level. Vidir has identified their key desired outcomes for this project to be:

- Reduction in overall manufacturing cost of the skyhook component.
- Reduction in manufacturing time.
- Reduction in labor intensity.
- Alternative actuator systems to the current gas shock system.

This report contains the project background and objectives, identify key stakeholders, target specifications, customer needs, constraints, and limitations, and provide details and dates for the project schedule. All project deliverables are clearly identified and provides an explanation to stakeholders with all the assumptions and expectations for project completion.

1.2 Company Background

Vidir Machine Inc. specializes in the manufacturer of merchandising carousels and display fixtures since 1986. These merchandising carousels and display fixtures are used to store, display, dispense and handle a wide variety of products. These products range from carpeting, sheet vinyl and tires to bikes and industrial products. Vidir operates two manufacturing plants located in Arborg and Teulon, Manitoba. Vidir also services customers in 30 different countries that include many Fortune 500 companies like Home Depot, Wal Mart, GM, Honda, Mercedes Benz and Nike[1].

1.3 Problem Background

Vidir is a manufacturer for a wide variety of products for unique applications worldwide. One of the unique products that Vidir offers is a Bike Merchandising System that is used for the merchandising, display and storage of multiple bicycles. Figure 1 below shows an overview of a complete BMS system [2].

Figure 1: An empty BMS [3].

Currently, the BMS system consists of a three-level bike storage display with pull out carriers on all levels for bike access. The BMS system is fully modular to accommodate different sizes of bikes, and each level of the BMS System holds up to 10 bikes [2]. Figure 2 shows a fully implemented BMS system at Wal-Mart.

Figure 2: A BMS fully populated at Wal-Mart [2].

The third level of the BMS system contains a special component called a Skyhook, a component that not only pulls out but also pulls down to lower the third level bikes. The Skyhook, shown in Figure 3, uses a gas shock to retract bikes of up to 40 lbs. In addition, the gas shock contains a dampening system that controls the retraction of the unit for safety reasons when it is empty [4].

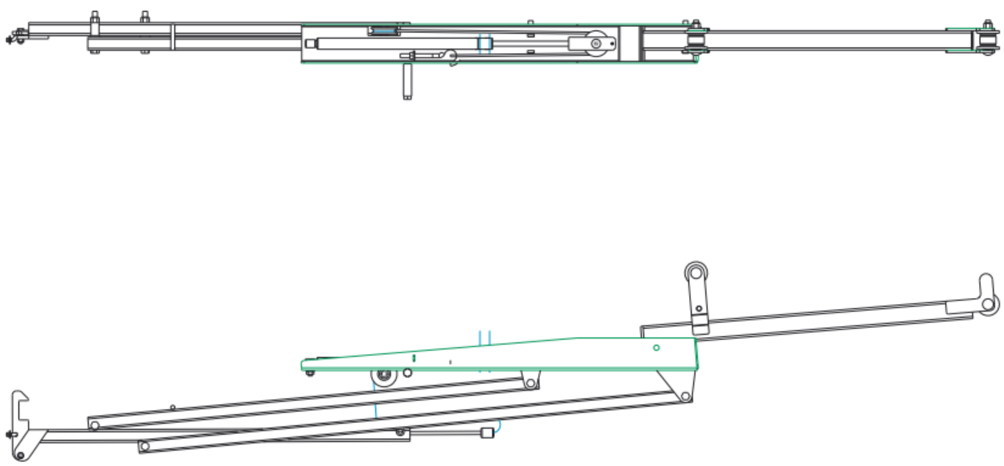


Figure 3: Skyhook Drawing [5].

Although the BMS system is fully functional and capable of proper display and storage for bicycles, there are improvements that can made to the Skyhook component of the system. These improvements will be further addressed in the next section.

1.4 Problem Statement

The current BMS is approximately 15 years old and in need of reanalysis. The possibility of new technology surfacing in the past 15 years that could improve cost efficiency and functionality are to be considered. Customers and fabrication/assembly workers of Vidir have reported issues regarding manufacturing that have been observed over the past years. The current BMS systems are very labour intensive to fabricate and assemble. A 2004 statistic from Vidir shows that it takes approximately 41 minutes to fabricate and assemble a skyhook: 15 minutes for welding, 1 minute for iron work and 25 minutes to assemble.

In addition to the manufacturing issues, Vidir would like to explore alternatives to the gas shock dampening system. This is due to receiving defective shocks in the past, and to see if there are more cost efficient ways to achieve the same function.

1.5 Project Objective

The project objectives from Vidir given to Team 24 were as follow:

- Reduction in overall manufacturing cost of the skyhook component.
- Reduction in manufacturing time.
- Reduction in labor intensity.
- Explore alternative actuator systems to the current gas shock system.
- Maintain or improve the safety level of the BMS.

- Explore ways to decrease the user effort to operate the skyhook.
- Visually pleasing design.
- Maintain current skyhook functionality and interaction with other BMS components.

The project was broken down into four main phases to accomplish the objectives from the customer. The first phase is focused on defining the customer needs and objectives, such that design exploration shall accomplish customer requirements. The second phase explores alternative concepts for redesign, manufacturing and actuator systems, upon which the three best alternatives to their current design and processes are presented to the customer. The customer ultimately has the decision on which concept is selected for the final design. Phase three composes from detailed analysis for the final design and the preliminary engineering design report for the project, a cost analysis will be completed for both the design evaluation phase and for the optimized final redesign. The redesign does not necessarily have to cost less than the per unit price of the current Skyhook, but be more cost efficient during mass production runs or offer functionality and features that outweighs the extra cost [4]. The fourth phase presents the final design and analysis to the customer at the University of Manitoba presentation dinner.

1.6 Project Scope and Expectations

Vidir has limited the scope of the BMS analysis to the Skyhook component. The redesign will include similar specification and dimensions as the current Skyhook to prevent any incompatibility issues with the existing BMS system. Priorities for the redesign are reduction of manufacturing cost of the Skyhook component, analysis and implementation of possible alternative options to the current gas shock dampening system of the Skyhook, and improvement for the fabrication and assembly process of the Skyhook. The scope of this design project will focus on the complete preliminary design process of the Skyhook component. This includes project definition, concept design and evaluation, and any project management components. Implementation is not necessary for this project but shall be considered during the design process [4].

1.7 Customer Needs

To provide a complete project definition, customer needs must be clearly and thoroughly analyzed. Along with the needs, it is important that corresponding technical specifications are quantified, and each need assessed as to its relative importance. In this section, all these factors are discussed and organized into rankings based on importance and priorities. Through meetings with the client target specifications are categorize into two categories: needs analysis, and target specifications and metrics.

1.8 Needs Analysis, Target Specification and Metrics

The customer needs taken from the objectives were evaluated according to their importance to the customer in Table I. The scale chosen is from 1 through 5. These ratings were prioritized based conversation with the client, and how necessary each one is to project success. A rating of 5 is defined by the client as essential to project completion, and a 1 is defined as not essential, but more of a value-added feature.

Table I: CUSTOMER NEEDS AND IMPORTANCE RATING

Need ID No.	Customer Need	Importance Rating (out of 5)
N1	Accommodates variety of bicycle weights	5
N2	Uses a dampening device to assist the BMS	4
N3	Improved cost of manufacturing	5
N4	Improved ease of assembly	5
N5	Improved serviceability/replacement of worn out parts	2
N6	Has increased service life	3
N7	Incorporated safety features if dampening device fails	4
N8	Does not work with competitors products	3
N9	Potentially eliminates the need for current pull rod	1
N10	Visually appealing	3
N11	Can be constructed with current Vidir equipment	5
N12	Can be easily and safely used by customers	5
N13	Maintains current BMS footprint	5
N14	Improved manufacturing time	5
N15	Accommodate variety of frame sizes	4
N16	Accommodate variety of wheel sizes	4
N17	Accepts current carrier design	5
N18	Accepts current rack design	5
N19	Prevents damage to nearby bikes	5
N20	Maintains extended position while dispensing payload	4

1.9 Target Specifications and Metrics

Following the identification of customer needs, target specifications and metrics were assigned to the customer needs in Table I. These specifications consist of a number, a range, or an inequality. Each value is labeled with the appropriate units. Table II provides the Metric ID number corresponding to its need ID number, metric, target specification ID number, target specification, and finally the appropriate units.

Table II: METRIC AND TARGET SPECIFICATIONS

Metric ID	Need ID	Metric	Target Spec. ID	Target Specification	Units
M1	N1	Weight	T1	40	Lbs
M2	N3	Cost	T2	C<38	dollar
M3	N4	Time	T3	minimize	minutes
M4	N6	Time	T4	maximize	years
M5	N10	Focus Group	T5	maximize	subjective
M6	N13	Size	T6	L=240, D=72	inches
M7	N14	Time	T7	T<41	minutes
M8	N15	Size	T8	29" frame	inches
M9	N16	Size	T9	29" wheels	inches
M10	N17	Operational	T10	Pass/Fail	—
M11	N18	Operational	T11	Pass/Fail	—

2 Constraints and Limitations

To fully define the scope of the project, it is important to determine the constraints and limitations which apply to the final design and design process. Through team brainstorming and meetings with the client, the team identified the following constraints and limitations:

1. The final design must be manufactured using the clients current equipment. Vidir has a large manufacturing facility which houses a wide range of equipment. This equipment includes lathes, mills, welders, wire benders, tube laser, sheet laser, and general shop tools. It is important that Vidir can seamlessly incorporate the new design into their current manufacturing process.
2. The redesign of the Skyhook component of the BMS system must fit within the current footprint of the entire system assembly. In addition, the Skyhook must be compatible with the current BMS assembly to prevent further workload for redesign of other components not within our groups design scope.
3. The cost of manufacturing the Skyhook must not exceed the current price point. However, through discussion with the client it was made clear that if the re-design does increase cost, the improvements on the previous design must be substantial and therefore justify the extra cost.
4. Completion of the design and report must be before December 7th, 2016. This gives Vidir an option to outsource a manufactured prototype of the redesigned Skyhook. This time constraint must push our team to complete all necessary designs to allow Vidir the time and providing them with drawings and specifications to produce a proper prototype of our teams design.

3 Research

The purpose of this section is to provide the background and support necessary for the concept analysis and selection phase. This section explores the different materials, mechanical systems and gas shock actuator alternatives, to meet the customer objectives. These alternatives are to be used for creating possible ideas for the redesign of the Skyhook component of the BMS system as well provide supporting evidence on justification for the concept design. Note that this section contains a cost comparison analysis of different materials and alternative systems to the gas shock system in North American manufacturer prices. This cost shown in this section reflects the price for a single component or material, the actual cost for the redesign of the Skyhook component will be based lower. The variation in cost comes from the mass production and outsourcing of parts production and purchasing too China. The cost comparison is used as a baseline for the cost factor of the evaluation and selection of the concept designs.

3.1 Gas Shock Alternative Cost Analysis

The parts list was compiled to include all major components required to build each concept, as well as the current Vidir design. To allow for accurate comparison, all parts were sourced form a single supplier, the parts were matched as closely as possible to the real life components utilized in the skyhook. For the purpose of the comparison, McMaster-Carr was chosen as the supplier. Please note the cost for parts on McMaster-Carr do no reflect actual cost for Vidir design, variation in cost comes from mass production, outsourcing parts production and purchasing to China.

Table III: PRICE COMPARISON OF ALTERNATIVE SYSTEMS TO GAS SHOCKS [6]

Mechanical Part	Wire or Rod Type	Max Value	Price (USD)
Pneumatic Cylinder	1/2” (Nut Diameter)	1378 N	$77.62
Threaded Rod	3/8”-16 x 36”	432.63 Mpa	$15.42
Spring and Angular Damper	3/8 (Rod Thickness)	10.5 Nm	$47.81
Spring and Rotational Damper	3/8 (Rod Thickness)	10.5 Nm	$47.81
Electric Motor	N/A	0.18 Nm	$168.45
Rack and Pinion	0.5 (Pitch Diameter)	N/A	$91.87
Hand Crank	3/8 (Cable Thickness)	800 lbs	$32.23
Spring Brake	1/8 (Cable Thickness)	60 lbs	$87.74
Coiled Spring	1/8 (Cable Thickness)	60 lbs	$724.72
Gas Shock	16.14 Stroke Length	200-250 lbs	$24.09

Table III shows the least expensive alternative to a gas shock is the threaded rod, however we need to consider that the price for the threaded rod is for a regular thread. The thread we require to raise or lower the bicycle would have to have a much steeper helical cut, as such the rod has to be custom made and will raise the cost per part by an substantial amount. Therefore we conclude the gas shock is the most inexpensive actuator system.

3.2 Materials Cost Analysis

Reduction of cost is one of the main customer needs of this project. To minimize cost of the redesigned Skyhook component, materials to be used for the redesign must be considered. Not only does the current design materials need to be evaluated, but also alternative materials that the redesign can be made from. Table IV shows the materials for the majority of components of the current Skyhook design.

Table IV: COMPONENTS AND MATERIALS OF CURRENT SKYHOOK [7]

Materials	Components	Total Number of Components
Sheet Metal	Skyhook Eyebolt Anchor	10
	Skyhook Base Plate	
	Track Wheel Fork Front Left Flat State	
	Track Wheel Fork Front Right Flat State	
	Skyhook Base End Cap	
	Skyhook Hinge Tab Short	
	Skyhook Hinge Tab Long	
	Kink Latch Hook	
	Track Wheel Fork Rear Left Flat State	
	Track Wheel Fork Rear Right Flat State	
Steel Square Tube	Skyhook Link Arm Short Tube	4
	Skyhook Link Arm Long Tube	
	Skyhook Lift Arm	
	Skyhook Track Tube	
DOM Steel Tubing	Lift Arm Hinge Pipe	2
	Skyhook Latch Roll Pipe	

All of the components listed above are made from steel. Furthermore, most components for the Skyhook are made from different thicknesses of sheet metal. To explore the alternatives of sheet metal, a brief cost analysis of different sheet metal was produced in the following table. Table V shows the base sheet metal prices for a standard North-American manufacturer/distributor of structural materials.

Table V: PRICE COMPARISON OF 4 FT. X 4 FT. SHEET METAL [8]

Material	Type	Thickness	Price/Piece)
Steel	Cold Rolled	20 GA. (0.036)	$38.88
		18 GA. (0.048)	$48.00
	Hot Rolled	16 GA. (0.060)	$44.96
		14 GA. (0.075)	$62.56
	Galvanized Steel	20 GA. (0.040)	$59.36
		18 GA. (0.052)	$77.76
		16 GA. (0.064)	$81.28
		14 GA. (0.079)	$118.08
Stainless Steel	Brushed Polish	20 GA. (0.036)	$120.96
		18 GA. (0.048)	$161.28
		16 GA. (0.060)	$224.86
		14 GA. (0.075)	$283.36
Aluminum Sheet	3003	1/16 Thick	$64.64
		1/8 Thick	$128.16
	5052	1/16 Thick	$72.00
		1/8 Thick	$140.00
	6061-T6	1/16 Thick	$124.32
		1/8 Thick	$229.28

Table V reinforces the selection of using steel as the choice of material for the metal sheets, as one of the main priorities of the redesign is a decrease in cost. Cold rolled steel sheets are the least expensive material option at $38.88 for a 20-Gauge, 4 ft. x 4 ft. piece [8]. In addition to sheet metal, the current design also contains multiple structural components using a hollow square cross section. To decrease cost even further, a cost comparison in Table VI shows the prices for structural members with different cross sections for a standard North-American manufacturer/distributor of structural materials.

Table VI: PRICE COMPARISON FOR DIFFERENT CROSS-SECTIONAL MEMBERS [8]

Structure Type	Material	Type	Dimensions (Per 4 ft x 4 ft Piece)	Price (Per Piece)
Hollow Square	Steel	A513 Square Tube	1 x 1 x 14GA (0.083 wall)	$9.64
Steel	A513 Square Tube	1 x 1 x 11GA (0.120 wall)	1 x 1 x 11GA (0.120 wall)	$12.20
Aluminium	6063 Square Tube	1 x 1 x 1/16 (wall)	1 x 1 x 1/16 (wall)	$10.00
Aluminium	6063 Square Tube	1 x 1 x 1/8 (wall)	1 x 1 x 1/8 (wall)	$13,20
Circular Tube	Steel	A-500 ERW Structural Pipe	1” SCH 40 (1.315 OD X 0.133 wall)	$14.08
Steel	A-53 ERW Structural Pipe	1” SCH 80 (1.315 OD X 0.179 wall)	1” SCH 80 (1.315 OD X 0.179 wall)	$29.04
Stainless Steel	304 Stainless Steel	1 x 1 x 16GA (0.062 wall)	1 x 1 x 16GA (0.062 wall)	$23.84
Stainless Steel	304 Stainless Steel	1 x 1 x 11GA (0.120 wall)	1 x 1 x 11GA (0.120 wall)	$25.84
Aluminium	6061-T6 Structural Pipe	1” SCH 40 (1.315 OD X 0.133 wall)	1” SCH 40 (1.315 OD X 0.133 wall)	$13.92
Aluminium	6061-T6 Structural Pipe	1” SCH 80 (1.315 OD X 0.179 wall)	1” SCH 80 (1.315 OD X 0.179 wall)	$31.08
I-Beam	Steel	A36/A572-50	3” x 2.33” x 0.170” [5 ft. piece]	$61.30
Aluminium	6061-T6 - AS	3” X 2.33” X 0.170” web	3” X 2.33” X 0.170” web	$69.00
Aluminium	6061-T6 - AA	3” X 2.50” X 0.150” web	3” X 2.50” X 0.150” web	$78.60

Table VI shows, the least expensive material for cross-sectional members are hollow square rods. As these are already used in Vidirs current design it is advised not to deviate from their use.

3.3 Research Conclusion

From the research goatherd in this section we can firstly conclude from Table IV that the current gas shock system is the most cost efficient actuator available. Secondly we can conclude that regular steel is the best material we can select for sheet metal and cross-sectional members from its low price when compared to the other alternatives in Table VI and Table III.

4 Concept Development

This section details the exploration for concept ideas developed by the team to meet Vidirs needs and objectives for the redesign BMS skyhook. The needs and objectives from section 1.5 and 1.8 respectively.

4.1 Gas Shock Alternative Concept Development

One of the customer needs for the project is an alternative to the gas shock system of the current design of the Skyhook component. After a group brainstorming activity, the following alternatives to the gas shock system are determined. Each alternative was subjected to a review by the team on the advantages and disadvantages of its use in a concept design:

4.1.1 Pneumatic Cylinder

The current design of the Skyhook implements a gas shock/pneumatic cylinder system. The pneumatic cylinder is a device that uses compressed air to impart a force or produce mechanical motion using pressure gradients within a cylindrical casing. This pressure gradient can also be used to dampen linear motion and does not need an external source of energy [9].

Advantages

- Proven and reliable actuator.
- Single actuator design.
- Fast raising and lowering of the Skyhook.
- Mechanical systems only.
- Provides both spring and damping actions.
- Long lasting.
- Higher reliability than springs.
- Constant force application.

Disadvantages

- Significant user effort to lower the skyhook.
- Allows for only short cable travel.
- Mid level expense item.

4.1.2 Threaded Rod and Coupler

Similar to the threaded rods found in most manual car jacks, a threaded rod and a coupler can be used for the current gas shock system. The threaded rod and coupler converts a rotating motion into a linear motion, such that it travels a vertical distance. Threaded rods come in varying diameters and materials depending on the amount of force needed put the object in motion. Generally, threaded rods are easy to manufacture and are readily available.

Advantages

- Simple mechanical design.
- Most inexpensive actuator.
- Minimal assembly work required
- Single Actuator system.
- Dose not require external safety mechanism.

Disadvantages

- Slow raising and lowering of the skyhook.
- Interferes with the pull-out of the skyhook.
- Takes significant torsional force to raise and lower
- Large vertical displacement of the rod above the skyhook.

4.1.3 Spring

A spring is a flexible machine element that uses elastic deformation to decelerate the rotary and linear motions. Usually in the form of a helix, springs can come in either compression or tension types. Springs can have varying stiffness and are chosen based on the type of loading and the amount of force to be exerted on the spring. Unlike the rotary damper, it does not need dampening fluid to dampen motion. To increase dampening, more springs in either parallel or series can be used to increase effect [10].

Advantages

- Inexpensive.
- Simple.
- Able to tune stiffness.
- Able to use in parallel or series.

Disadvantages

- Uncontrollable speed.
- Constant force independent of carrier load.
- Custom designed springs may increase complexity and assembly time or cost.

4.1.4 Spring and Rotary/Angular Damper

The rotary/angular damper resists motion when it is rotated in a specified direction, to acomplish this the damper uses a high viscous fluid encased in a sealed housing and uses the high visconsity fluid to resist rotating and/or angular motion. The housing can either made from metal or plastic depending on the application that it is needed for, becaus of the encased viscous fluid the damper allows smoother and accurate declaration of rotary and angular movements, unlike the gas shock. Typically the increased cost of rotary and angular dampers is from thespecial casing needed to house the viscous fluid [11].

Advantages

- Lowering and Raising the skyhook occurs in the same manner as with the current design.
- Raising the skyhook occurs without effort form the user.
- Simple mechanical design.
- Springs and Damper are inexpensive systems.
- Does not require alteration to the skyhook carrier.
- Actuator method does not interfere with other storage space.

Disadvantages

- Not a single component actuation system system.
- Large force required to lower the skyhook.
- If the rotary dampers fail the skyhook will jump up.
- Longer installation time compared to current gas shock.
- Springs creep under continues load over time.
- Springs have non constant force application.

4.1.5 Electric Motor

The basic function of an electric motor is to convert electrical energy into mechanical energy. A motor uses a stator that induces an opposing magnetic field to a rotor, which causes this rotor to rotate and produce mechanical motion. Electric motors can have adjustable speeds and are very easy to use once the electric motor is set-up. The set-up does require an electrical source and the use of a cable management system for safety [12].

Advantages

- Fast raising and lowering of the skyhook.
- Requires no user effort.
- Easy for users to operate.
- Single actuator system.

Disadvantages

- Complicated design.
- High part cost.
- Requires electricity to function.
- Breaks down easier than mechanical designs.
- Shorter life span than mechanical systems.

4.1.6 Rack and Pinion

A rack and pinion is a mechanism commonly used in steering systems for vehicles. The mechanism consists of a rack and pinion gear set that converts rotational motion in a linear motion, the difference in gear ratios can be used to increase or decrease the force necessary to move an object. Similar to a threaded rod concept as it would need an rotational input energy from the user, the required rotational input can be achived by use of a twisting rod [13].

Advantages

- Can be used with long cable travel.
- Mechanical systems only.
- Fast raising and lowering of the skyhook.

Disadvantages

- Can increase complexity of design.
- Custom pinion.
- Significant user effort to lower the skyhook.
- Longer installation time due to multiple actuator parts.

4.1.7 Hand Crank

The hand crank utilizes two perpendicular gears in order to allow for a user at ground level to operate a gear that will turn a mechanism that can allow the cable to lower or raise. This concept allows for adjusting gear ratios in order to achieve the desired resistance.

Advantages

- Mechanical system only.
- Can be used with long cable travel.
- Gear ratio is able to be refined

Disadvantages

- Increased complexity.
- May be awkward for user to operate
- additional tool required to operate crank

4.1.8 Spring Brake

The cable reel utilizes a feature called a spring break mechanism. This works by coiling a spring that clamps tightly around the shaft, of the reel to restrict its movement. The tails of the spring are turned perpendicular to the shafts surface, creating a tang on each end. When a force is applied to one side of the tang it uncoils the spring allowing rotation in that direction. Once the force is removed, the spring clamps down on the shaft once again to restrict its movement. When force is applied to the opposite tang, the spring rotates the other direction. In this way the cable can be reeled and unreeled with ease, and not unravel when no force is applied.

Advantages

- Allows for long cable travel.
- Single actuator design.
- Fast raising and lowering of the skyhook.
- Mechanical systems only.

Disadvantages

- Significant user effort to lower the skyhook.
- Custom design.
- Complex design.
- Longer manufacturing time.

4.1.9 Coiled Spring

Coiled springs or torsion springs are special type of springs that use twisting or rotary motion instead of the linear motion that is normally use by compression or tension springs. To help visualize this idea think of a garage door assembly found in most homes, this design functions in a similar manner. These torsion springs are mounted at top of the garage door, and transfers torque through a shaft and then to a cable system and converts into linear motion of the garage door. This system can similar be integrated in a Skyhook design where the user can move the bike in a linear motion from the rotational force of the torsion spring [14].

Advantages

- Able to carry heavy loads
- Long life cycle
- Controlled linear motion

Disadvantages

- Susceptible to fatigue
- Multiple parts needed
- Complicates assembly
- Expensive
- Broken coil may cause serious injury

4.2 System Concept Development

This section of the report takes the concept research and applies them to fully functional systems that are alternatives to the current skyhook design.

4.2.1 Single Member Sliding Linkage

The single arm sliding concept aims at eliminating the most amount of members to reduce the cost of material as well as manufacturing. This design consists of one member which at one end uses a roller to slide along a channel in the upper housing. At the other end of the member is the mounting point for the bike carrier, as well as the connecting point for a cable as seen in Figure 4.

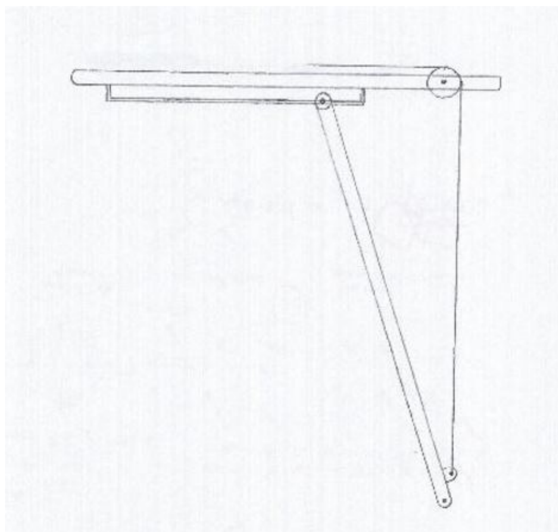


Figure 4: Sketch of the single member sliding linkage concept.

Advantages

- Low material cost
- Low manufacturing time
- Simple
- Few moving parts

Disadvantages

- Requires long cable travel
- Lateral instability
- Increased overhang in storage state
- Potentially difficult to move along slider
- 2 degrees of freedom to lock when in dispensed state

4.2.2 Single Member Pivoting Arm

The single arm pivoting member is based an the sliding single arm concept. The goal of the pivoting arm is to reduce the number of moving parts, as well as limit the degree of freedom to one when the bike is dispensed. The reduction of degrees of freedom allows for a simpler locking mechanism. Instead of a sliding channel at the top end of the single member, it is simply constrained by a bolt pivot style. Figure 5 shows the concept drawing for the single member pivoting arm concept.

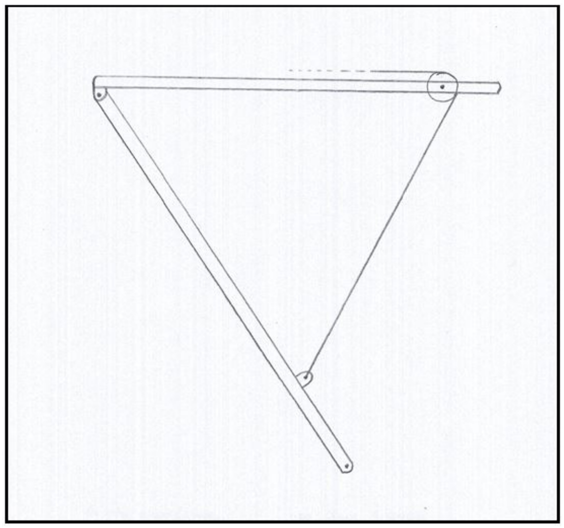


Figure 5: Sketch of the single member pivoting arm concept.

Advantages

- Low material cost
- Low manufacturing time
- Simple
- Few moving parts
- Single degree of freedom

Disadvantages

- Requires long cable travel
- Lateral instability
- Increased overhang in storage state
- Large moment to overcome due to geometry

4.2.3 Telescopic Arm

The telescopic arm concept is similar to the single member pivoting design however, it eliminates some overhang when in the storage state. This concept replaces the single member from the pivoting design with a telescoping arm. The internal mechanics of the telescoping mechanism are yet to be determined. Figure 6 shows the concept drawing for the telescopic arm concept.

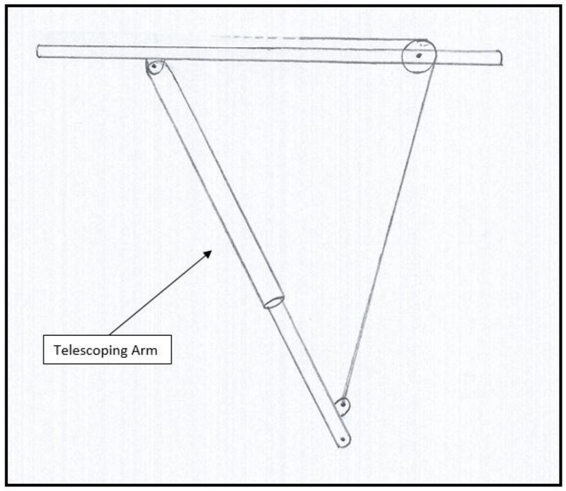


Figure 6: Sketch of the telescopic arm concept

Advantages

- Low manufacturing time
- Few moving parts
- Reduced overhang in storage state

Disadvantages

- Requires long cable travel
- Two degrees of freedom to lock when in dispensed state
- Increased complexity

4.2.4 Two Arm Folding Linkage

The two arm linkage system consists of two solid members which fold into one another. This design is aimed at reducing the number of linkage arms, and therefore cost, while maintaining a similar packaging size. This design does have two degrees of freedom, one at each of the pivots, which has potential to result in difficulty locking when dispensed. This concept does include a two part locking arm which addresses this issue. Figure 7 shows the concept drawing for the two arm folding linkage concept.

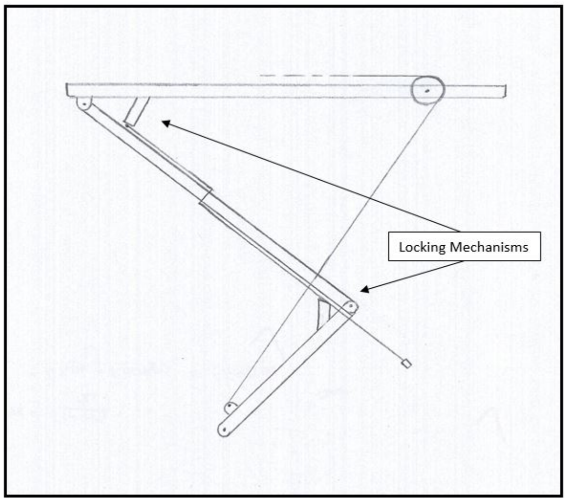


Figure 7: Sketch of the two arm linkage concept.

Advantages

- Lower manufacturing time than current design
- Few moving parts
- Similar overall size to current design

Disadvantages

- Increased load on members over current design
- Requires long cable travel
- Potential lateral instability

4.2.5 Two Arm Scissor Linkage

The two arm y-linkage system is made from two solid members, an arm slider or guide rail, and a cable and pulley system. Similar to the two arm linkage system, the design reduces linkage arms and cost. All components are attached and move in a synchronized motion and have one degree of freedom, resulting in a fluid motion when lowering or elevating the bike from the third level shelf. However the addition of the arm slider does slightly increase complexity of the design. Figure 8 shows the concept drawing for the two arm scissor linkage concept.

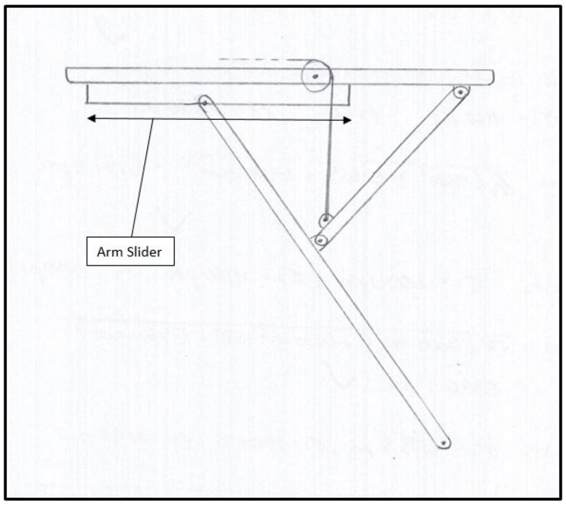


Figure 8: Sketch of the two arm Y concept.

Advantages

- Low manufacturing time as a result of simple design
- Few moving parts
- Short cable travel

Disadvantages

- Large bending moments
- Added maintenance from slider

4.2.6 Three Arm Linkage

The three arm linkage system is the current system that Vidir utilizes in the BMS Skyhook. The purpose of the third arm relative to the two arm system is to regulate the path of the bottom member. As a result of the third arm, the path of the bottom member is a function of the angle of the top members. This design results in a single degree of freedom and therefore has a simple locking mechanism. Figure 9 shows the concept drawing for the three arm linkage concept

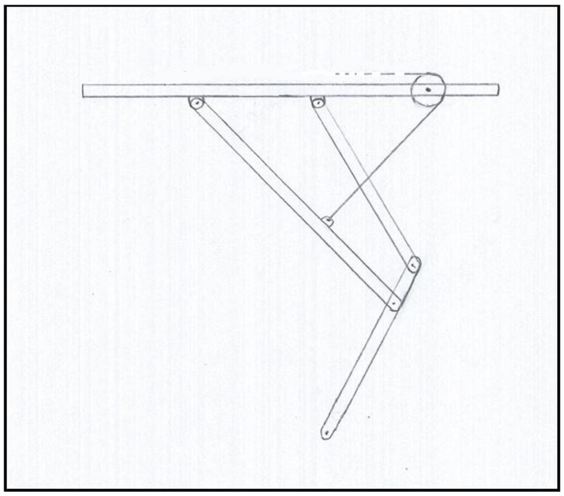


Figure 9: Sketch of the three arm linkage concept.

Advantages

- Proven mechanism
- Single degree of freedom
- Fits in the existing space
- Sort cable travel
- Laterally stable

Disadvantages

- High material cost
- High manufacturing time
- High level of complexity

4.2.7 Three Arm Sliding Linkage

The three arm sliding linkage is similar to the current three arm design, but includes a sliding channel on one of the linkage arms which allows the cable mount to slide along the supporting member. The aim of this system is to refine the sliding of the support such that the constant force from the cable can create a variable moment based on the movement of the slider position along the arm. This design has potential to either vary the slider position as the system is lowered to create varying resistance, or to allow a two to three set positions that the operator can change based on the load of the carrier. Figure 10 shows the concept drawing for the three arm sliding linkage concept.

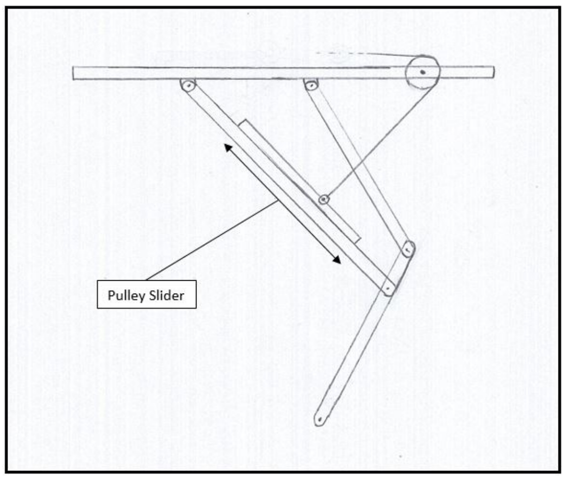


Figure 10: Sketch of the three arm sliding linkage concept.

Advantages

- Single degree of freedom
- Fits in the existing space
- Short cable travel
- Laterally stable
- Variable resistance

Disadvantages

- High material cost
- High manufacturing time
- High level of complexity
- Increased number of parts

5 Concept Analysis and Selection

The purpose of this section is to evaluate the suitability of the designs explored in the concept development section, the concepts advantages and disadvantages are measured in a ranked matrix against the customer needs and objectives. From the screening process, the top three choices are presented to the customer for their approval, from which the customer chooses their preferred design which will advance to phase three, the detailed design analysis. The concepts are rated for the metrics in Table VII below.

Table VII: NEEDS AND WEIGHTINGS

Need	Rank	Weight
Cost	1	0.4
Ease of Manufacture	2	0.2
Ease of Use	3	0.15
Complexity	4	0.1
Reliability	5	0.05
Durability	6	0.05
Safety	7	0.05

This screening will ensure the three designs that meet the customer's needs are chosen for the customer to select from.

5.1 Gas Shock Alternative Screening

After taking all design options into consideration, the team weighed the advantages and disadvantages of all designs and matched them up against one another. The main criteria brought into consideration in the selection of our top designs stem from the client's main constraints and limitations.

1. A viable design must be able to be manufactured using the client's current equipment, which increases the ease of manufacturing.
2. A viable design must fit within the current footprint of the entire BMS system assembly. In addition, it is import that the bike does not overhang any more than the current Skyhook allows.
3. A viable design must not exceed the current price point, and if possible have a lower manufacturing cost.

To establish a baseline reference for the gas shock alternative, the gas shock is evaluated in Table VIII with assigned rating ranges from one to five. Five is the highest attainable rating and one is the lowest attainable rating.

Table VIII: GAS SHOCK SCREENING BASE LINE

Need	Rating	Weight	Score
Cost	5	0.4	2.0
Ease of Manufacture	3	0.2	0.6
Ease of Use	3	0.15	0.45
Complexity	4	0.1	0.4
Reliability	5	0.05	0.25
Durability	4	0.05	0.2
Safety	4	0.05	0.2
-	-	-	-
Total	-	-	4.1

The first step is to eliminate any designs pertaining to the mechanical linkage system that would not function as required to be compatible with the BMS. These include interference with other bicycle storage below, to the left or right, and the lowering motion must be directly perpendicular through out the lowering process to the main beam.

5.1.1 Threaded Rod

The threaded rod focused on sacrificing a slight amount of usability for a low cost. In many ways, there were multiple linkage designs which could be operated by a threaded rod configuration. After inspecting the BMS units in Wal-Mart which had bikes loaded on them, a clear issue arose. The problem is that there was no ideal location to place the threaded rod that would not have physical interference with the bike. Also, the threaded rod requires a long length to raise and lower a bicycle. Table IX shows the metric scores for the threaded rod.

Table IX: THREADED ROD SCREENING

Need	Rating	Weight	Score
Cost	4	0.4	1.6
Ease of Manufacture	5	0.2	1.0
Ease of Use	2	0.15	0.3
Complexity	5	0.1	0.5
Reliability	4	0.05	0.2
Durability	4	0.05	0.2
Safety	3	0.05	0.15
-	-	-	-
Total	-	-	3.95

5.1.2 Spring and Angular Damper

After completing the cost analysis on potential alternatives to a gas shock design, the team came to realize that two stand-alone dampers is needed for the spring and damper concept to meet performance specification. Table X shows the metric score for the spring and damper.

Table X: SPRING AND ANGULAR DAMPER SCREENING

Need	Rating	Weight	Score
Cost	4	0.4	1.6
Ease of Manufacture	4	0.2	0.8
Ease of Use	3	0.15	0.45
Complexity	3	0.1	0.3
Reliability	3	0.05	0.15
Durability	3	0.05	0.15
Safety	3	0.05	0.15
-	-	-	-
Total	-	-	3.6

Overall, it would far exceed the price point of the current system being used: a simple pneumatic gas shock. This design would be unnecessarily expensive.

5.1.3 Spring and Rotary Damper

The spring and rotary damper was deemed not viable for the same reasons as the spring and angular damper

5.1.4 Electric Motor

Despite the effectiveness of the electric motor, due to the expensive nature of a fully electric system to raise and lower the Skyhook, this design was deemed unsuitable. Electronic operation has reliability uncertainties, such when a power failure occurs, this can lead to safety hazards such as the bicycle in storage falling to the floor. Such failures can remain under control more confidently with a purely mechanical system. Table XI shows the metric score for the electric motor.

Table XI: ELECTRIC MOTOR SCREENING

Need	Rating	Weight	Score
Cost	1	0.4	0.4
Ease of Manufacture	1	0.2	0.2
Ease of Use	5	0.15	0.75
Complexity	1	0.1	0.1
Reliability	3	0.05	0.15
Durability	3	0.05	0.15
Safety	2	0.05	0.1
-	-	-	-
Total	-	-	1.85

For these reasons the electric design was deemed not-viable.

5.1.5 Rack and Pinion

The rack and pinion is able to provide increased travel for a given motion assist design. While there are expensive options available, it is also possible to manufacture a system using laser cut sheet metal. Table XII shows the metric score for the rack and pinion design.

Table XII: RACK AND PINION SCREENING

Need	Rating	Weight	Score
Cost	2	0.4	0.8
Ease of Manufacture	3	0.2	0.6
Ease of Use	3	0.15	0.45
Complexity	3	0.1	0.3
Reliability	3	0.05	0.15
Durability	3	0.05	0.15
Safety	3	0.05	0.15
-	-	-	-
Total	-	-	2.6

However, the manufacturing time and time to install the system would exceed that of the current gas shock, thus violating one of the customer needs and objectives. Therefore this design was deemed unsuitable.

5.1.6 Hand Crank

The hand crank is appropriate for long and short travel cable retraction. Table XIII shows the metric score for the hand crank design.

Table XIII: HAND CRANK SCREENING

Need	Rating	Weight	Score
Cost	3	0.4	1.2
Ease of Manufacture	3	0.2	0.6
Ease of Use	2	0.15	0.3
Complexity	3	0.1	0.3
Reliability	3	0.05	0.15
Durability	3	0.05	0.15
Safety	3	0.05	0.15
-	-	-	-
Total	-	-	2.55

This concept faces similar issues to the threaded rod linkage design. The problem is there is minimal space to place the gear reel, such that there is no contact interference with the bicycle. The extension arm which is required to operate the hand crank mounted to the skyhook would have to be large and its operation would be awkward. The design would take longer and was deemed to be more effort than the current Vidir design, violating the a customer objective. For the stated reasons this option was deemed unsuitable.

5.1.7 Spring Brake

This design is appropriate for long and short travel cable retraction. Table XIV shows the metric score for the spring break design.

Table XIV: SPRING BREAK SCREENING

Need	Rating	Weight	Score
Cost	3	0.4	1.2
Ease of Manufacture	2	0.2	0.4
Ease of Use	3	0.15	0.45
Complexity	2	0.1	0.2
Reliability	3	0.05	0.15
Durability	3	0.05	0.15
Safety	3	0.05	0.15
-	-	-	-
Total	-	-	2.7

This concept has the same issues as the hand crank. Mounting locations are minimal, the design is complex, and the usability is low making the design is unsuitable.

5.1.8 Coil Spring Pulley

This design is appropriate for long and short travel cable retraction.Table XV shows the metric score for the coil spring pulley design.

Table XV: COIL SPRING PULLEY SCREENING

Need	Rating	Weight	Score
Cost	2	0.4	0.8
Ease of Manufacture	2	0.2	0.4
Ease of Use	3	0.15	0.45
Complexity	2	0.1	0.2
Reliability	3	0.05	0.15
Durability	3	0.05	0.15
Safety	3	0.05	0.15
-	-	-	-
Total	-	-	2.3

The major issue this design presents is its bulky nature and high price point. In order to achieve the reeling strength required to lift the bike, the coil springs would extend far outside the current Skyhook footprint giving it a bulky aesthetic. Gauging the approximate price of this reel design confirmed its extreme expense. For those reasons this option is not viable.

5.1.9 Conclusion and final design selection

The concept design is to continue to use the gas shock system, it was found to be the most functional and sound design as it has the highest total score of any system evaluated. The table below shows the results of all gas shock alternatives are shown in table XVI

Table XVI: GAS SHOCK ALTERNATIVES SCREENING SUMMARY

Gas Shock Alternatives	Total Score	Rank
Gas Sock Reference	4.1	1
Threaded Rod	3.95	2
Spring and Angular Damper	3.6	3
Spring And Rotary Damper	3.6	3
spring Break	2.7	5
Rack and Pinion	2.6	6
Hand Crank	2.55	7
Coil Spring Pulley	2.3	8
Electric Motor	1.85	9

The supporting research in Table III shows it is the most cost effective design, since the most important metric for our customer is the price, we can only conclude in favor of the gas shock design.

5.2 Mechanical System Screening

This section explores the suitability of the mechanical linkage system used for raising and lowering the skyhook, the design must lower and raise the bicycle within the current footprint of the BMS.

5.2.1 Single Member Sliding Linkage

The sliding arm design can accommodate a long or short reel mechanism. This design would have a tendency to swing from side to side. It is a low cost alternative to the current Skyhook system. This design is viable.

5.2.2 Single Member Pivoting Arm

This design promotes extreme ease of manufacturing and simplicity. Although, in order to make a single arm be able to retract the bike to a proper height when lowered, it will not be able to maintain the bike within the BMS footprint when in the storage position. Due to overhang the bike would encounter in the storage position, this design does not meet the constraints held by the client.

5.2.3 Telescopic Arm

This linkage design must be paired with the rack and pinion long travel cable mechanism. This is due to its long telescoping arm requiring the cable mounting point to be at the end in order to fully retract the arm in storage state. The design could potentially cause difficulty in manufacturing, and still requires two long members. This design is viable, but not cost effective.

5.2.4 Two Arm Folding Linkage

This design has an average complexity and would need to utilize the rack and pinion long travel cable mechanism. This design is not suitable due to the expensive and complex rack and pinion reel design paired with a linkage assembly which does not offer a significant amount of cost reduction.

5.2.5 Two Arm Scissor Linkage

This design is able to cut costs because it only requires a short cable pull, and is accommodating to the gas shock design. In addition, the system only has two linkage arms, instead of the current three arm system. In this design the second shorter arm helps stabilize the linkage assembly. This design is highly suitable.

5.2.6 Three Arm Linkage

The three arm linkage is the current design that Vidir uses. The design is viable as it has been tested extensively in stores. In order to meet the customer need of reducing costs, exploring potential manufacturing improvements through DFMA analysis to reduce time and cost are considered.

5.2.7 Three Arm Sliding Linkage

The main objective of this concept is to be able to calibrate the moment force on the arm (due to the cable) according to the presence, or absence of a bike. In this way a damper would be less necessary. Issues develop when trying to move the pulley across the slider. In most cases this would require too much force for most people to exert. In addition, the slider would be elevated too high and would require a stool to reach. For the above reasons the design was deemed unsuitable.

5.3 Concept Screening Summary

Through evaluation of the set of linkage assemblies designs, as well as the compatibility of the gas shock alternative systems, three design combinations became clear contenders for the final design.

At first glance, the telescopic arm and two arm folding designs is innovative, but after further evaluations, the price savings of the linkage assembly could not justify the high price and complexity of the long travel cable rack and pinion design. This left the last two options: The sliding arm design, and the two arm scissor design. Both these designs can be operated using a short cable pull system in order to accommodate the low price gas shock. In addition, the sliding arm design uses a single linkage, and the two arm scissor uses two linkages. This can save cost in materials, manufacturing time, and design complexity. The third option is to keep the current skyhook design. The team will analyse Vidir's current skyhook design in order to eliminate complex manufacturing operations, decrease assembly time, welding operations, total number of parts in the assembly, and overall save costs. In summary, the three choices designs are:

1. Two arm scissor with gas shock design
2. Single sliding arm with gas shock design
3. Manufacturing redesign of the current skyhook

5.4 Concept Scoring

Next the three combined concepts were evaluated in a weighted matrix to determine the relative priorities of the designs.

Table XVII: SCORING OF COMPLETE CONCEPTS

		Single Member Sliding Arm		Two Arm Scissor Linkage		Three Arm Linkage	
Selection Criteria	Weight	Rating	Score	Rating	Score	Rating	Score
Cost	0.4	4	1.6	3.5	1.4	3	1.2
Ease of Manufacture	0.2	4	0.8	3.5	0.7	3	0.6
Ease of Use	0.15	2.5	0.375	3	0.45	3	0.45
Complexity	0.1	4	0.4	3.5	0.35	3	0.3
Durability	0.05	3	0.15	3	0.15	3	0.15
Reliability	0.05	3	0.15	3	0.15	3	0.15
Safety	0.05	2	0.1	2.5	0.125	3	0.15
Total Score		3.575		3.325		3	
Rank		1		2		3	

Based on the findings of Table XVII, the single member sliding arm is the optimal candidate for further analysis. The numbers obtained from the scoring matrix, can however, be deceiving. The three concepts resulted in total scores within half a point of each other. Therefore they are all feasible candidates for further design analysis.

5.4.1 House of Quality

The House of Quality on the next page compares the engineering characteristics of the design to the customer requirements and compares them to each other, as such they show the relationship between each requirement and characteristic. The House of Quality also compares the relative weight between customer needs and engineering characteristics, the full designs are also considered and are shown in a path diagram how they compare to each other for each customer requirement. [15]

Figure 11: House of Quality.

5.5 Concept Development Summary

The concept development considers various alternatives to the gas shock system, linkage arm design and overall design of the skyhook component. The concept designs are evaluated against the customer needs and objectives, of which the most important need was the price of the Skyhook redesign and secondly the customer wants a design that is easier to manufacture than the current skyhook design. These are the two highest priority needs as identified by the customer.

The concept development and cost analysis for the alternatives to the gas shock system shows, there is no alternative system that has a lower price point. Therefore the team concluds the gas shock system shall be used for the successful concepts.

The concept development and cost analysis for materials clearly show that steel is the material of choice as it has the lowest price point of any considered material.

The evaluation and analysis of design concepts showed the three best design concepts are:

- Improve ease of manufacturing and assembly for the current skyhook design.
- New design for sliding arm and gas shock.
- New design for two arm scissor and gas shock.

Of the three designs the sliding arm and gas shock are considered to be the most cost effective design, followed by the two arm and gas shock design, followed by the improved manufacturing methodology for the current skyhook design.

6 Final Skyhook Concept Selection

To reiterate the results from the concept screening and concept scoring sections, the three design concepts that were chosen are the following:

1. Two Arm Scissor with Gas Shock Design
2. Single Sliding Arm with Gas Shock Design
3. Manufacturing Redesign of the Current Skyhook

To select the final concept design for optimization, a meeting with Vidir was held on November 4, 2016 at the Vidir Machine Inc. Teulon facility.

During the meeting, the team presented the three best concept designs for the Skyhook redesign. Each design choice was explained thoroughly, along with the advantages and disadvantages of each design. After careful consideration from Vidir and the team, the option of performing a Manufacturing Redesign of the Current Skyhook is selected for the final design phase. As a result, Vidir and team 24 have reached an agreement to keep the overall design similar to the original to maintain compatibility with the current BMS rack and also avoid dimensioning problems that could impact the first two levels of the of the BMS rack.

At this final phase of the project, the team will focus on manufacturing and assembly improvements to the current skyhook. The deliverables of final phase of this project includes includes a 3D SolidWorks model of the new designed Skyhook with manufacturing optimizations, a cost analysis outlining possible savings of using the new design of the Skyhook, recommendations for manufacturing and assembly processes and a list of tools that are needed to product the newly designed Skyhook.

7 Research and Analysis for Manufacturing Redesign of the Skyhook

7.1 Manufacturing Improvements Idea Generation

The first step to optimizing the Skyhook is generating ideas that can result in increasing the ease of manufacturing and assembly process. The ideas generated can range from methods to decrease cost, decrease assembly/manufacturing time, and/or increase in functionality. To generate ideas, the team completed multiple brainstorm activities to produce ideas for manufacturing and assembly improvements of current Skyhook. In addition, Vidir previously mentioned areas of the Skyhook that could benefit from a redesign or improvements. These areas involved the crimping process of the cables and the method to mount the pneumatic cylinder. Furthermore, to obtain a better visualization of the Skyhook assembly and motion, the team disassembled an actual Skyhook during brainstorm for analytic purposes. The outcome of these brainstorms result in the following list of possible improvements and optimizations that can be performed on the current Skyhook:

- Use a special tool or jig/fixture to ease the crimping process
- Redesign latching component of Skyhook to provide me accurate latching
- Design special tool or jig/fixture to ease pneumatic cylinder mounting
- Reverse cylinder orientation to allow decrease in space or gap within the main beam of the Skyhook
- Reducing/thinning material at areas where large amounts of material or thickness are not needed.
- Use of pulleys without bearings
- Redesign the main beam to reduce welding/assembly and increase ease of manufacturability of the part
- Shrink/decrease width main beam/channel to reduce sheet metal used
- Reduce current amount of weldings being used by redesigning welded components
- Redesign to reduce overall amount of components needed for Skyhook, as a result reducing assembly time
- Use integrated tabs on the main beam instead of welded or separate tabs
- Use of screws and bolts instead of weldments
- Redesign three-arm linkages for increase manufacturability

To illustrate the ideas that were generated during the multiple brainstorming activities, the following figure displays a top view and side view of the current skyhook with each component labelled with the corresponding idea of improvement.

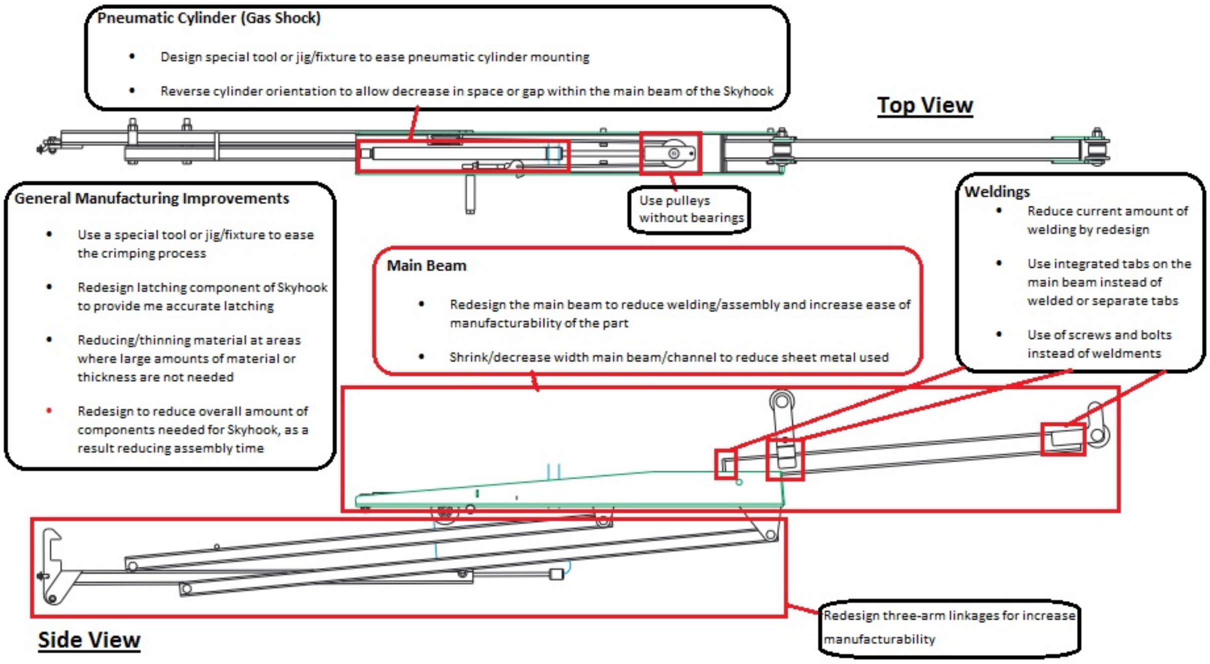


Figure 12: A skyhook top view and side view drawing with brainstorm idea detail for each corresponding component

7.2 Screening of Design Optimization Ideas

In order to filter the brainstorm optimization ideas, each idea is analyse using the following table. The table is meant to assess the benefit of implementation and more importantly, the issues that could pose difficulty with implementation of the idea. Once the analysis is complete, each idea is given a verdict. Depending on the verdict, the proposed idea will result in a type of action. The action for each verdict is as explained below:

1. **Consider** - The proposed idea will be implemented in the final redesign of the Skyhook for manufacturing optimization.
2. **Do not consider** The proposed idea will not be implemented in final design.
3. **Research** The proposed idea will be considered in the final design but implementation may be out of scope.

Table XVIII: Brainstorm Screening

Brainstorm Idea	Benefit of Implementation	Issue	Verdict
Use a special tool or jig/fixture to ease the crimping process	• Decrease overall assembly time	• Need to know if tool is available for purchase or a custom one needs to be made	Research
Redesign latching component of Skyhook to provide me accurate latching	• Prevents incorrect latching of Skyhook	• Does not increase overall efficiency of manufacturing or assembly process. • Redesign could cause increase complexity of Skyhook	Do not consider
Reverse cylinder orientation to allow decrease in space or gap within the main beam of the Skyhook	• Less material needed to accommodate parts. • Reduced material cost	• Reversing orientation is not possible with internal assembly of the Skyhook	Do not consider
Redesign three-arm linkages for increase manufacturability	• Decrease assembly time • Decrease material in each arm to reduce material cost	• Redesign could cause compatibility issues with BMS • Time consuming, as three parts need to be considered	Do not consider
Use of screws and bolts instead of weldments	• Decrease assembly time and worker with welding training.	• Adds cost of screws and bolts • Extra manufacturing cost from production of holes for screws and bolts.	Do not consider
Use integrated tabs on the main beam instead of welded or separate tabs	• Reduces weldments • Decrease in welding material cost and equipment wear	• Redesign of the main be performed to implement integrated tabs	Consider
Redesign to reduce overall number of components needed for Skyhook	• Reduction in assembly time	• A redesign of the Skyhook would be needed to reduce overall number of components	Consider
Design special tool or jig/fixture to ease pneumatic cylinder mounting	• Decrease overall assembly time	• Need to know if tool is available for purchase or a custom one needs to be made.	Research
Reducing/thinning material at areas where large amounts of material or thickness are not needed	• Reduce overall cost of manufacturing a Skyhook	• Thinning out certain structures could compromise structural stability of the system • Reduction of material could cause reduction in design life	Do not consider
Use of pulleys without bearings	• Reduce material cost for manufacturing a Skyhook	• Use of pulley without bearings could cause decrease in life and/or compromise the system	Do no consider
Redesign the main beam to reduce welding/assembly and increase ease of manufacturability of the part	• **Decrease overall assembly time** • **Decrease material cost** • **Decrease manufacturing cost**	• **FEA and redesign of the main is required**	**Consider**
Shrink/decrease width of main beam/channel to reduce sheet metal used	• Decrease material cost for manufacturing a Skyhook	• Redesign of main beam will be needed • Rearrangement of components in main beam is needed	Consider
Reduce current amount of welding's being used by redesigning welded components	• Reduces weldments and therefore reducing assembly cost. • Decrease in welding material cost and equipment wear	• A redesign to combine certain component into a single component is needed	Consider

The results of the tables show that five ideas will be implemented in the redesign of the Skyhook and two ideas need to be considered but may be out of scope of the project. Corresponding to the results of the brainstorm screening, an observation from the table can be made that the idea of redesigning the main beam will result in the implementation of the other brainstormed ideas. Therefore, a redesign of the main beam will have the possibility of:

1. Reducing the current amount of weldings being.
2. Decreasing the width of main beam/channel to reduce sheet metal material used for manufacturing.
3. Reducing overall number of components needed for Skyhook, as a result reducing assembly time.
4. Using integrated tabs on the main beam instead of welded or separate tabs.

In addition to the main beam redesign, the following proposed ideas will be further researched if implementation is possible or if the items are out of the scope of the project.

1. Use a special tool or jig/fixture to ease the crimping process
2. Design special tool or jig/fixture to ease pneumatic cylinder mounting

In the following section, designs of alternative main beams for the Skyhook is shown. Furthermore, each of the presented designs is processed through another evaluation phase that results in the selection of a final design.

8 Design Optimization of the Current Skyhook

8.1 Presentation of Design Concepts for Main Beam of the Skyhook

To incorporate each proposed idea in a redesign of the Skyhook to increase overall manufacturability, four designs are presented in the following. Each design employs the idea of reducing the amount of weldments by making the main beam one single unified piece. The single main beam also results in a reduction of the overall number of components needed for assembly.

The first design uses a single angled beam. The angle is taken directly from the angle that is found in the original Skyhook design. The middle tabs are also integrated to the beam for the purpose of reducing weldments in the main beam.

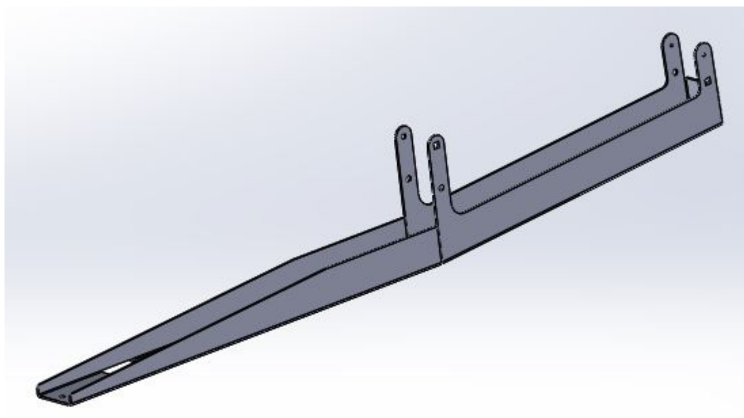


Figure 13: Angled Beam with Integrated Tabs - An angled design of the main beam with integrated middle tabs

Similarly, the second design utilizes a single angled beam taken from the original design of the Skyhook. The main difference is the middle tabs are not integrated in the beam and are a separate of tabs that are welded.

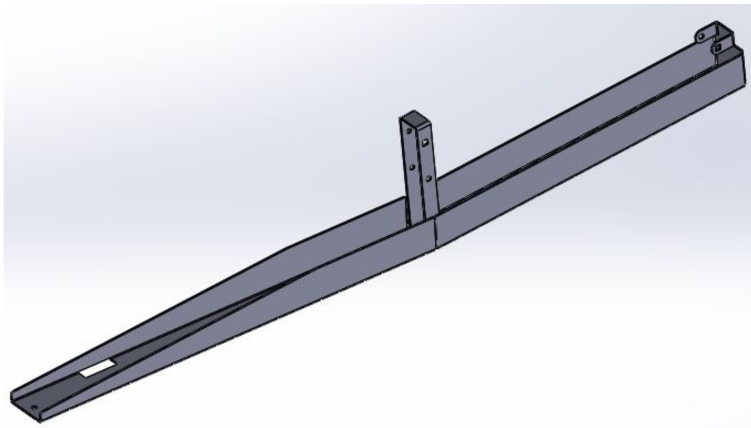


Figure 14: Angled Beam with Separate Tabs - An angled design of the main beam with separate middle tabs

The third design applies a single flat beam design to the main beam. This results in the walls of the beam becoming one consistent section with no breaks; this was originally located at the section of the bend in the angled design. The middle tabs in this design are also integrated to the body of the main, to also reduce the amount of weldments.

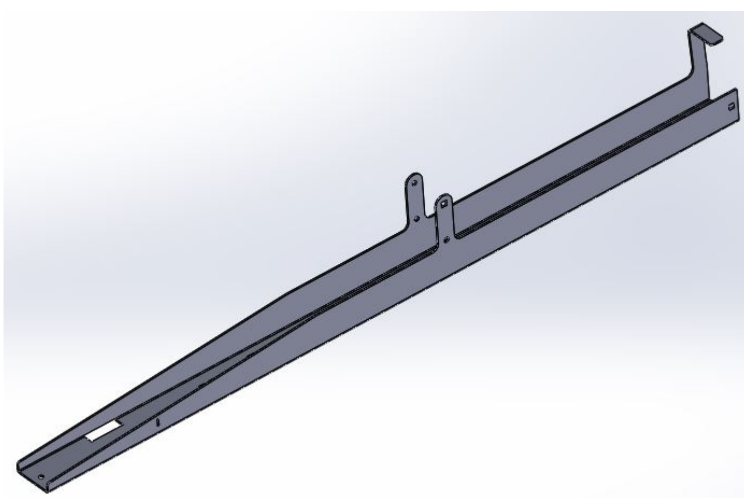


Figure 15: Flat Beam with Integrated Tabs - A flat design of the main beam with integrated middle tabs

Likewise, the fourth design also makes use of a single flat beam design with a consistent section of side walls. The difference as with the second design is the middle tabs are a separate entity and would need to be welded together to the body of the main beam.

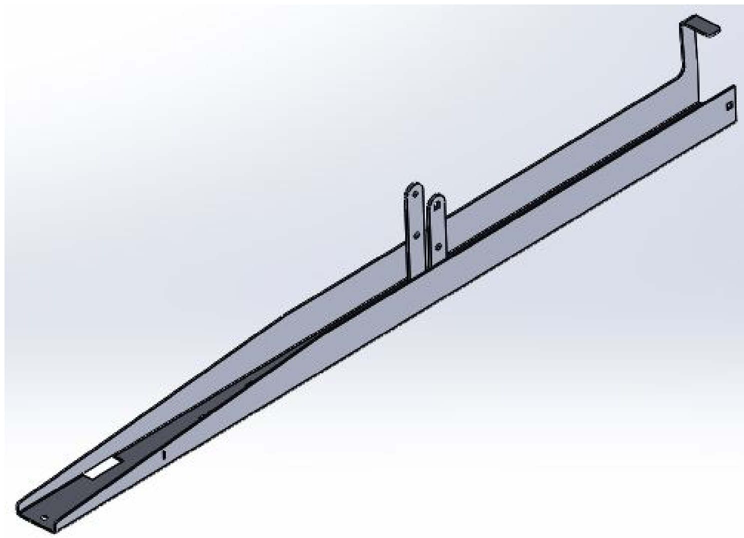


Figure 16: Flat Beam with Separate Tabs - An flat design of the main beam with separate middle tabs

In the following section, a comparison of the manufacturing and assembly method between the presented designs and the current Skyhook design is discussed. The purpose of this section is to provide insight on how each proposed design improves on the efficiency of manufacturing.

8.2 Manufacturing and Assembly Process Comparison

Reducing the cost to manufacture the Skyhook can come from two different categories; Material and manufacturing time. In this section the process to manufacture the main beam on the current Skyhook will be analyzed and compared to the process to manufacture the four new beam designs. It is important to take into account the amount of steps it takes in the manufacturing process, jigs required for assembly, amount of consumable materials used, and the number of machines necessary.

8.2.1 Current Main Beam Design from Vidir

First, a baseline will be set by analyzing the main beam on the current Skyhook produced by Vidir. The main beam comprises of two parts; the rear section which uses the square tube, and the front section using the bent sheet metal. The rear section uses 5 laser cut pieces, 3 bolts, 2 nuts, 2 reels, and 2 plastic spacers. The front section uses 6 laser cut pieces, 1 nut, 1 bolt, and a pulley. The steps and jigs to manufacture the main beam is as follows:

Manufacturing Process Current Skyhook

1. Bend main channel
2. Cut square tube to length
3. Cut angle channel to length
4. Bend rear bracket
5. Weld angle to square tube
6. Weld forward wheel arms
7. Weld rear wheel arms
8. Bold on rear guide arm
9. Assemble wheels and plastic guides
10. Weld cable hook plate
11. Weld back plate
12. Weld pulley bolt
13. Weld hook rod
14. Weld on 4 arm mount brackets
15. Weld the square member and main channel together

Jigs Required for Assembly

1. Jig to bend the main channel into its U shape
2. Jig to hold all components onto the square tube for welding
3. Jig to hold all components onto the main channel for welding
4. Jig to hold the partially assembled square member and main channel together for welding

In all, the current design for the main beam uses 23 parts, 44 inches of weld, 15 manufacturing steps, and 4 jigs.

8.2.2 Angled Beam with Integrated Tabs

The Angled Beam with Integrated Tabs design uses a single piece of laser cut sheet metal to eliminate many components. This can significantly reduce manufacturing time due to the main beam no longer having a front and back section. This design comprises of 5 laser cut parts, 3 bolts, 3 nuts, 2 wheels, 2 spacers, and a pulley. The steps and jigs to manufacture the main beam is as follows:

Angled Beam with Integrated Tabs Manufacturing Process

1. Bend main channel
2. Bend Angle in main channel and weld
3. Assemble wheels and plastic guides
4. Weld on the 4 arm mount brackets
5. Weld pulley bolt

6. Weld hook rod

Jigs Required for Assembly

1. Jig to bend the main channel into its U shape
2. Jig to line up the pulley bolt and hook rod

In all, the Angled Beam with Integrated Tabs design for the main beam uses 16 parts, 10 inches of weld, 6 manufacturing steps, and 2 jigs. A major manufacturing concern with having the tabs integrated into the main beam, is how the holes in the tabs are located after bending. The two holes in the tabs are used to mount the wheels to slide the Skyhook back and forth. In the bending process, if the main beams center line shifts at all during the bend process it will offset the holes on each side. Since the main beam is only 3 inches wide, a slight variation between the two holes will cause the wheels to be crooked and not slide in the bike rack properly. The bending operation will have to be extremely precise.

8.2.3 Flat Beam with Integrated Tabs

This design is very similar to the previous design, but it eliminates another step by keeping the channel flat. It uses the same amount of parts as the angled beam design, and the steps and jigs to manufacture the main beam is as follows:

Flat Beam with Integrated Tabs Manufacturing Process

1. Bend main channel
2. Assemble wheels and plastic guides
3. Weld on the 4 arm mount brackets
4. Weld pulley bolt
5. Weld hook rod

Jigs Required for Assembly

1. Jig to bend the main channel into its U shape
2. Jig to line up the pulley bolt and hook rod

In all, the Flat Beam with Integrated Tabs design for the main beam uses 16 parts, 4 inches of weld, 5 manufacturing steps, and 2 jigs. This design will have the same manufacturing issue as the previous design, which is keeping the wheel holes located through the bending of the main beam.

8.2.4 Angled Beam with Separate Tabs

The Angled Beam with Separate Tabs designs is a variation on the Angled and Flat Beam with Integrated Tabs. The difference is that the Tabs are no longer integrated, and are welded on separately. Using a design were the wheel mounting tabs are not integrated into main beam will add more fixtures and operations. The steps and jigs to manufacture the main beams are as follows:

Angled Beam with Separate Tabs Manufacturing Process

1. Bend main channel
2. Bend Angle in main channel and weld
3. Weld on back plate
4. Weld on rear wheel tabs
5. Weld on front wheel tabs
6. Assemble wheels and plastic guides
7. Weld on the 4 arm mount brackets
8. Weld pulley bolt
9. Weld hook rod

Jigs Required for Assembly

1. Jig to bend the main channel into its U shape
2. Jig to line up the pulley bolt and hook rod
3. Jig to line up front tabs
4. Jig to line up rear tabs

In all, the Angled Beam with Separate Tabs design for the main beam uses 21 parts, 17 inches of weld, 9 manufacturing steps, and 4 jigs.

8.2.5 Flat Beam with Separate Tabs

The Flat Beam with Separate Tabs designs is another variation on the Angled and Flat Beam with Integrated Tabs. The difference is that the Tabs are no longer integrated, and are welded on separately. The steps and jigs to manufacture the main beams are as follows:

Flat Beam with Separate Tabs Manufacturing Process

1. Bend main channel
2. Drill hole for rear wheel
3. Weld on front wheel tabs
4. Assemble wheels and plastic guides
5. Weld on the 4 arm mount brackets
6. Weld pulley bolt
7. Weld hook rod

Jigs Required for Assembly

1. Jig to bend the main channel into its U shape
2. Jig to line up the pulley bolt and hook rod
3. Jig to line up front tabs
4. Jig to line up holes for rear wheel

In all, the flat beam with separate tabs design for the main beam uses 18 parts, 6 inches of weld, 7 manufacturing steps, and 4 jigs.

8.2.6 Manufacturing Summary

Quickly comparing the four new options to the current manufacturing process for the Main Beam of the Skyhook, it is clear that the number of steps and parts can be reduced significantly. In many of the new designs the amount of manufacturing steps reduced over half, the parts necessary for assembling dropped significantly, and the amount of welding needed is reduced drastically. After closely reviewing all five designs, this is how they rank, with first being the easiest to manufacture, and fifth being the hardest to manufacture:

1. Flat Beam with Integrated Tabs
2. Angled Beam with Integrated Tabs
3. Flat Beam with Separate Tabs
4. Angled Beam with Separate Tabs
5. Current Beam Design

It is notable that the machines required to manufacture the any of the new designs do not differ from the current skyhook. No new equipment will be necessary. Although, new jigs will need to be manufactures in order to comply with the new geometries.

In the following section, the advantages and disadvantages of each of the four designs are discussed. Furthermore, each of the presented designs will be processed through a second evaluation phase that results in the selection of a final design. This evaluation phase considers a number of selection parameters that are also discussed in the next section

8.3 Design Evaluation of Design Concepts for Main Beam of the Skyhook

To determine the main beam design that will be selected for the final design, the advantages and disadvantages of the main components that differ in each design is discussed. In Table XIX, the advantages and disadvantages between a flat beam and an angled beam design are discussed. Table XX discusses the advantages and disadvantages between an integrated tab and a separate tab for the tabs located in the middle.

Table XIX: ADVANTAGES AND DISADVANTAGES OF EACH TYPE OF BEAM DESIGN FOR MAIN BEAM

Feature	Advantages	Disadvantages
Flat	- Fewer bend operations - Fewer weld operations - Maintains original carrier "storage" position - Side walls are uniform (no break)	- Possible compatible issues with BMS rack, since angle of original design is not maintained
Angled	- Maintains angle of original design	- Side walls are not uniform - Increased bend operations - Increased weld operations - Weld seam may introduce weak point in design

*note that there was no evident reason for the angle in the previous design, so this was not seen as an important feature

Table XX: ADVANTAGES AND DISADVANTAGES FOR EACH MIDDLE TAB DESIGN FOR THE MAIN BEAM

Feature	Advantages	Disadvantages
Integrated Tabs	- Eliminates weld operations for tabs - Ensures one and only one of each side is present (round and square for carriage bolt)	- Prevents members from being packed tightly on laser cut sheet. - Non 90 degree bends may result in misalignment of bolt holes (due to the length from bend, the rear holes are close to the bend line, so a the same deviation in angle will result in less misalignment in holes)
Separate Tabs	- Able to ensure tabs are parallel and will align. - Allows for tighter packing on laser cut sheet/ eliminates wasted material between cut parts	- Increased weld operations - Potential for two round tabs or 2 square tabs being installed instead of one each**

**note that poka- yoke was incorporated to ensure this

Summarizing the previous tables, the flat beam design is the optimal design over the angled beam design. Using a flat beam decreases overall complexity of the main beam and gains a number of advantages.

Although in the manufacturing summary in the previous section stated that the integrated design is the easiest to manufacturer, it adds a lot of disadvantages and misalignment issues. Therefore, using integrated tabs add complexity to the overall design of the Skyhook.

To gauge which design will be used, the four designs will be evaluated using a weighted evaluation matrix with selection parameters that the team deemed important for the final design. The selection parameters also consider the results from the manufacturing comparison and advantages and disadvantages section of each design. These selection parameters are:

1. **Material Cost**: A reduction in material can decrease overall cost of producing a Skyhook
2. **Ease of Manufacturing**: Decrease in amount and complexity manufacturing processes can lead to increase in ease of manufacturing a Skyhook
3. **Ease of Assembly**: Decrease in weldments, and amount of components to connect after manufacturing all lead to increase in ease of assembly of a Skyhook
4. **Complexity**: Extra components, complicated manufacturing processes, complex shapes, sizing and packaging issues, and incompatibility issues; these are all external factors that add to complexity of a design.
5. **Aesthetics**: The visual appeal of the design is an important factor when designing any mechanical device that is sold to the public.

Each of these selection parameters are weighted and used to evaluate each design. Furthermore, each selection factor will be given a rating out of five for each selection parameter. The rating is from one to five, with one as the lowest possible rating and five as the highest possible rating,

Table XXI: SCORING OF MAIN BEAM DESIGNS

		Bent with Integrated Tabs		Bent with Separate Tabs		Flat with Integrated Tabs		Flat with Separate Tabs	
Selection Criteria	**Weight**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Material Cost	0.35	3	1.05	5	1.75	3	1.05	5	1.75
Ease of Manufacturing	0.20	4	0.80	2	0.40	5	1.00	3	0.60
Ease of Assembly	0.20	5	1.00	3	0.60	5	1.00	3	0.60
Complexity	0.20	4	0.80	2	0.40	3	0.60	4	0.80
Aesthetics	0.05	4	0.20	3	0.15	5	0.25	4	0.25
Total Score		3.85		3.30		3.90		4.00	
Rank		3		4		2		1	

8.4 Final Design Selection for Main Beam of the Skyhook

Based on the findings of evaluation matrix, and the analysis of the advantages and disadvantage of each design, the flat beam design with separate middle tabs will be used as the final design.

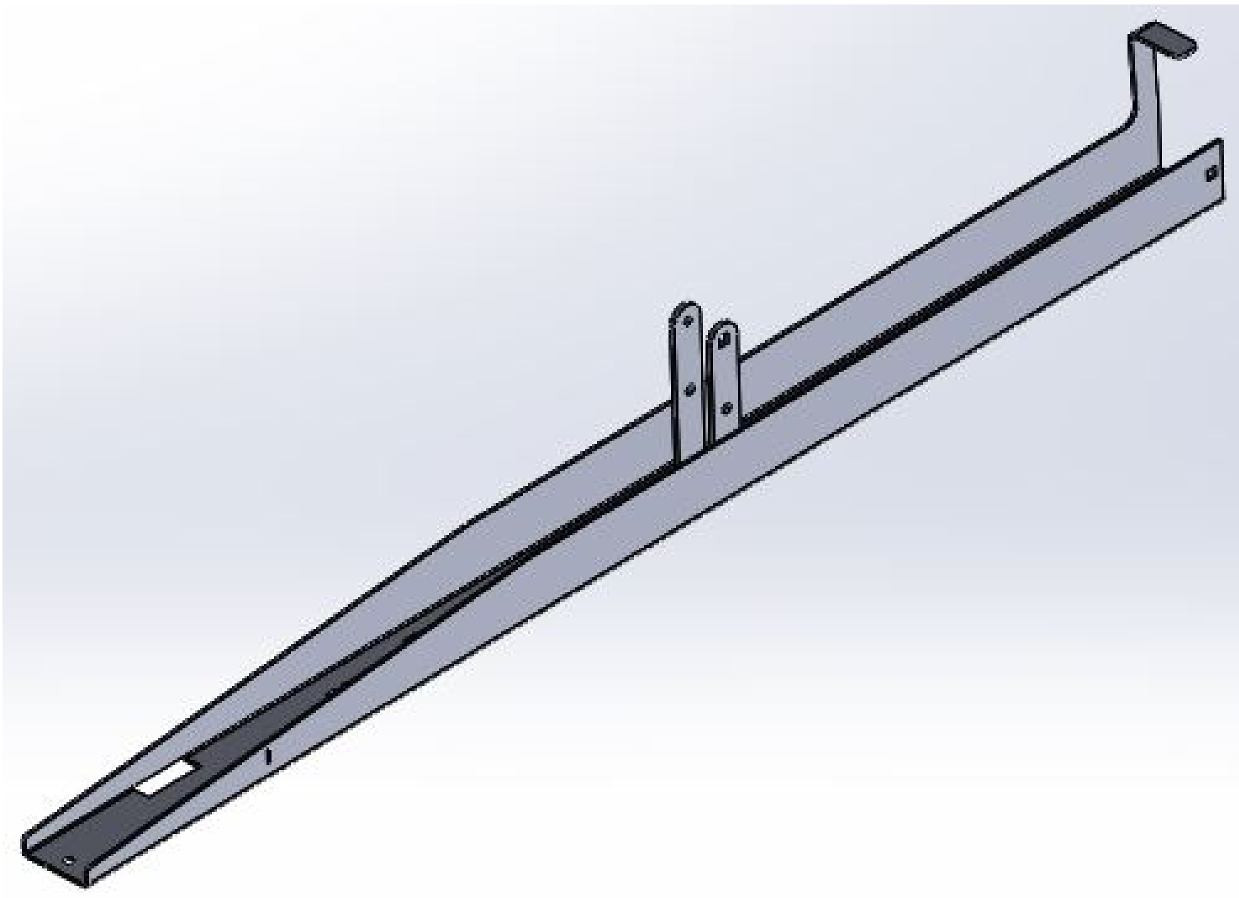


Figure 17: The final design for the main beam; The flat body with separate middle tabs.

In the next section, details of this design are discussed. Additionally, a cost savings analysis is performed the cost conserved if the redesigned Skyhook is used over the current design of the Skyhook. Any manufacturing processes that correspond to the final design are also discussed

9 Final Design and Analysis of the BMS Skyhook

This section entails the in depth analysis performed on the customer chosen concept design for the improved manufacturing redesign for the current Skyhook design.

9.1 Details of the Final Design

The final design of the skyhook has utilized several DFMA techniques to reduce complexity, and therefore manufacturing cost, while maintaining the function, form and structural integrity of the original design. As previously mentioned, the total number of components has been reduced from 23 to 18, and a total reduction of 8 processes.

The main reduction in cost ultimately comes from the design choice of utilizing one piece of sheet metal, with a minimal number of bends, in this case 3. The final design beam can be cut on a laser cutter and with three process on a hydraulic press brake. the simplicity is illustrated below in Figure 18

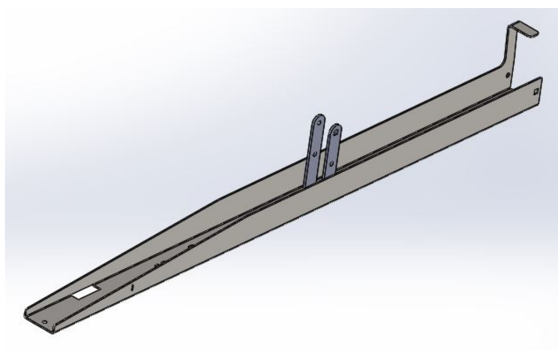


Figure 18: Final Design

As shown in Figure 18, there are two main support tabs which are not included in the single laser cut piece. The main center tabs are separate for two main reasons, the first reason is to ensure alignment of the mounting holes at the end of the tabs. were the tabs to be integrated, they would require the two 90 degree bends to be exactly 90 degrees, as well as the bends to be perfectly located. The second reason the tabs are not integrated is to increase the packing efficiency of laser cutting multiple pieces on one sheet as highlighted in section 9.5.2 on page 65 . In order to ensure the separate tabs are spaced apart properly, and located correctly along the length of the member, two holes have been included in the design to fit locating tabs, similar to the locating holes found on the bottom tabs which hold the scissor mechanism. The main tabs are similar, but not the exact same due to one tab requiring a square cut out for a carriage bolt, as shown below in Figure 19.

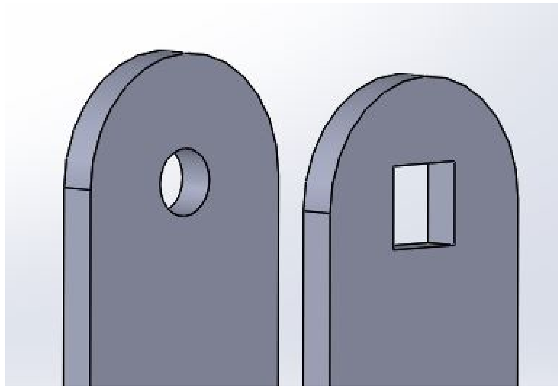


Figure 19: Main tab comparison

Due to the differences in the two main mounting tabs, as opposed to the lower mounting tabs which are the same tab, it is important to ensure that one, and only one of each side are installed. In order to ensure one of each side are installed, a poka-yoke design approach was used as illustrated below in Figure 20.

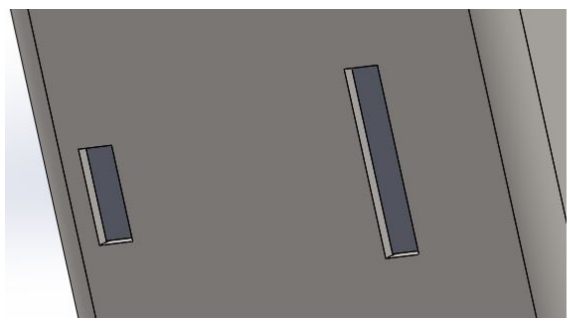


Figure 20: Poka-yoke design

The concern being addressed by the poka-yoke feature is not that the tabs might be on the wrong sides, but instead that the same tab would be installed on both sides. In the case of both the round tabs being installed, the carriage bolt would not sit properly, and therefore not work. In the case of both square sides being installed, there would be increased slip resulting in increased wear on the mounting tab. In either of these cases there is needed rework, which results in increased unnecessary cost.

The rear end of the beam also has a square and round hole for a carriage bolt. While there is still some concern of alignment due to bends not being exactly 90 degrees, because the hole location is closer to the bent corner, a small deviation in degree will result in a negligible difference in alignment. There is still a concern that if the bends are not spaced accurately, then the holes will not line up with each other though, so it is for this reason that the square hole will be laser cut in order to define the correct location, and as it is difficult to drill a square hole. the integrated rear tabs is illustrated below in Figure 21.

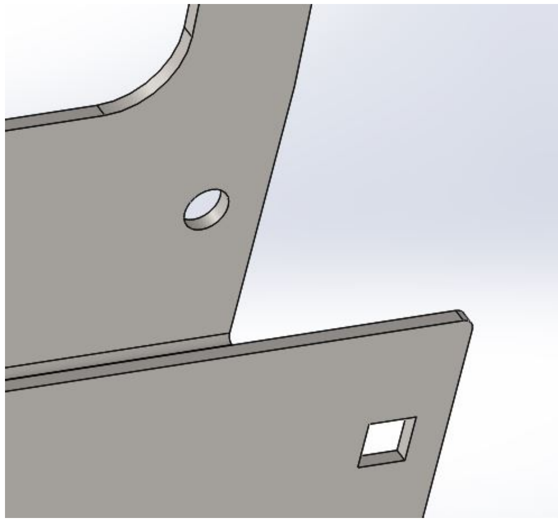


Figure 21: Rear tab bolt holes

As previously mentioned, one of the main issues with assembling the skyhook was the installation of the gas shock. In the original design, the top U-channel was much shorter and hard to install the shock into. With the new design, the top U-channel is completely open allowing easier installation of the gas shock.

While there are two separate tabs in the middle of the beam, the rear section has seen a reduction from three external tabs to zero external tabs with the external features being incorporated into the main beam, this improvement is illustrated by the two following figures.

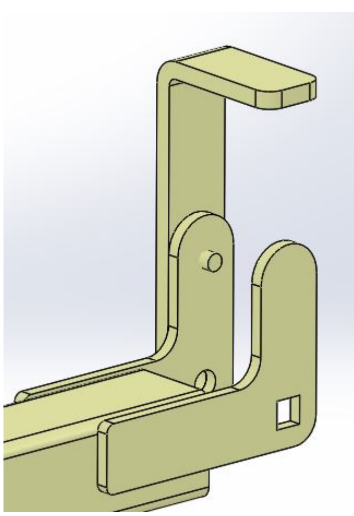


Figure 22: Original rear tab design

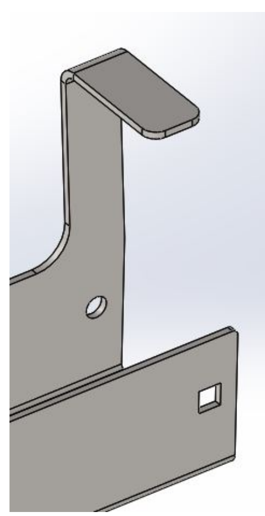


Figure 23: Final rear tab design

One notable difference between the previous design and the final design presented is the elimination of a 3 degree angle at the mid point along the top member of the beam. The new design does not have an angle, and instead is just a flat channel. The bend in the original design was small and did not seem to serve a useful function, however in order to ensure the carrier did not interfere with the middle rack while in the storage state, the original design assembly was rotated about the pin where the carrier connects to the linkage arms, and the new design was built around the rotated assembly.

The final design is illustrated below as incorporated in the display rack, as well as with the linkage mechanism installed as well.

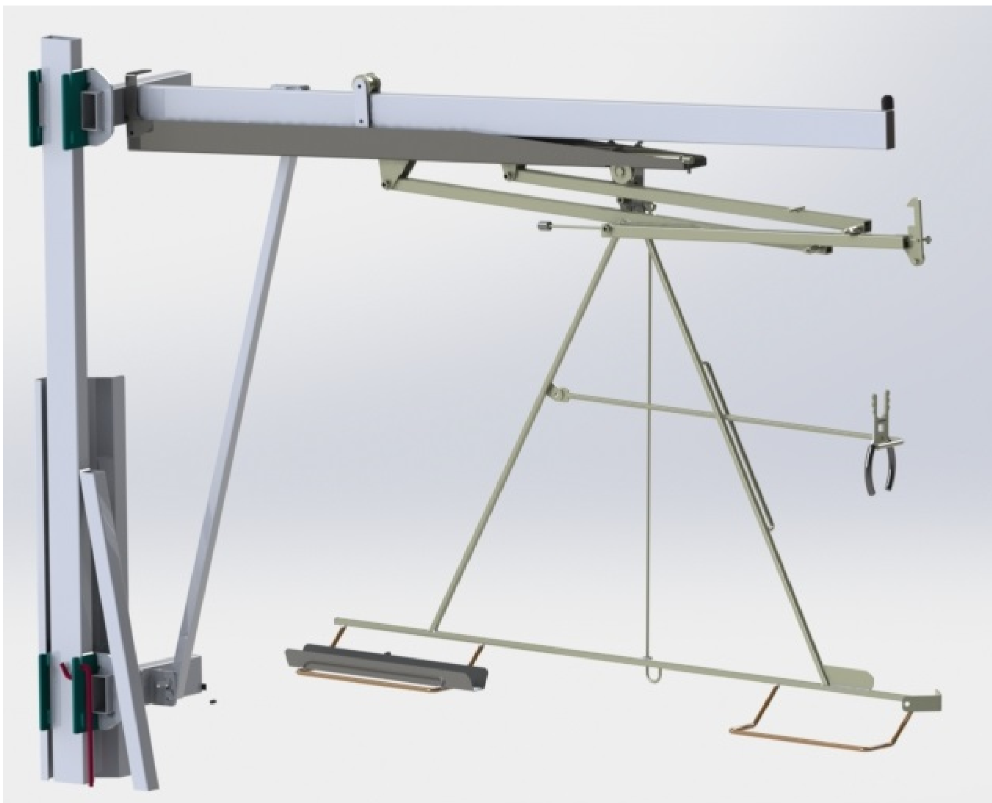


Figure 24: Final render of complete design

To ensure that the design chosen for the Skyhook meets stress requirements of the current Skyhook, an Finite Element Analysis (FEA) will be conducted on the redesign and the current design of the Skyhook. The following section outlines the parameters that need to be provided in order to perform this FEA.

9.2 Loading Parameters for FEA Testing

9.2.1 Analytical Evaluation

In order to perform FEA testing on the redesigned Sky Hook components, it was essential to choose a proper force to apply to the structure. The team decided to determine this load both analytically and through physical testing to find the maximum load in order to operate the Skyhook.

The gas shock which is currently incorporated into the Sky Hook is rated for a force of 1150N. As shown in Figure 25 the cable is fixed on one end and is routed around a pulley which is attached to the gas shock.

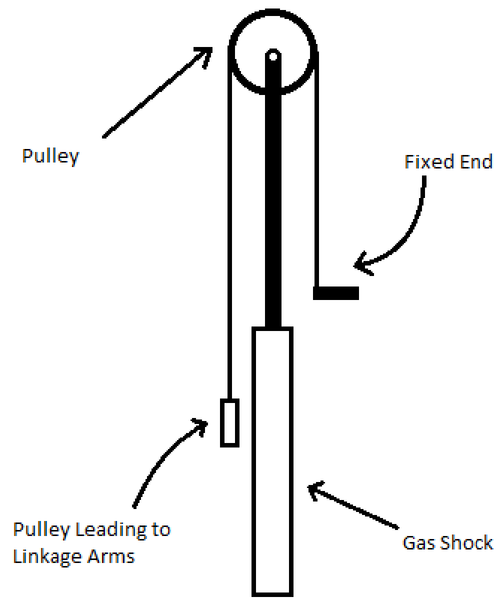


Figure 25: Gas Shock Cable System

The cable then is routed around a second pulley, and then attached to the linkage arm used pull the assembly down. This cable configuration reduces the force of the gas shock by a factor of 2. The following equations provides the resultant forces:

$$\sum F = T_2 + T_1 - F = 0 \tag{1}$$

Therefore, since $T_2 = T_1$

$$T_1 = \frac{F}{2} = \frac{1150\ N}{2} = 575\ N \tag{2}$$

Converting Newtons to applied weight,

$$575\ N\ \times\ \frac{1}{9.81\ \frac{N}{Kg}} = 58.6\ Kg = 130\ lbs \tag{3}$$

9.2.2 Physical Testing Evaluation

In order to physically test the force on the upper beam when lowering the Skyhook, the team placed a bathroom scale directly underneath the Skyhook. The team then attached the metal rod (the device used to pull down the Skyhook down) to a point on the Skyhook right next the location that the cable attaches to the linkage arm. A member of the team stood on the scale and pulled the Skyhook down slightly. While holding steady, we recorded a change in weight of 120 lbs or approximately 533 Newton's. Comparing this value to the theoretical value we obtain 7.88 percent difference which is acceptable.

After determining the load needed to operate the Skyhook analytically and through physical testing, the team realized an issue. Since the operation of the Skyhook is by Walmart employees, not all pull strengths will be the same. It can be assumed that some employees will be pulling the Skyhook down much faster than others. What this means, is that the maximum stress occurring in the system will be higher than the load to simply operate it due to the dynamic loading scenario.

In order to test the dynamic load, a member of the group once again stood on a scale and pulled down on the Skyhook. Multiple trials were conducted where the Skyhook was pulled down with various velocities. After multiple tests, the maximum change in weight seen on the scale was 140 lbs. This converts to a force of 623 Newton's.

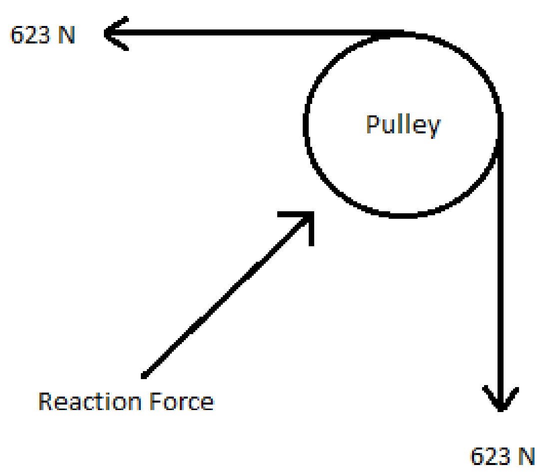


Figure 26: Pulley Free Body Diagram

Figure 26is the free body diagram which occurs at the pulley leading to the linkage arms. 623 N was recorded in the vertical direction when pulling down on the on the cable. Likewise, 623 N will also be present in the horizontal portion of the cable. Adding these two vectors up, the total load on the pulley is:

$$Reaction\ Force = \sqrt{623^2 + 623^2} = 881\ N \tag{4}$$

The forced used to test the Skyhook in Solidworks FEA will be 881 N applied at 45 degrees.

9.3 FEA Analysis of Current and Redesigned Skyhook

At this point in the analysis, Finite Element Analysis, or FEA will be performed to compare stress values and distributions between Vidirs current proven design, and the new flat piece design. Because Solidworks is effective at presenting stress behaviour, but not the most reliable for numerical data, the FEA will only be used to confirm that the new design is equivalent or comparable to the previous design. Both designs were fixture and loaded using the following values:

Bearing load of 1246N at the cylinder mounting pin

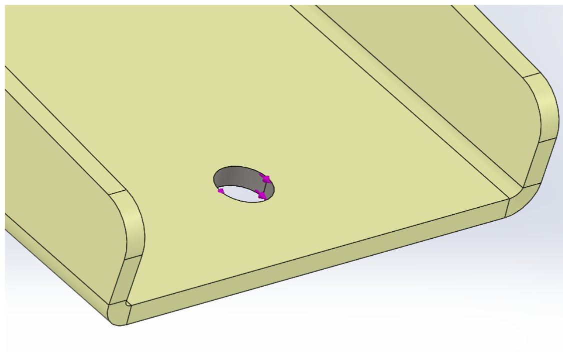


Figure 27: Location of applied force resulting from gas shock

Bearing load of 881N at the pulley mounting nut

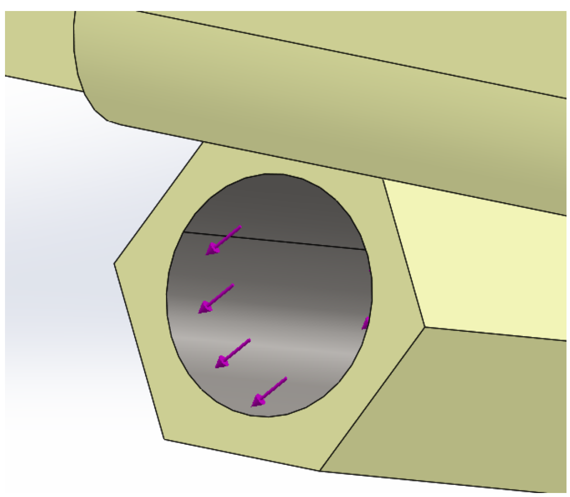


Figure 28: Location of applied force resulting from pulley

Force of 623N at the hole where the cable anchor tab is located

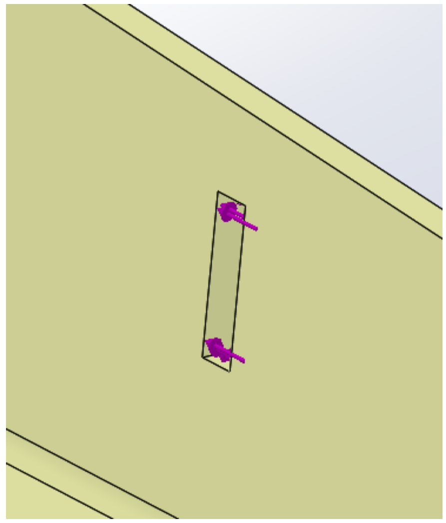


Figure 29: Location of applied force from cable anchor

The holes for the mounting bolt for the guide wheels were restrained using slider fixtures, and for the new design, an area around the locating holes was fixture to represent the area covered by the welding process.

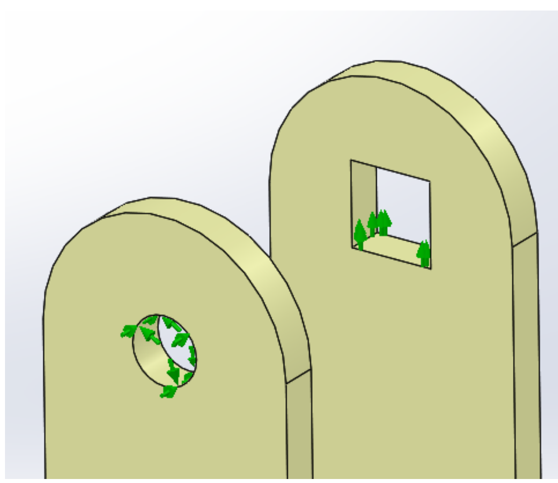


Figure 30: Mounting tab fixture location for initial design

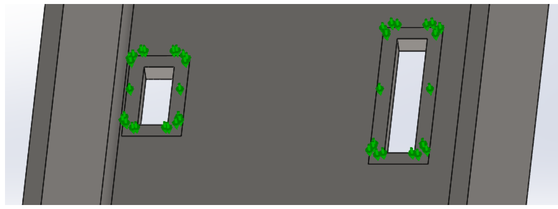


Figure 31: Mounting tab fixture location representing weld area

Due to the main geometry of the members being comprised of sheet metal, an ideal mesh strategy would be to treat the beam as sheet metal and use a surface mesh. Due to the load bearing hex component illustrated in 28, the entire body was not able to be converted to a surface, and instead a solid body mesh was used comprising of a 4 point Jacobian elements. To ensure points of interest on the analysis receive thorough inspection, an h-adaptive mesh refinement was used with a maximum of 5 iterations.

The results of the loading scenario for the initial Vidir design is shown below in Figure 32

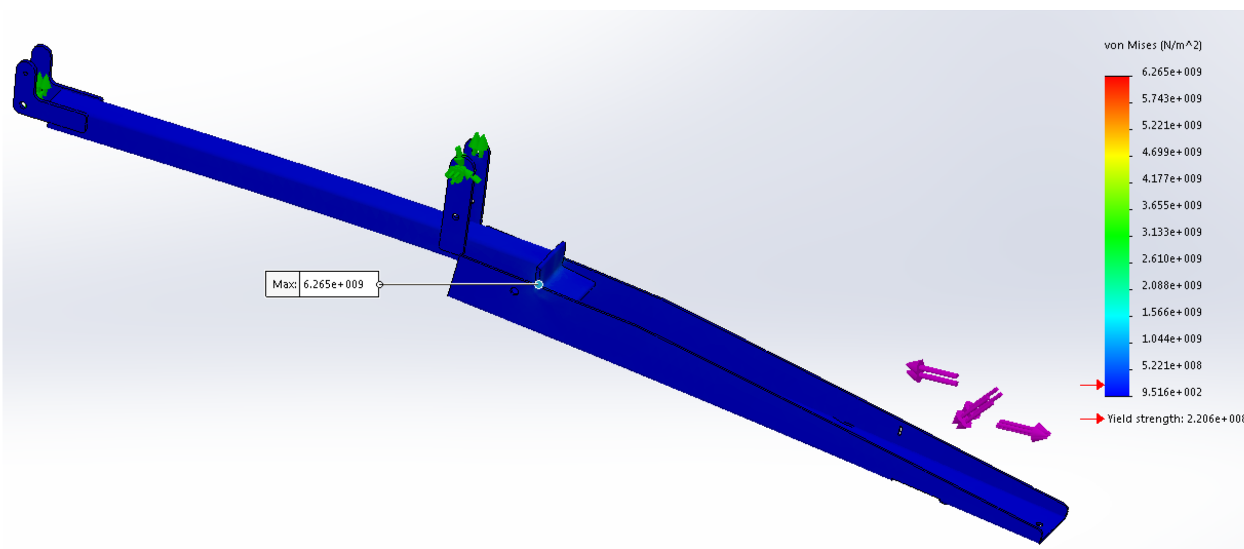


Figure 32: VonMises stress plot for initial design

As illustrated in Figure 32, there is a maximum stress value of 6.3 GPa. This stress value is far beyond the yield strength of the mild steel, however this element reading can be considered to be a singularity due to geometry as it is located at a sharp corner, and the stress value drops by 5 GPa within 3mm of the probed max value as illustrated below in Figure 33.

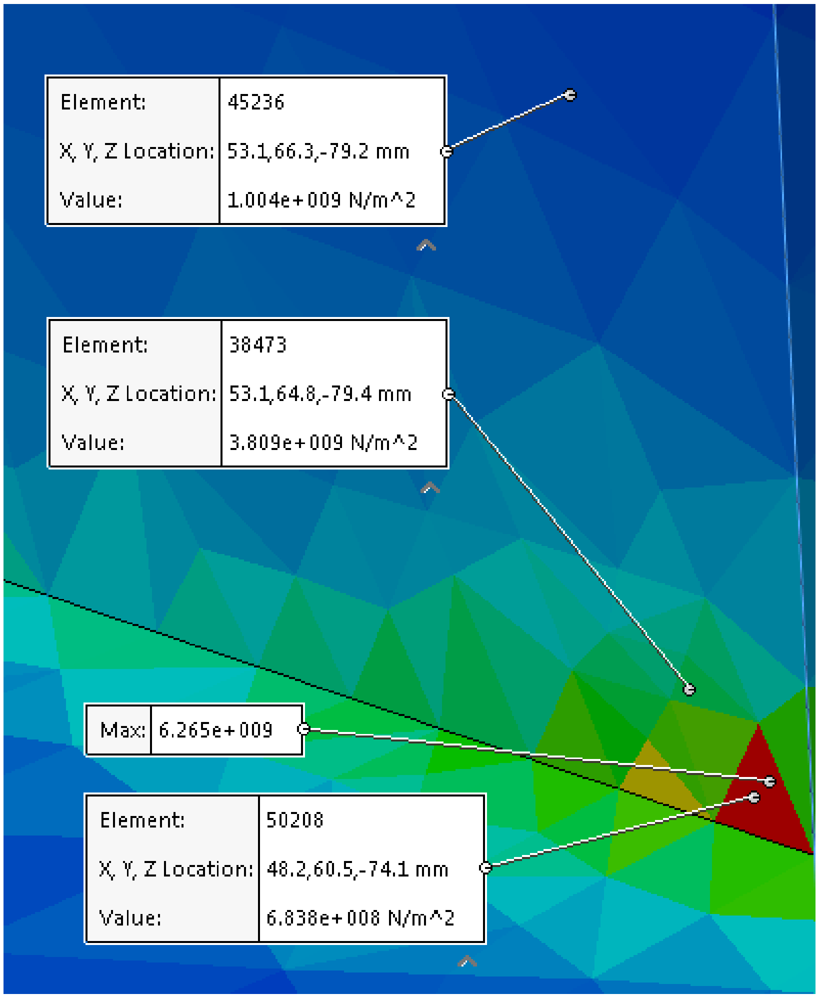


Figure 33: Probe analysis for initial design

The results for the new proposed design can be found in Figure 34.

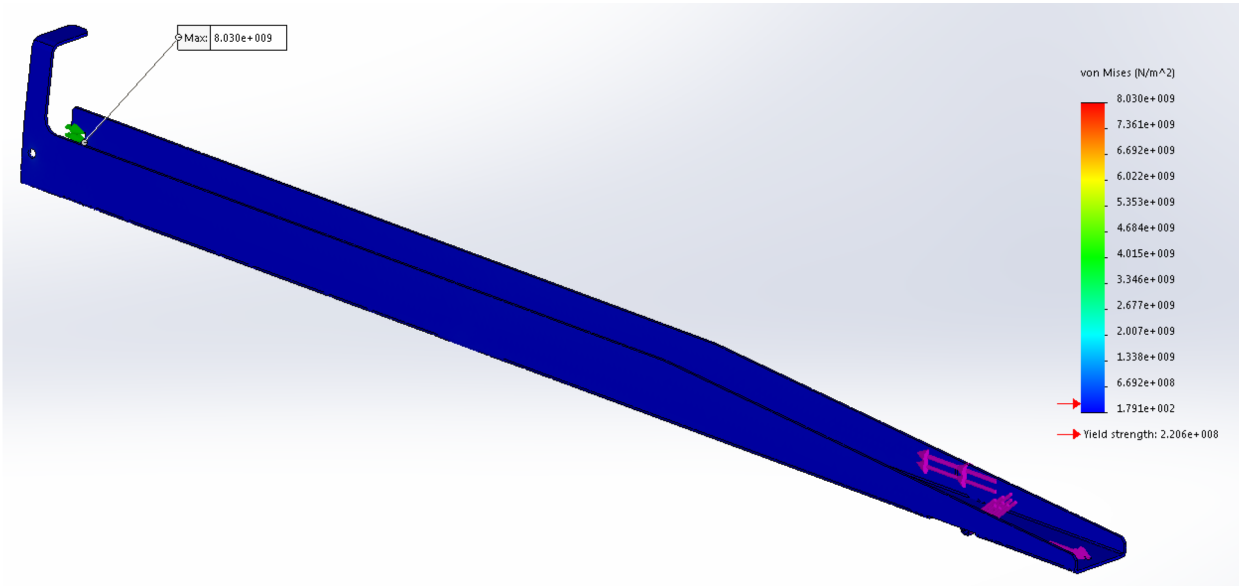


Figure 34: VonMises stress plot for new proposed design

Similar to the original design, there is an extreme stress concentration located at a sharp corner. After probing the elements nearby the concentration, a large drop in VonMises stress values is observed. This analysis is shown below in Figure 35.

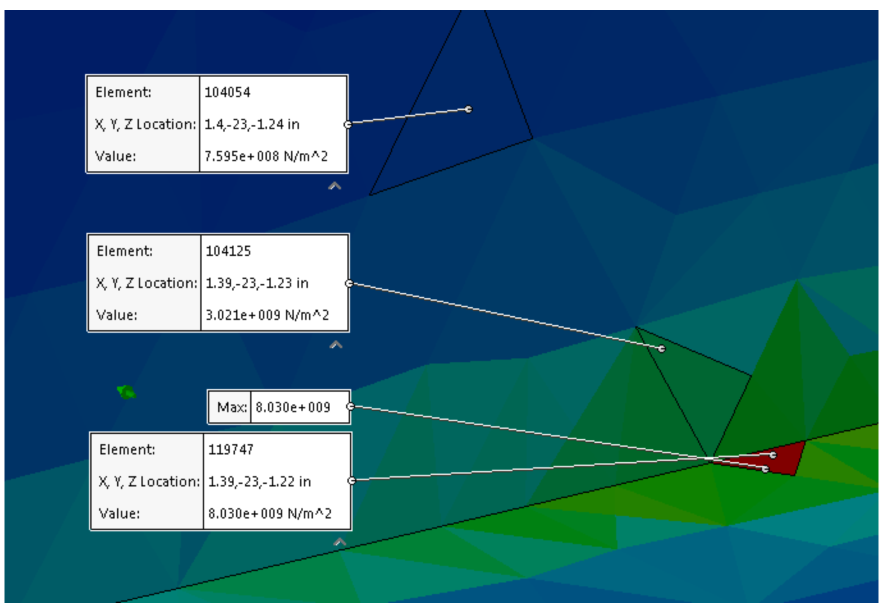


Figure 35: Probe analysis for new proposed design

The VonMises findings for the new flat member are similar to those found for the current Vidir design. This analysis suggests that the new design is capable of withstanding the same loads seen by the current design.

The following section will discuss the summary of manufacturing and assembly improvements of the redesign Skyhook. This section will also address recommendations for other manufacturing improvements for the Skyhook that were not included in this report.

9.4 Summary of Manufacturing and Assembly Improvements of Redesigned Skyhook

The final design chosen is the Flat Beam with Separate Tabs. The manufacturing process was created with precision in mind, so that every Skyhook made would be dimensionally perfect. This is how the new Skyhook design is intended to be manufactured:

1. The large laser cut piece for the main beam will be placed in a hydraulic plate bending machine. As seen in the figure below, the bending jig will consist of a square channel die, and a punch. The sheet metal will be placed over top of the die, and the punch is pressed down over top to mold the square channel.

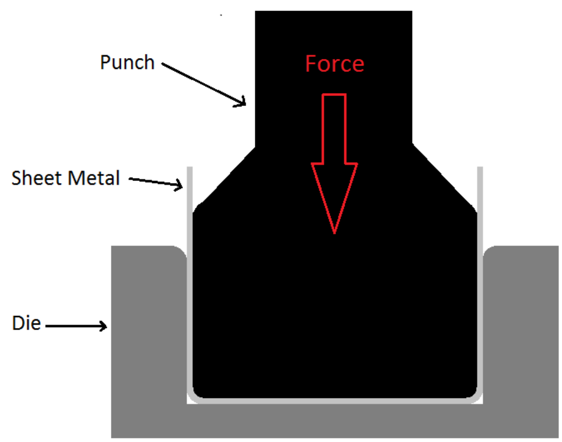


Figure 36: Punch and die Jig

2. Bend the rear tab using the same hydraulic plate bending machine. Another option is to clamp a steel block to the length of the rear tab and using a hammer fold down the end to a 90 degree angle.
3. Now the second hole in the rear section of the main beam needs to be drilled. Figure 37 shows the cross section of a circular shaft centring jig. To use it, one end is placed in the square laser cut hole and pressed flush against the wall of the main beam. Using a drill bit, it can be inserted through the middle of the jig to drill the hole in the wall. This hole will be used as a centring locater for the correct size drill bit.

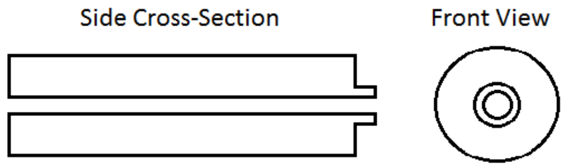


Figure 37: Rear mounting hole locator

4. The next step is to weld on the two front tabs to hold the wheel. In order to ensure the tabs are perfectly lined up before welding, the jig show in Figure 38 will be used. The jig will be placed snugly into the channel of the main beam and positioned to the correct place along the length of the beam. The two tabs will be clamped tightly to the thinner portion of the jig to ensure they are square to one another, and square to the main beam. Now the tabs can be welded into place. Once the tabs are secure, remove the jig and finish fully welding the tabs on.

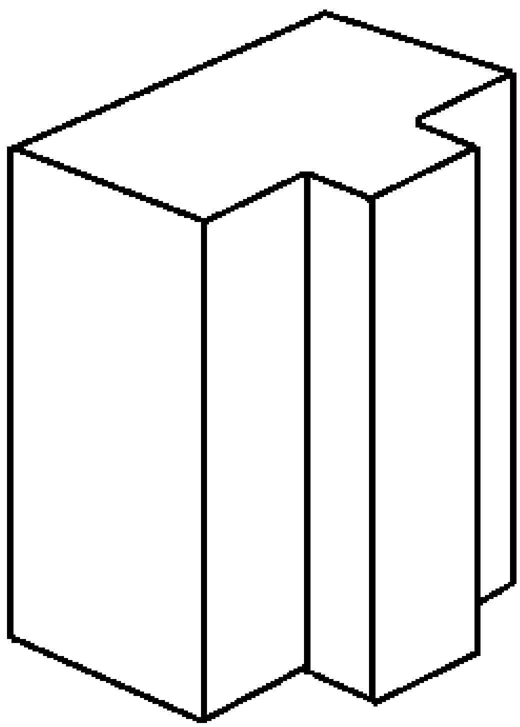


Figure 38: Front tab locating fixture

5. The last step before assembly is welding on the 4 tabs on the bottom of the Skyhook to mount the linkage arms. This will be done using the jig shown in Figure 39

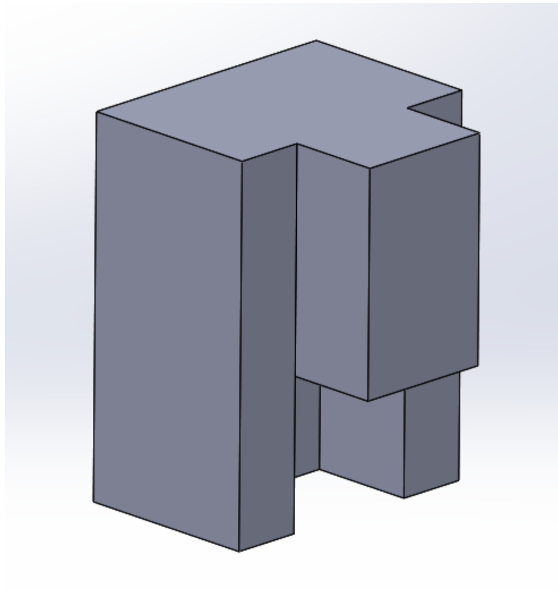


Figure 39: Tab Alignment Jig

6. Assemble the rest of the components.

From a manufacturing standpoint, the new design is significantly easier to manufacture then the current rendition of the Skyhook. The amount of welding went from 44 inches to 12 inches, 15 operations to 7 operations, and a total of 21 parts to 18 parts. It was important that during construction, the important hole locations were easy to keep true to spec. Another aspect of this design which makes manufacturing simpler, is that there is no need for any large jigs. The old design required large jigs to hold many parts for the welding process. The new design has small jigs which mount to the main beam itself.

The next section will provide a price analysis of the design Skyhook. This price analysis is meant to provide the possible dollar savings from switching the current design of the Skyhook to the redesigned Skyhook.

9.5 Final Design Price Analysis

This section of the final design analyses the cost associated with the improved manufacturing design for the current Skyhook design, and the component under analysis in the redesign of the main beam, as this component was altered from the original design.

9.5.1 Informal Supplier Price Quote

The informal consultation with Russel Metals Winnipeg Manitoba is used for the establishing the baseline price for the sheet metal used to manufacture the re-designed main beam and Vidir's current main beam design.

The informal consultation from Russel Metals gave a price for sheet metal with a five foot by ten foot length and width dimensions, the thickens considered are:

- one quarter of an inch.
- three sixteenth of an inch.
- one eighth of an inch.

The cost of interest for this analysis is the cost of mass production for the part, as such the informal quote focused on the cost for 100 pieces of sheet metal or one role of sheet metal, which was informally quoted at 22,950.00 Canadian Dollars for one role. Russel Metals stated the three thicknesses considered do not have a minimal impact on the price per role, as such all three thicknesses are considered to have the informal quote price of 22,950.00 dollars. This results in a cost of 229.50 Canadian Dollars per piece of five foot by ten foot sheet metal.

9.5.2 Vidir Main Beam Design Price

This section considers the number of Vidir main beam designs that can be manufactured form a single five foot by ten foot piece of sheet metal, to obtain a base line price of the current main beam design. The design was then drawn on a 6:1 scale for all the parts required to make the main beam, the figure 40.

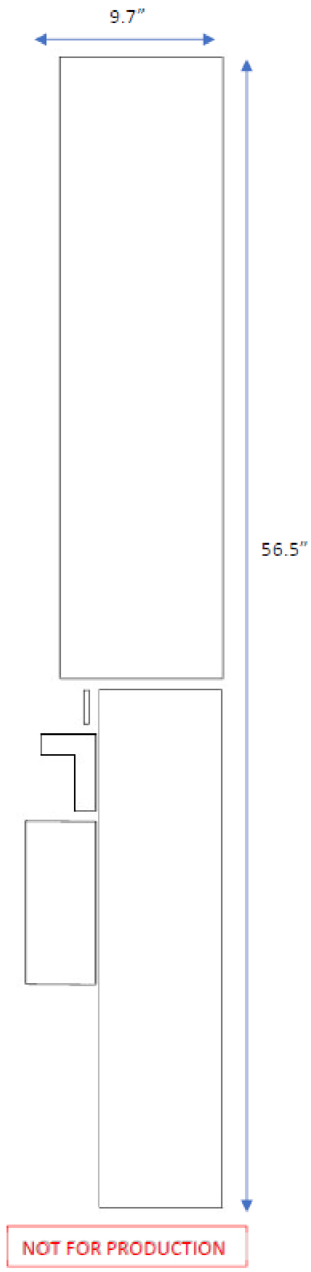


Figure 40: Vidir Main Beam Parts

The main beam parts layout was then refined to achieve a the smallest area possible such that the least amount of material would be used. Figure 41 shows the optimum layout for the Vidir main beam design with all required parts. The overall dimension of the refined layout was found at 56.5 inches height and 24.0 inches width.

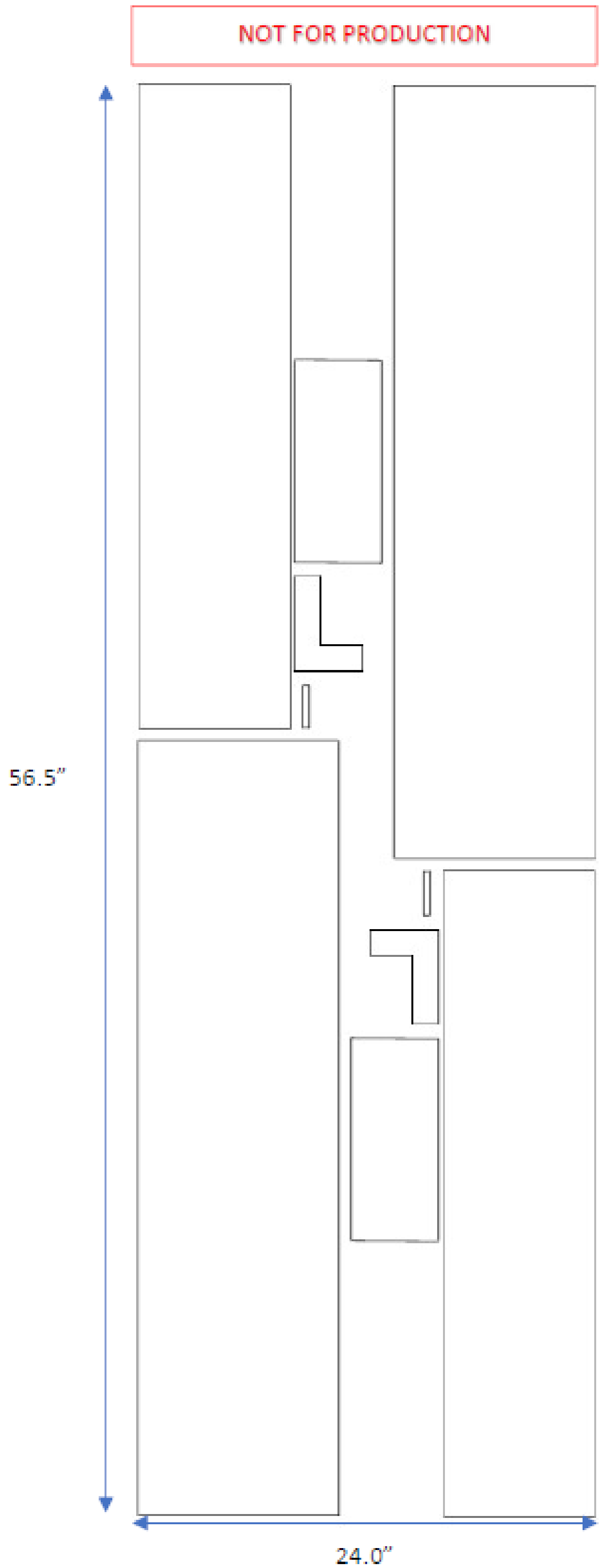


Figure 41: Vidir Main Beam Parts

This refined layout fits inside a five foot by ten foot piece of sheet metal priced at 229.50 dollars five times, thus bringing the total number of manufacture able Vidir main beams from a single piece of sheet metal to ten. This gives a price of 22.95 dollars per main beam, for the materials required to manufacture. The time to manufacture the main beams from sheet metal is not available for this method, but the total number of sized pieces that require to be cut can be established. There are 5 different pieces per main beam to cut, for each different size piece the manufacturing time increases, this provides a base line reference for roughly how much longer or faster the process would be when compared to the re-design main beam.

9.5.3 Re-Design Main Beam Price

This section considers how many re-design main beams can be manufactured form a single five foot by ten foot piece of sheet metal, to obtain a base line price of the current main beam design. See Figure 42 shows the optimum layout for the new main beam design with all required parts. The overall dimension of the new beam refined layout was found at 54.33 inches height and 8.9 inches width.

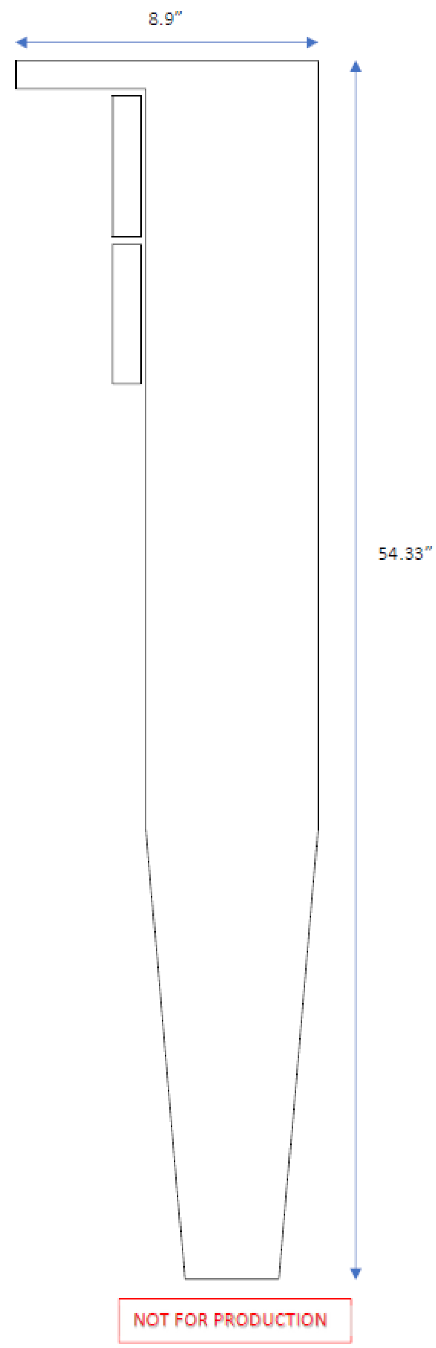


Figure 42: Vidir Main Beam Parts

The re design main beam parts layout was then refined to achieve a the smallest area possible such that the least amount of material would be used. Figure 43 shows the optimum layout for the Vidir main beam design with all required parts. The overall dimension of the refined layout is found at 55.9 inches height and 16.25 inches width.

Figure 43: Vidir Main Beam Parts

This refined layout fits inside a five foot by ten foot piece of sheet metal priced at $229.50 seven times, thus bringing the total number of manufacture able Vidir main beams from a single piece of sheet metal to fourteen, thus increasing the number of main beams that can be produced by 40 percent. This gives a price of $16.39 per main beam, for the materials required to manufacture. The time to manufacturing main beams from sheet metal is not available for this method, but the total number of sized pieces that require to be cut can be established. There are two different pieces per main beam to cut, this is three pieces less than the current design, the overall dimensions for the new beam design are also lower than that of the current design. As such the new design is easier and faster to manufacture, when compared to the current design.

9.5.4 Price Analysis Conclusion

The improved manufacturing redesign for the current main beam has shown to be more cost efficient, faster and easier to manufacture. The re-design for the main beam increases the number of main beams that can be made from a single five foot by ten foot piece of sheet metal by 40 percent, the cost is reduced by $6.56 or 28.59 percent. The final price of the improved manufacturing methodology for the current skyhook is therefore obtained by taking the old price, for the skyhook which is 38.00 dollars and subtracting the reduced cost of 6.56 dollars. Making the final price of the improved manufacturing methodology skyhook 31.44 dollars.

9.5.5 Final Design Price Analysis Summary

The price analysis performed on both the current main beam and the re-design of the main beam has shown the re-designed main beam to be more cost efficient to manufacture, see table XXII for results.

Table XXII: PRICE COMPARISON BETWEEN CURRENT AND RE-DESIGN MAIN BEAMS

Main Beam	Price Per Main Beam (CDN)	Main Beams Per Piece of Sheet Metal
Current Main Beam Design	22.95	10
Re-Design Main Beam	16.39	14

Table XXIII shows the skyhook with the re-design main beam has a lower price than the current skyhook.

Table XXIII: PRICE COMPARISON BETWEEN CURRENT AND RE-DESIGN SKYHOOKS

Skyhook	Price Per skyhook (CDN)
Current Skyhook	38.00
Skyhook with re-designed Main Beam	31.44

Table XXII shows that the new design is more cost efficient to manufacture than the current beam design, table XXIV shows on a percentage base how much more efficient the new design is.

Table XXIV: PRICE COMPARISON BETWEEN CURRENT AND RE-DESIGN MAIN BEAMS

	Percent Price Reduction	Percent Production Increase
Re-Design Main Beam	28.59	40.00
Improved Manufacturing Redesign for current skyhook	8.27	N/A

Therefore, the customers two main objectives are met, the most important being reduction of cost for the Skyhook. The price per Skyhook, not including manufacturing costs is $38.00, the improved manufacturing methodology for the skyhook reduces cost to $31.44, not including manufacturing cost. This is a 8.27 percent decrease form the current design, this meets the three most important customer requirements for cost reduction, ease of manufacture and decreasing the assembly time because there are less parts for the main beam.

10 Conclusion

The team was involved with redesigning the Skyhook component of the BMS system by the client, Vidir Machine Inc. Vidir specified the desired outcomes of the redesign to the team. These outcomes include a reduction in overall manufacturing cost, reduction of manufacturing time, and reduction of labor intensity of the Skyhook. Vidir also identified that the current gas shock system should be explored for cheaper alternatives.

The first two phases of the project involved the project definition and concept definition phases. In the project definition phase, the team focused on defining the purpose and deliverables of the project, customer needs, design constraints and limitations. Once the project has been deemed fully defined, the team moved on to the concept definition phase. In this phase, the team focused on research and concept development for the redesign of the Skyhook. During this phase the team proposed several alternatives to the gas shock system, material, and concepts of functional system. After further research on the gas shock alternatives and Skyhook component material, the team concluded that that current gas shock and materials for the design were the cheapest options available based on prices from North American manufacturers. Furthermore, after consulting with Vidir and presenting concepts of different functional system, the team and Vidir opted to maintain the current functional system and instead perform a redesign of the Skyhook based on improving ease of manufacturing and assembly.

The final phase of the report consisted of the teams effort to redesign the Skyhook to increase manufacturability and ease of assembly. In this phase, the team brainstormed ideas that could help with the redesign. From these brainstorm four designs were conceived that involved the redesign of the main beam component of the Skyhook. The four designs were then evaluated using a weighted matrix. Based on the criterions of material cost, ease of manufacturing, ease of assembly, complexity and aesthetics, the final design selected is the Flat Beam Design with Separate Middle Tabs.

In this design, the main beam of the current Skyhook is redesigned to become one single unified piece. The angle that was currently instilled in the Skyhook main beam has been replaced with a uniform flat surface. The tabs in the middle have been kept separate to prevent compatibility issues with the current BMS system. Also, the tabs in the rear has been reduced to zero external tabs, instead the rear tabs are incorporated in the main beam.

FEA was completed and resulted in assurance that the design will withstand loads similar to the current design of the Skyhook. From a manufacturing analysis, the amount of weldings went from 44 inches to 6 inches, 15 operations to 7 operations, and total of 21 components to 18 components. After a cost analysis, the new main beam shows a decrease of 28.59% in cost, and the full newly designed Skyhook shows a decrease of 8.27 % of overall cost.

From the FEA, manufacturing, and cost analysis, the clients desired outcomes have been fulfilled. Gas shock alternatives were explored, and a design resulting in the decrease of intensity of labour, reduction of overall manufacturing cost and reduction of manufacturing time has been completed.

11 Schedule

The Work Breakdown Structure revision two (WBS) and Gantt chart revision two, are updated significantly from the first revisions issued in the Project Definition Report. The WBS has been modified to show concept selection methodology and detailed design methodology for the Final Report and Concept Design Report. As a result the Gantt chart has been updated according to the WBS.

11.1 Work Breakdown Structure

The following section details how the major phases and their associated subtasks are organized, in order of completion. The WBS details the work to be completed during the four phases of the project.

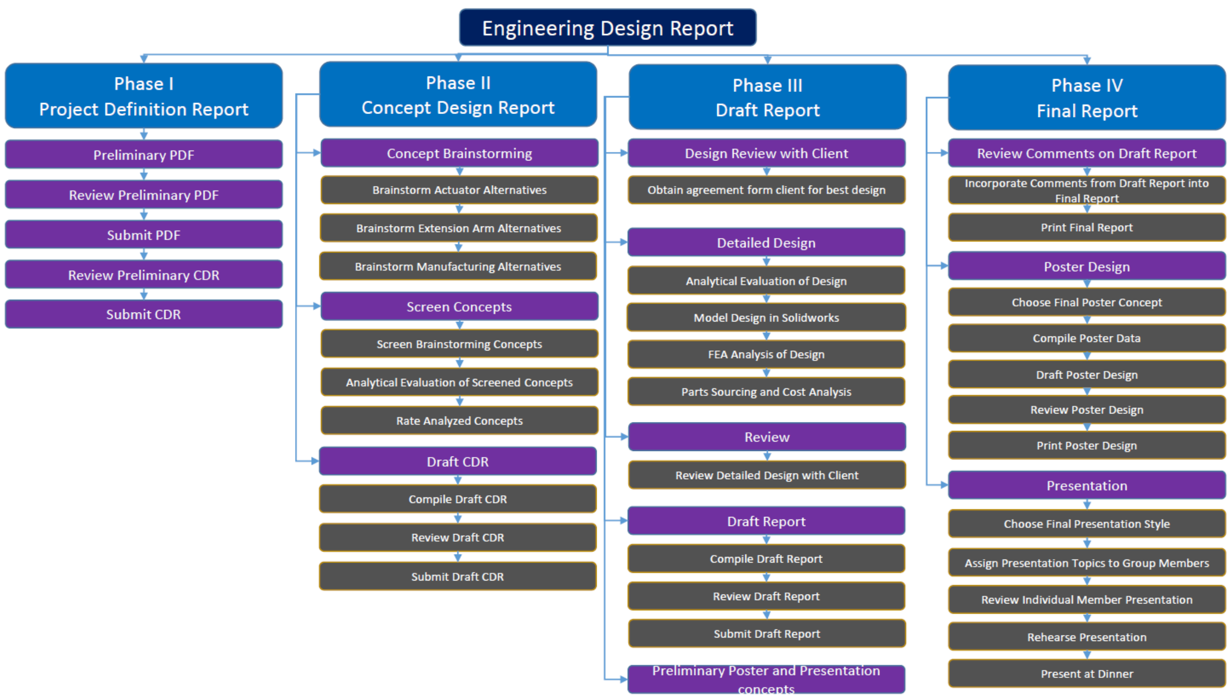
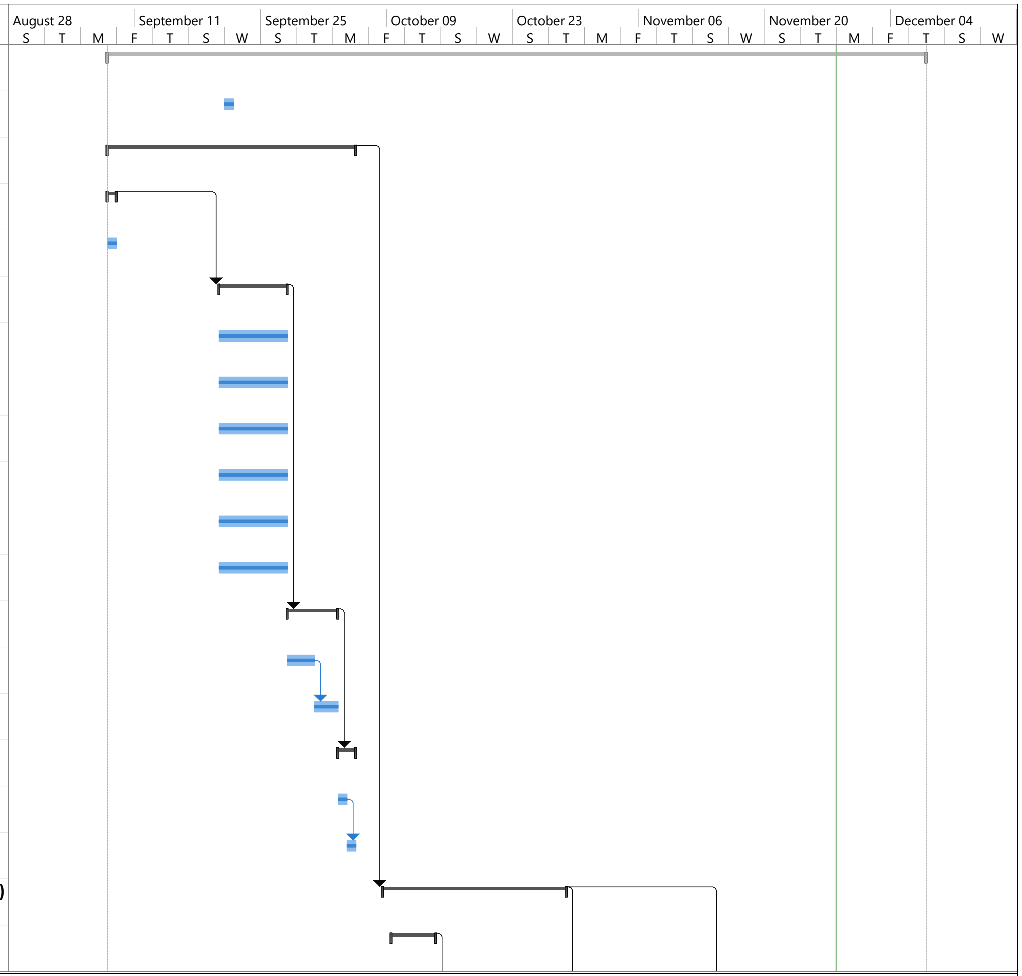


Figure 44: Work breakdown structure

11.2 Gantt Chart

This section details the time constraints to which this project adheres. The Gantt chart details specific tasks and their associated sub tasks that are required to complete each phase of the project. It is critical that the tasks are completed on time such that the project can move forward and be completed on time, the chart is an excellent time keeping tool that is used to keep the project on schedule, and give a visual representation for individual tasks ant their completion status.

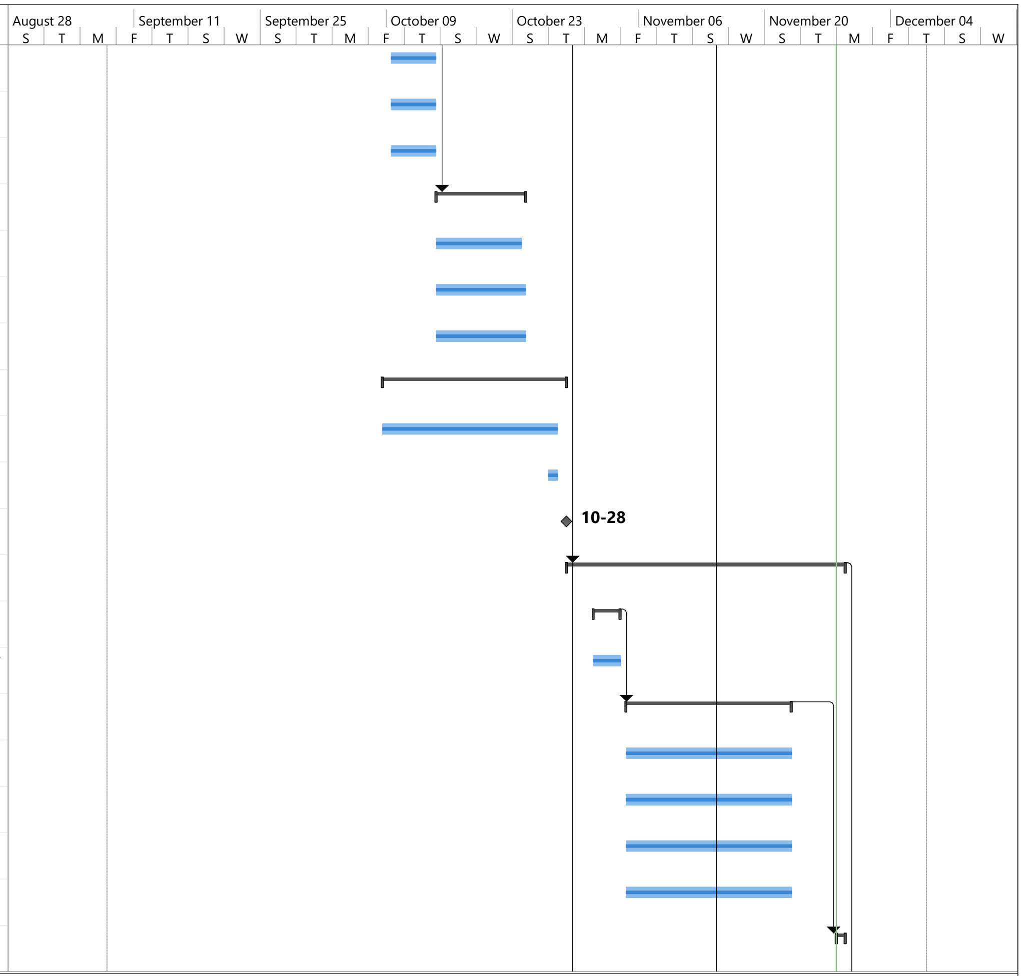
ID	Task Mode	Task Name
0		**Team24_Gantt_Chart**
1		Team Meeting
2		**Phase I: Project Definition Report (PDR)**
3		**Meet with customer**
4		Meeting with Customer
5		**Draft PDR**
6		Illustrations
7		Problem statement and background
8		Project Objectives
9		Target Specs
10		Constraints and Limitations
11		Project Schedule
12		**Review Draft PDR**
13		Review Comments
14		Incorporate Comments
15		**Submit PDR**
16		Submit Final CDR
17		Oral Presentation
18		**Phase II: Concept Design Report (CDR)**
19		**Concept Brainstorming**



Project: Team24_Gantt_Chart
Date: Mon 16-11-28

Task		Inactive Task		Manual Summary Rollup		External Milestone	
Split		Inactive Milestone		Manual Summary		Deadline	
Milestone		Inactive Summary		Start-only		Progress	
Summary		Manual Task		Finish-only		Manual Progress	
Project Summary		Duration-only		External Tasks			

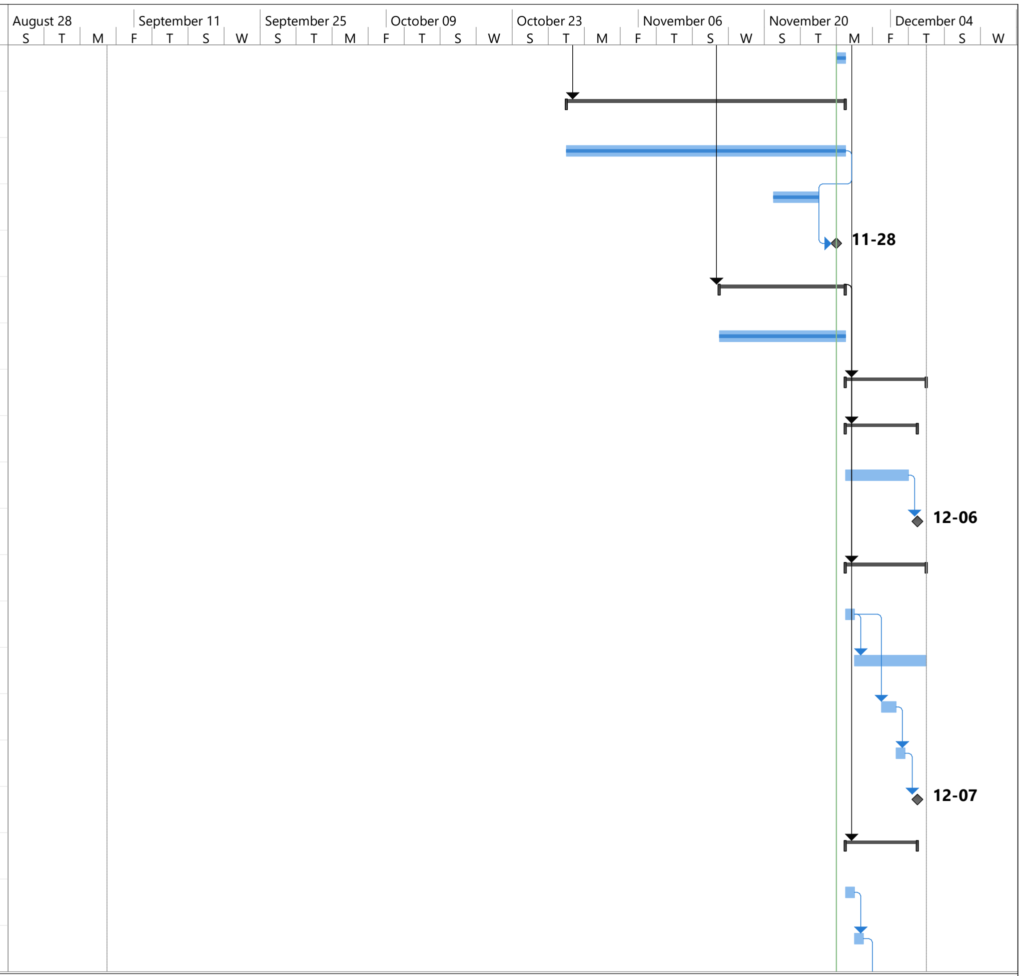
ID	Task Mode	Task Name
20		Brainstorm Actuator Alternatives
21		Brainstorm Extension Arm Alternatives
22		Brainstorm Manufacturing Alternatives
23		**Screen Concepts**
24		Screen Brainstorming Concepts
25		Analytical Evaluation of Screened Concepts
26		Rate Analyzed Concepts
27		**Draft CDR**
28		Compile Draft CDR
29		Review Draft CDR
30		Submit Draft CDR
31		**Phase III: Draft Report**
32		**Design Review with Client**
33		Obtain agreement form client for best design
34		**Detailed Design**
35		Analytical Evaluation of Design
36		Model Design in Solidworks
37		FEA Analysis of Design
38		Parts Sourcing and Cost Analysis
39		**Review**



Project: Team24_Gantt_Chart
Date: Mon 16-11-28

Task	Inactive Task	Manual Summary Rollup	External Milestone
Split	Inactive Milestone	Manual Summary	Deadline
Milestone	Inactive Summary	Start-only	Progress
Summary	Manual Task	Finish-only	Manual Progress
Project Summary	Duration-only	External Tasks	

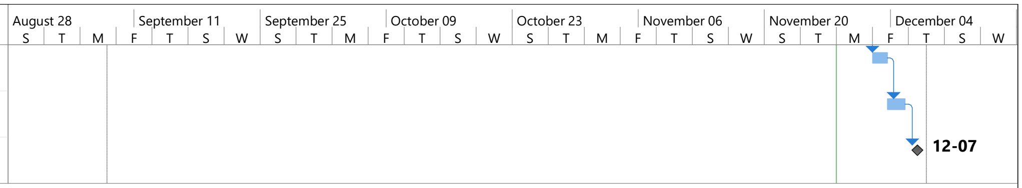
ID		Task Mode	Task Name
40	✓		Review Detailed Design with Client
41	✓		**Draft Report**
42	✓		Compile Draft Report
43	✓		Review Draft Report
44	✓		Submit Draft Report
45	✓		**Preliminary Poster and Presentation concepts**
46	✓		Brainstorm Poster and Presentation Concepts
47			**Phase IV: Final Report**
48			**Review Comments on Draft Report**
49	(calendar icon)		Incorporate Comments from Draft Report into Final Report
50	(calendar icon)		Print Final Report
51			**Poster Design**
52			Choose Final Poster Concept
53			Compile Poster Data
54	(calendar icon)		Draft Poster Design
55	(calendar icon)		Review Poster Design
56	(calendar icon)		Print Poster Design
57			**Presentation**
58			Choose Final Presentation Style
59			Assign Presentation Topics to Group Members



Project: Team24_Gantt_Chart
Date: Mon 16-11-28

Task	Inactive Task	Manual Summary Rollup	External Milestone
Split	Inactive Milestone	Manual Summary	Deadline
Milestone	Inactive Summary	Start-only	Progress
Summary	Manual Task	Finish-only	Manual Progress
Project Summary	Duration-only	External Tasks	

ID		Task Mode	Task Name
60			Review Individual Member Presentation
61			Rehearse Presentation
62			Present at Dinner



Project: Team24_Gantt_Chart
Date: Mon 16-11-28

Task	Inactive Task	Manual Summary Rollup	External Milestone
Split	Inactive Milestone	Manual Summary	Deadline
Milestone	Inactive Summary	Start-only	Progress
Summary	Manual Task	Finish-only	Manual Progress
Project Summary	Duration-only	External Tasks	

12 References

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