University of Texas of the Permian Basin

Humanitarian Deminer

MENG 4366 Senior Design 1

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Introduction

Product Description

Our product is a low-cost machine that safely neutralizes anti-personnel mines. Our design will consist of a roller attached to a modified pre-purchased off-road vehicle. The machine will apply force to mine fuses causing their detonation as it moves across the terrain.

Team Organization

Our team includes four University of Texas of the Permian Basin students: Ahmed Mohamed, Daniel Hernandez, Dylan Rothganger, and Xavier Carrillo.

Potential Buyers

Our target market includes: international humanitarian organizations, localized governments, and farmers. Target areas include locations with large amounts of unrecovered anti-personnel mines such as: Somalia, Azerbaijan, Afghanistan, Egypt, Laos, Angola, etc.

Assumptions and Constraints

The deminer will:

- Retain functionality after neutralizing mines
- Be transported from our manufacturers to mine sites
- Abide by international commerce regulations
- Neutralize anti-personnel mines only
- Function in areas of low vegetation

Marketing Information

Competition Research

Below is a compilation of existing methods and technologies that perform the task we wish to accomplish.

Mine Kafon Drone

Figure 1. Mine Kafon Drone [1]

Description: The Mine Kafon Drone is unmanned airborne system that uses three process to remove land mines. First, the system flies over the area with an aerial 3D mapping system to identify all the dangerous areas with GPS way points. Once it has detected what could be a dangerous area, MKD hovers about 4 centimeter over the ground to detect the explosives using its robotic metal detecting arm. The detected mines are geotagged as they are found in the ground. For the final phase, MKD places a small detonator over the mine with its robotic gripping, which is detonated by a timer after the drone has flown away to safety.

Comments:

The Kickstarter campaign set an initial pledged goal of about $78554. The Kickstarter pages contain is a useful source of information on the issue, such as figures that illustrate the scope of the land mine issue across the world. The Kickstarter page can be found at:
https://www.kickstarter.com/projects/massoudhassani/mine-kafon-drone/description
The Mine Kafon Drone design outlines gives interesting solutions that may be considered for future problems in designing.

(MW240) Mini MineWolf

Figure 2. Mini MineWolf Deminer [2]

Description: a medium class (8 tonnes) remote-controlled machine which can be equipped with either a flail or a tiller for mine clearance; a robotic arm for the remote manipulation of suspected explosive devices; a runway clearance attachment for collecting and dispensing cluster munitions; and a range of multi-purpose attachments for other EOD and general engineering tasks.

Comments:
The MineWolf engineering website can be found at: www.minewolf.com/products/mw240/. Which provides design details for any device that can be viewed there. More design specifications can be found here:
http://www.humanitarian-demining.org/2010Design/resources/MineWolf_FS-30Jun2016.pdf
-The Mini MineWolf is a machined solution to the issue. But the compactness of the design could be useful to look into.

Piranha

Figure 3. Piranha remote controlled machine and its controller [3]

Features:

Remote controlled with up to four cameras.

Multipurpose, skid-steer chassis.

Description:

The Piranha platform, remote, cameras, and tools completed technical testing in June 2013.The system is undergoing an operational field evaluation in Cambodia with the Mines Advisory Group. The Piranha is a medium sized, mine and vegetation clearance system based on a commercially available high horsepower skid steer loader. The platform, Supertrak SK-140-CTL-C, is a modified Caterpillar 299C skid steer. The base 299C was upgraded to a 140 horsepower (hp) CAT diesel engine that provides 40 hp to the drive system and 100 hp to the auxiliary/attachment system. The skid steer is modified with an upgraded remote control system and four cameras. The Piranha has two primary tools, a highly-effective, commercial Denis Cimaf vegetation cutter and a Humanitarian Demining Program-designed and fabricated tiller. The tiller is designed for area reduction and to breach lanes in potential AP minefields. The Piranha-II was designed to be slightly wider than the Supertrak's track width to allow the prime mover to operate on a 100% tilled path**.**

Customer Needs

Below is a list of anticipated customer needs to be met by the humanitarian deminer design team. A set of final specifications were decided to meet these needs as effectively as possible. The final specifications are shown in Table 1.

1. Needs to be effective at neutralizing anti-personnel mines.
2. Needs to neutralize different types of AP mines.
3. Needs to neutralize AP mines at various depths.
4. Needs to neutralize AP mines on the surface.
5. Sales price needs to be affordable.
6. Needs to survive AP mine detonations without undergoing significant damage.
7. Needs to resist shrapnel penetration.
8. Needs to be reliable.
9. Needs to have a long operational life.
10. Needs to be able to operate outdoors.
11. Needs to be able to traverse vegetation.
12. Needs to resist rolling/tipping over.
13. Needs to be operated safely.
14. Needs to be simple to operate.
15. Controls need to require little effort to operate.
16. Needs to be easily refueled.
17. Needs to be able to run for a reasonable amount of time before powering down.
18. Needs to demine in a reasonable time.
19. Needs to not overheat when used for an extended amount of time.
20. Needs to stop quickly in an emergency.
21. Needs to be easy to learn to use.
22. Needs to have minimal setup on arrival to user.
23. Needs to allow easy replacement of worn parts.
24. Needs to be maintained with readily available tools.
25. The displays need to be easy to read.
26. Needs to be easily transported to minefield.
27. Needs to be maneuverable.
28. Needs to be able to warn the user when fuel level is low.

Final Specifications

Table 1. Final Specifications for the humanitarian deminer

Metric #	Need #	Metric	Units	Values
1	1, 2, 3, 4	Percentage of mine neutralization	%	> 85
2	2	Number of types of AP mines deminer can neutralize	list	> 5
3	3, 4	Effective depth	cm	> 15
4	5	Unit sales price	US$	< 40,000
5	6, 7	Number of impacts deminer can withstand	Detontations	> 200
6	8, 9	Mean hours before failure	hrs	> 500
7	10	Ambient temperature	°C	(-20) - (60)
8	10	Ambient relative humidity	%	0 - 100
9	11	Height of traversable vegetation	m	> 0.2
10	12	Angle of approach	Degrees	> 15
11	12	Angle of leave	Degrees	> 15
12	12	Allowable roll angle	Degrees	> 15
13	13	Range of distance between operator and deminer	m	0-300
14	14	Number of controls		<20
15	15	Manual force required to operate contoller	N	< 5
16	16	Mean time required for one person to repower	hrs	< 3
17	17,19	Mean hours of continuous operation	hrs	> 6
18	18	Area covered per hour	m^2/hr	>200
19	20	Stopping distance at operating speed	m	< 3
20	21	Time to train operator	hrs	<8
21	22,23	Number of parts to assemble for owner		< 15
22	22,23	Assembly/setup time	hrs	< 8
23	23	Time to disassemble for maintenance	hrs	< 8
24	24	Special tools required for maintenace		< 5
25	25	Display dimensions	cm	2-25
26	25	Display brightness	Nits (cd/m^2)	> 400
27	26	Total mass	kg	< 5000
28	26	Width of deminer	m	< 2.6
29	26	Length of deminer	m	< 10
30	26	Height of deminer	m	< 4.9
31	27	Turning radius	m	< 3.5
32	28	Reserve fuel required to trigger alert	%	20

Improving mine clearance

To ensure that our mine neutralization percentage reaches an acceptable rate, we repeat the use of the deminer over an area multiple times. At 85% mine neutralization for one run we can attain a 99.99% mine clearance over three runs as shown below.

$$\square = 1 - \square \tag{1}$$

Here, *P* is the percentage of mines that are cleared and *B* is the percentage that remain. Therefore the equation representing one run is:

$$\square(1) = 1 - (0.15) = 0.85 \tag{2}$$

The equation representing two runs is shown in Equation (3).

$$\square(2) = 1 - (0.15)^2 = 0.977 \tag{3}$$

Finally the equation representing three runs is shown in Equation (4).

$$\square(3) = 1 - (0.15)^3 = 0.997 \tag{4}$$

Concepts

Below is a compilation of the concepts that were considered in the design process of the deminer along with their descriptions.

Mine Neutralization Methods

The mechanism and method by which the deminer will effectively render an AP mine harmless. The mechanism will apply a force that will detonate, destroy, or deactivate AP mines.

Rotating Flail: Hammers on the ends of chains are attached to a rotating drum or shaft. The spinning axle causes the hammers to beat the ground, detonating or destroying anti-personnel mines. Figure 4 shows a rotating flail fitted to a preserved World War II tank.

Figure 4. M4 Sherman tank fitted with flail [4]

Tiller: A rotating drum filled with overlapping rows of teeth or blades. The teeth chew up the ground as the drum is lowered to desired depth and the mines are detonated or destroyed as the teeth impale them. Figure 5 shows a tiller device designed by Istrazivac.

Figure 5. Istrazivac VF-001 demining tiller [5]

Roller: A dense, vehicle driven, rotating drum or series of drums used to compact soil. The roller is designed to deliver force to anti-personnel mine fuses. Figure 6 shows a basic IED roller.

Figure 6. HRI Route Clearance Roller – Basic [6]

Controlled Detonation with Mine Detection:
Manual or remote controlled metal detection is used to locate subsurface anti-personnel mines. Explosive charges are the placed above the mines and remotely detonated to trigger or destroy the mines. Figure 7 shows a demining drone that uses this method currently in development.

Figure 7. Mine Kafon drone [7]

Locomotion Methods
The main component that generates power and delivers it to the road surface, or air. The method that the deminer will use to transport itself from place to place.

Standard Pneumatic Tires: Standard construction used a combination of bias wrapped cords and sheet rubber layers with a molded-on tread. An example is shown on Figure 8.

Figure 8. Standard Pneumatic tire used for military vehicles. [8]

<u>Solid Tires:</u> Solid tires are tires that do not contain pressurized air in them. They are usually used in off-road vehicles that operate where the risk of tire puncture is high.

Figure 9. Solid rubber tires with a sectional cut view. [9]

Rotor Blades: Rotor blades consist of several rotary wings that generate an aerodynamic lift that carries the weight deminer. Rotary wing aircraft are difficult to maneuver and consume a lot of energy to generate the lift force needed.

Figure 10. Aerial drone that uses rotary blades as its locomotion system [10]

Rubber Tracks:
Rubber Tracks is a vehicle propulsion method in which a continuous band of threads is driven by two or more wheels.Rubber tracks distribute a machine's weight more evenly than tires, so they offer better flotation and stability, especially on sand or mud, or any soft or wet surface. Shown below in Figure 11 is an example of a continuous rubber track.

Figure 11. 505 continuous rubber tracks [11]

Steel Tracks:
Steel tracks is a comparable mechanism to rubber tracks. However, steel tracks are much more durable and they offer more traction, especially on hills or uneven surfaces. This comes at a high cost; steel tracks are very heavy and expensive. Figure 12 shows a tractor using steel continuous tracks.

Figure 12. John Deere steel continuous tracks [12]

Protection Methods
The methods by which we protect our machine from the impact of anti-personnel mines. This is meant to protect the internal parts of the vehicle driving the demining device.

Blast Shield: A Blast Shield can be a viable concept you use to protect the deminer from multiple impacts. The blast shield will be between the neutralization mechanism and the deminer to provide the protection needed. The blast shield can be made of high strength steel materials like Armox 500T(shown in Figure 13) which has a tensile strength of 1450-1750 MPa and a yield strength of 1250 MPa.

Figure 13. Plates of Armox 500T [13]

Deminer Armor: Instead of a blast shield, the deminer can be manufactured with the armor on its external frame. Again this can be made of a high strength material like Armox(shown in Figure 14).

s

of Armox 440T [14]

Deflection: The deminers armour can have geometry to dissipate the force received from the mines by having angles.

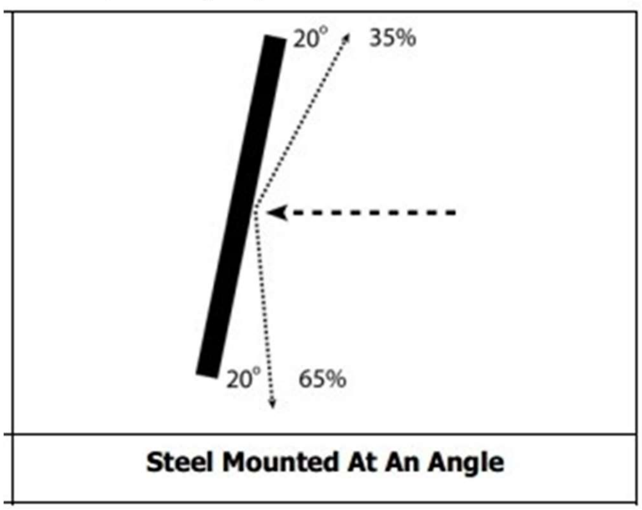

Figure 15. Deflection Model [15]

<u>Distance Between the Deminer and the AP Mine:</u> A large distance between the deminer and the AP mine will greatly help reduce the danger the deminer will be in.

Figure 16. Roller with distance between it and the deminer [16]

Expendable Attachment: A cheap, easily replaceable attachment absorbs the brunt of the mine detonation impact protecting the integrity of the deminer. The attachment is then discarded appropriately and a new one takes its place.

Figure 17. Ripple Design vehicle with roller attachment [17]

Motive Power Generation
A device, or system, that will supply energy to a load. The power supply will have a power input, which receives energy from a source, and a power output that delivers energy to a load.

Gasoline Engine: A combustion engine that uses gasoline as its source of fuel to produce mechanical energy(shown in Figure 18). This engine, along with some other combustion, utilizes the four-stroke cycle of intake, compression, power and exhaust.

Figure 18. Honda Horizontal OHV Engine. [18]

Diesel Engine: A combustion engine that uses diesel fuel as its source of fuel to produce mechanical energy(shown in Figure 19). Again, this engine, utilizes the four-stroke cycle of intake, compression, power and exhaust. However, one advantage over the gasoline engine is that the diesel fuel does not require a spark plug for ignition inside the cylinder [25].

Figure 19. Kawasaki FD750D 25HP Diesel Engine [19]

Pneumatic Motor: This motor produces energy from the flow of compressed air in a linear motion through a piston air motor, air turbine, vane type air motor, or a gear type motor. It is also known as an air motor or a compressed air engine(shown in Figure 20).

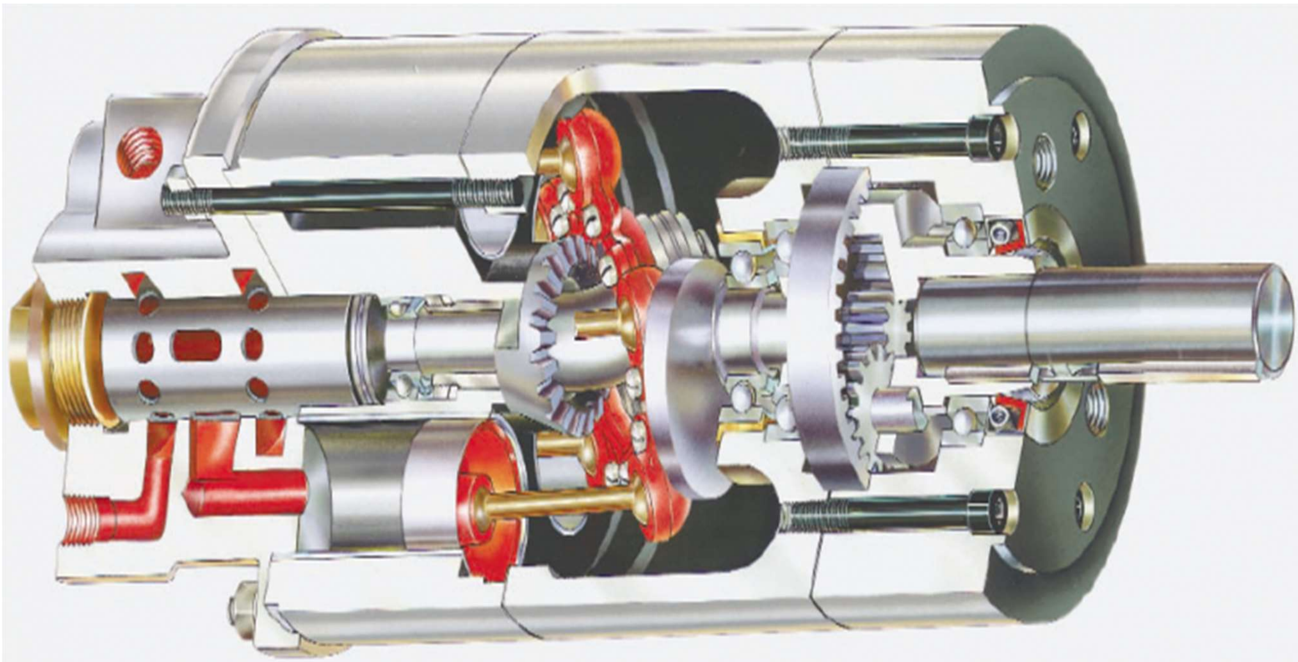

Figure 20. Cutaway view of an axial-piston air motor [20]

Rechargeable Battery Pack Powered Electric Motor: An electric motor that uses a battery pack as its source of power to produce mechanical energy(shown in Figure 21). This concept is used in a various number of modern vehicles similar to the Tesla.

Figure 21. Electric motor from a Tesla called the powertrain 1.5 [21]

Hydrogen Fuel Cell Powered Electric Motor: This concept uses Hydrogen fuel to power a fuel cell that then powers an electric motor, which then produces mechanical energy. Schematic of fuel cell power process is shown below in Figure 22.

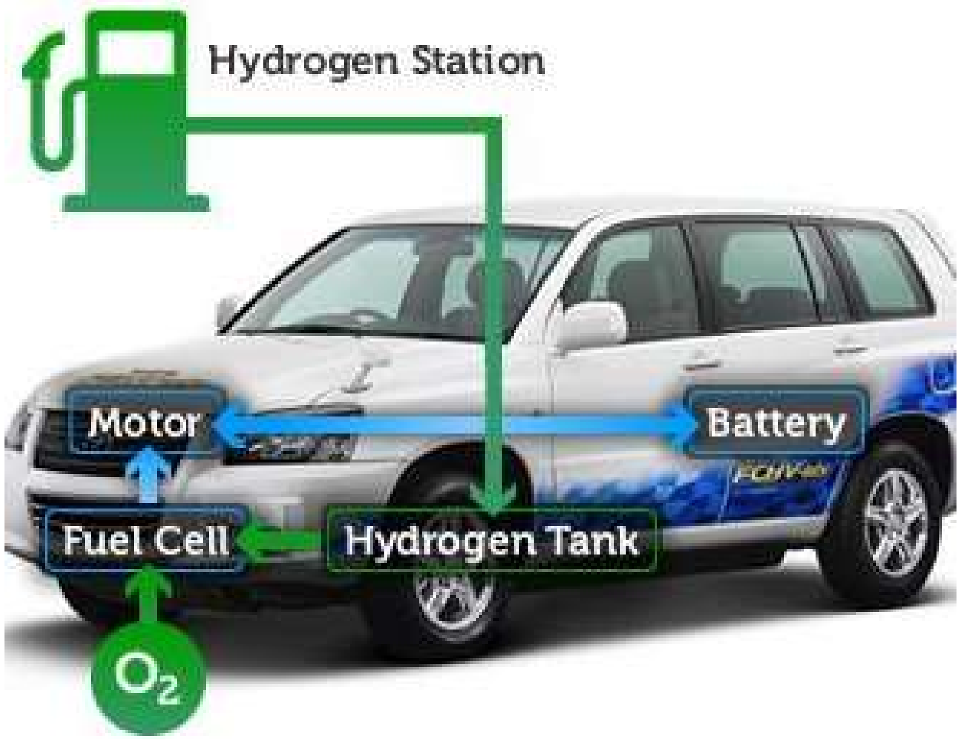

Figure 22. Process the hydrogen fuel takes [23].

Solar Panel Powered Electric Motor: This concept uses a solar panel to power a battery through a solar regulator. Then the battery powers an electric motor, which then produces mechanical energy. The solar panel power process is shown in Figure 23.

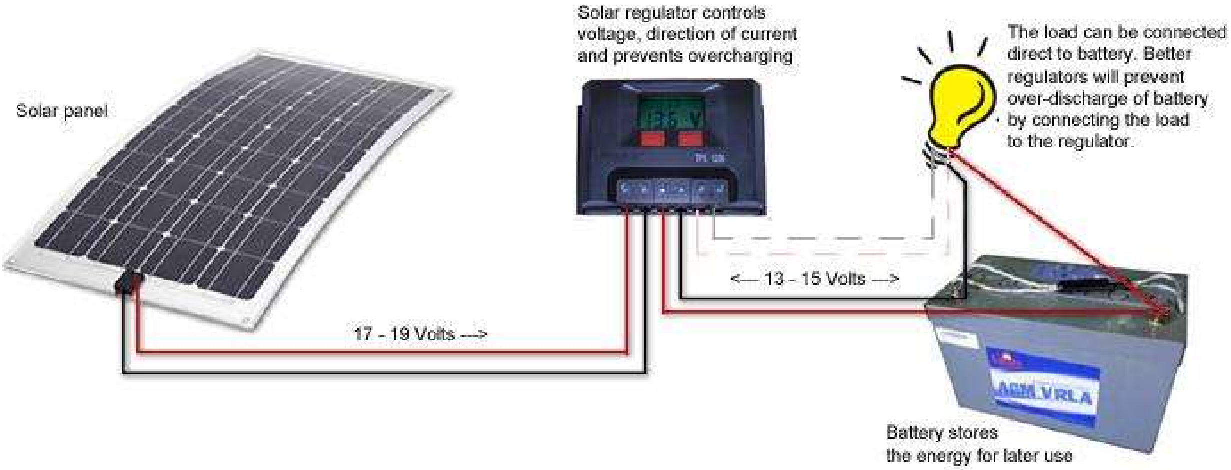

Figure 23. Solar panel produces voltage to send to a regulator which is then safely sent to a battery [23]

Controlling Methods: Human-machine interaction, in order to allow effective operation and control of the machine from the operator. while the machine simultaneously feeds back information that aids the operator in decision making.

Wired Controllers: Communication is done between the operator and the deminer through an electrically wired connection between the controller and the deminer.

Remote Controlled: Input commands from the operator to the deminer are done wirelessly from a distance. Digitally-coded signals of infrared radiation are used to control the functions of the deminer.

Manned: The user is in direct control of the deminer's functions through levers and switches that are mounted onboard the deminer.

Automated: The deminer performs its functions on a preprogrammed path of operation, with the most minimal input from the operator possible.

Concept Selection

Neutralization Method: The roller neutralization method was selected after analysis using screening and selection matrices. Compared to other concepts, the roller excelled in clearance speed, transportation cost, maintenance cost, and manufacturing cost [6]. The screening and selection matrices used are shown below in Table 2a and Table 2b.

Table 2a. Screening Matrix for Neutralization Method

	Neutralization Method			
Selection criteria:	**Tiller**	**Roller**	**Flail (Reference)**	**Controlled Detonation**
Effective Depth	-	-	0	+
Cost to Operate	-	+	0	0
Energy Consumption	-	0	0	+
Life-span	-	0	0	0
Maintenance Cost	-	+	0	+
Safety	+	0	0	0
Manufacturing Cost	-	+	0	+
Transportation to Site	-	+	0	+
NET SCORE	-6	3	0	5
RANK	5	2	4	1
CONTINUE?	NO	YES	YES	YES

Table 2b. Selection Matrix for Neutralization Method

Neutralization Method								
		Flail (Reference)		Roller		Controlled Detonation		
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	
Effective Depth	0.15	3	0.45	2	0.3	3	0.45	
Operating Cost	0.075	3	0.225	3	0.225	4	0.3	
Life-Span	0.125	3	0.375	3	0.375	3	0.375	
Maintenance Cost	0.075	3	0.225	4	0.3	4	0.3	
Safety	0.15	3	0.45	3	0.45	3	0.45	
Clearance Speed	0.15	3	0.45	5	0.75	1	0.15	
Transportation Cost	0.125	3	0.375	5	0.625	5	0.625	
Manufacturing cost	0.15	3	0.45	4	0.6	4	0.6	
Total Score		3		3.625		3.25		
Rank		3		1		2		
Develop?		NO		YES		NO		

Locomotion: After screening and selection shown in Table 3a and Table 3b, solid rubber wheels were selected for continued development. Compared to the other concepts, solid rubber wheels were more durable and required maintenance less frequency. The maintenance required for them was also less labor intensive [24].

Table 3a. Screening Matrix for Locomotion

Locomotion						
Selection Criteria	Standard Pneumatic	Solid rubber wheels	Continuous Track	Continuous Track	Robotic Legs	Rotary Blades
Cost	0	0	-	-	-	-
Efficiency	0	0	0	0	-	-
Weight	0	0	-	-	0	+
Ease of Manufacture	0	0	-	-	-	-
Durability	0	+	+	+	-	-
Flotation	0	0	+	+	+	+
Maneuverability	0	0	+	+	+	+
Traction	0	0	+	+	-	-
NET SCORE	0	1	1	1	-3	-3
RANK	4th	1st	1st	1st	5th	5th
CONTINUE?	YES	YES	YES	YES	NO	NO

Table 3b. Selection Matrix for Locomotion

Locomotion									
		Standard Pneumatic Wheels (reference)		Solid Rubber Wheels		Continuous Track (Rubber)		Continuous Track (Steel)	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Capital cost	0.3	3	0.9	3	0.9	1	0.3	1	0.3
Durability	0.2	3	0.6	4	0.8	5	1	5	1
Diffculty and frequency	0.2	3	0.6	4	0.8	1	0.2	1	0.2
Weight	0.1	3	0.3	3	0.3	2	0.2	1	0.1
Flotation	0.1	3	0.3	3	0.3	4	0.4	4	0.4
Maneuverability	0.1	3	0.3	3	0.3	5	0.5	5	0.5
Traction	0.1	3	0.3	3	0.3	4	0.4	4	0.4
NET SCORE		3.3		3.7		3		2.9	
Rank		2nd		1st		3rd		4th	
Develop?		NO		YES		NO		NO	

<u>Protection Method</u>: After analysis using screening and selection matrices the distance between the AP mine and the deminer concept and the blast shield concept tied. However, in the end with further research and consideration the distance concept was selected. Compared to other concepts it excelled in the deminers overall life-span and operational cost when considering the roller concept as our primary neutralization method [6]. The screening and selection matrices used are shown below in Table 4a and Table 4b.

Table 4a. Screening Matrix of Deminer Protection Concepts

	Protection Method				
Selection criteria:	Blast Shield (reference)	Deminer Armour	Deflection	Distance Between AP Mine and Deminor	Expendable Attachment
Manufacturing Cost:	0	-	+	-	0
Operational Cost:	0	0	0	+	-
Weight:	0	-	+	-	0
Life-span:	0	-	0	0	0
Safety:	0	0	0	+	0
Maintenance Cost:	0	-	0	+	+
NET SCORE	0	-4	2	1	0
RANK	3rd	5th	2nd	1st	3rd
CONTINUE?	YES	COMBINE	COMBINE	YES	Yes

Table 4b. Selection Matrix of Deminer Protection Concepts

		Protection Method							
		Distance between AP mine and deminer		Blast Shield (reference)		Deminer Armour with Deflection Geometry		Expendable Attachment	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Manufacturing Cost:	0.2	2	0.4	3	0.6	2	0.4	1	0.2
Operational Cost:	0.2	4	0.8	3	0.6	3	0.6	2	0.4
Weight:	0.05	3	0.15	3	0.15	2	0.1	2	0.1
Life-span:	0.2	4	0.8	3	0.6	3	0.6	1	0.2
Safety:	0.15	3	0.45	3	0.45	3	0.45	5	0.75
Maintenance Cost:	0.2	2	0.4	3	0.6	2	0.4	1	0.2
Total Score		3		3		2.55		1.85	
Rank		1st		2nd		3rd		4th	
Develop?		YES		NO		NO		NO	

Motive Power Source: The diesel engine was selected after analysis using screening and selection matrices. Compared to other concepts, the diesel engine excelled in efficiency, energy density, and safety [25]. The screening and selection matrices used are shown below in Table 5a and Table 5b.

Table 5a. Screening Matrix of Motive Power Sources

Selection criteria:	Gasoline Engine (reference)	Desiel Engine	Pneumatic Motor	Electric Motor: Battery Pack	Electric Motor: Hydrogen Fuel Cell	Electric Motor: Solar
Capital cost	0	0	0	+	-	-
Maintanence cost	0	0	+	+	+	0
Efficiency	0	+	-	+	+	0
Energy Density	0	+	-	-	-	-
Availability	0	0	0	0	-	-
Safety	0	+	0	0	+	+
NET SCORE	0	3	-1	2	0	-1
RANK	3	1	5	2	4	3
CONTINUE?	YES	YES	NO	YES	NO	NO

Table 5b. Selection Matrix of Motive Power Sources

Power Scource							
		Gasoline Engine (reference)		Desiel Engine		Electric Motor: Battery	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Capital cost	0.3	3	0.9	3	0.9	4	1.2
Maintanence cost	0.1	3	0.3	3	0.3	4	0.4
Efficiency	0.1	3	0.3	4	0.4	5	0.5
Energy Density	0.1	3	0.3	4	0.4	1	0.1
Availability	0.2	3	0.6	3	0.6	1	0.2
Safety	0.2	3	0.6	4	0.8	4	0.8
Total Score		3		3.4		3.2	
Rank		3rd		1st		2nd	
Develop?		NO		YES		NO	

<u>Controlling Method:</u> We chose to include and combine two concepts for our controlling method: a remote-controlled and an automated system. The two methods were very close in comparison in all criteria. After more research, we found that several competing deminers utilize both methods simultaneously. The screening and selection matrices used are shown below in Table 6a and Table 6b.

Table 6a. Screening Matrix for Controlling Method

Controlling Method				
Selection Criteria	Wired	Controlled (Reference)	Manned	Automated
Safety	-	0	-	+
Implementation	0	0	-	0
Cost	0	0	-	-
explosion)	-	0	-	+
NET SCORE	-2	0	-4	2
RANK	3rd	2nd	4th	1st
CONTINUE?	NO	YES	NO	YES

Table 6b. Selection Matrix for Controlling Method

Controlling Method					
		Remote Controlled (Reference)		Automated	
Selection Criteria	**Weights**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Safety	0.3	4	1.2	5	1.5
Implementation	0.2	3	0.6	2	0.4
Cost	0.1	3	0.3	2	0.2
Range (from mine explosion)	0.2	4	0.8	5	1
NET SCORE		2.9		3.1	
RANK		2nd		1st	
Develop?		YES (COMBINE)		YES (COMBINE)	

Design Illustrations/Selections

Vehicle Selection

The vehicle selection process was to select a vehicle from a vendor that met the specifications and selection criteria, in order to drive the roller mechanism along its path. Research was put into varying vendors (John Deere, CAT, Bobcat, etc.) and different kinds of vehicles, mostly centering the focus on tractors and loaders, for their high tractive force and modifiability. The choices were narrowed down to four varying vehicles, each from different vendors. The first of the vehicles was the John Deere 3025E, which would serve as the benchmark for the selection.

Figure 26. John Deere 3025E

A “basic” compact utility tractor. Includes a gross 24.7 hp, three cylinder diesel engine, a towing capacity of 1356 lbs, and a mass of 986 kg [26].

Dimensions:
Length: 2.810m
Width: 1.430m
Height with ROPS: 2.090m [27]

Figure 27. Kubota BX2370-1 [28]

The second vehicle for the selection is the Kubota BX2370-1, a compact garden tractor with a 3 cylinder 17.7 hp diesel engine, four-wheel drive, Towing capacity of 1765 lbs, and a mass of 640 kg [28].

Dimensions: Length: 2425 mm Width: 1130mm

Height with ROPS: 2215 mm

The third vehicle is the CAT 226D skid steer loader, A 3 cylinder engine with a power capacity of 67.1 hp, a towing capacity of 1550 lbs, and a mass of 2588 kg [29].

Dimensions:
Length: 2524 mm
Width: 1497 mm
Height: 2028 mm [30]

Figure 28. CAT 226D

The fourth and final vehicle is the Bobcat S590 skid steer loader. This vehicle is on higher end in terms of engine capacity (66 hp), towing capacity (2100 lb), and size (2991 kg).

Dimensions: Length: 3378 mm Width: 1727 mm Height: 1976 mm [31]

Figure 29. Bobcat S590

A concept selection process was implemented in order to select the most appropriate vehicle for this project. The criteria included purchase cost, towing capacity, overall compactness or size of the vehicle (this included the overall volume and mass), turning radius, and engine power.

Table 7a. Concept Selection Table (Vehicle Selection)

	Vehicle Selection			
	Concepts			
Selection Criteria: (Benchmark is the John Deere)	(BM) John Deere (3025E)	Kubota (BX2370-1)	CAT (226D)	Bobcat (S590)
Cost	0	+	-	-
Tow Capacity	0	0	+	+
Compactness	0	+	-	-
Turning Radius	0	+	+	+
Engine Power	0	-	+	+
NET SCORE	0	2	1	1
RANK	3	1	2	2
CONTINUE?	N	Y	N	N

Table 7b. Concept Selection Table Legend

Rating Legend
"+" for better than the benchmark
"-" for worse than the benchmark
"0" for same as benchmark
Net score = (No, +'s) - (No. '-s)

The John Deere 3025E served as the benchmark for the selection process. The John Deere's market price was $17,324 USD, the Kubota's price being $11,720 USD, the CAT 226D' price was only available by request (never obtained), but similar models cost $32,000 to $42,000; and finally the Bobcat S590 price was in the $40,000 to $46,000 range. In this category, the Kubota had the advantage.

The towing capacity for each vehicle was included with the presentation of each vehicle, due to the nature of the two skid steer loaders, they both had the advantage on towing capacity. The Kubota's specifications state the lift capacity is 680 lbs, and a quote obtained from a vendor specify that the vehicle can tow up to 1765 lbs [32]. So, the Kubota was conservatively marked to be the same as the benchmark.

The compactness was measured by calculating the overall volume of each vehicle with a simple "length times width times height (L x W x H)" calculation. John Deere's volume multiplied to be 8.40 m^3, Kubota's volume multiplied to be 6.07 m^3, CAT's ended up being 7.66 m^3, and the Bobcat S590's volume ended as 11.5 m^3. In the case of compactness, the Kubota had the advantage in this category.

The turning radius is shown in each vehicle's specification sheet. The John Deere's turning radius is shown to be 9.2 feet (110.4 inches), the Kubota: 90 inches, the CAT 226D: 43.5 inches, and the Bobcat: 79.9 inches. All vehicles have an advantage over the benchmark, but the skid steer loaders, due to their nature of turning by dragging their fixed-orientation wheels across the ground, have better advantage of maneuverability.

The engine power was presented above for each vehicle. The skid steer loaders have an advantage over the benchmark with about three times the engine output, while the Kubota has an inferior engine power output.

Ultimately, the vehicle that was selected was the Kubota by having a net score of 2 while the skid steer vehicles had a net score of 1. With the results of this selection process, the Kubota BX2370-1 is the chosen vehicle for this project.

Vehicle Specifications

Below is a compilation for the vehicle we have chosen, the Kubota BX2370.

BX Series Specifications

BX1870/BX2370 BX2670/BX25D Kubota

Specifications

Model	BX1870	BX2370	BX2670	BX25D
Engine				
Type	Liquid-cooled, 3-cylinder diesel			
Model	Kubota D722	Kubota D902	Kubota D1005	Kubota D902
Engine gross HP at 3200 rpm* HP (kW)	18.0 (13.4)	23.0 (17.2)	25.5 (19.0)	23.0 (17.2)
PTO horsepower at 3200 rpm HP (kW)	13.7 (10.2)	17.7 (13.2)	19.5 (14.5)	17.7 (13.2)
Displacement cu.in. (cc)	43.9 (719)	54.8 (898)	61.1 (1001)	54.8 (898)
Fuel tank capacity gal. (ℓ)	6.6 (25)			
Drive train				
Transmission	HST, High-Low gear shift (2 forward / reverse)			
Drive method	2WD and 4WD selection			
Brakes	Wet disc			
PTO	Live independent, wet hydraulic clutch			
Rear	STD (540rpm)			
Mid	STD (2500rpm)			
Hydraulics				
Pump output gpm (ℓ/min.)	6.2 (23.5)			
3-point hitch	Category I			Optional
Lift capacity @ 24" behind pin lbs. (kg)	680 (310)			
Steering	Hydrostatic Power Steering			
Tire size				
Front Turf/Bar/Industrial	16x7.5–8 / 16x7.5–8 / N.A.	18x8.5–10 / 18x8.5–10 / 18x8.5–10		18x8.5–10 / N.A./ 18x8.5–10
Rear Turf/Bar/Industrial	24x12–12 / 24x12–12 / N.A.	26x12–12 / 26x12–12 / 26x12–12		26x12–12 / N.A./ 26x12–12
Traveling speeds at rated engine rpm (Turf) Forward mph (km/h)	0–7.8 (0–12.5)	0–8.4 (0–13.5)		
Reverse mph (km/h)	0–5.9 (0–9.5)	0–6.5 (0–10.5)		
Dimensions				
Length with 3-point hitch in. (mm)	92.1 (2340)	95.5 (2425)		
Width (w/ turf tire) in. (mm)	44.5 (1130)			
Height with ROPS in. (mm)	86.2 (2190)	87.2 (2215)		
Wheelbase in. (mm)	52.8 (1340)	55.1 (1400)		
Ground clearance (front axle) in. (mm)	9.0 (230)	8.7 (220)		
Tread Front in. (mm)	34.6 (880)	36.6 (930)		
Rear in. (mm)	32.2 (820)			
Turning radius (w/o brake) feet (m)	7.2 (2.2)	7.5 (2.3)		
Tractor weight lbs. (kg)	1345 (610)	1410 (640)	1466 (665)	1587 (720)

Figure 30. Kubota vehicle specifications [28].

Hitch Design

The design of the hitch connects the frame of the vehicle to the frame of the roller. The hitch consists of a heavy duty block and plate, as shown in Figure 31, with a heavy duty 2” ball trailer hitch, as shown in Figure 36. The thickness of the block was designed to be 2.5” thick to support the trailer ball and to get the high factor of safety of at least 4, as shown in the calculations below. The plate has a ¼” thickness and has 3 slots in the middle for the block to be slot welded and fillet welded to the plate, as shown in the engineering drawings DM-0008, DM-0009, ASM-002. The predicted cost to manufacture the hitch assembly without the ball is $800.

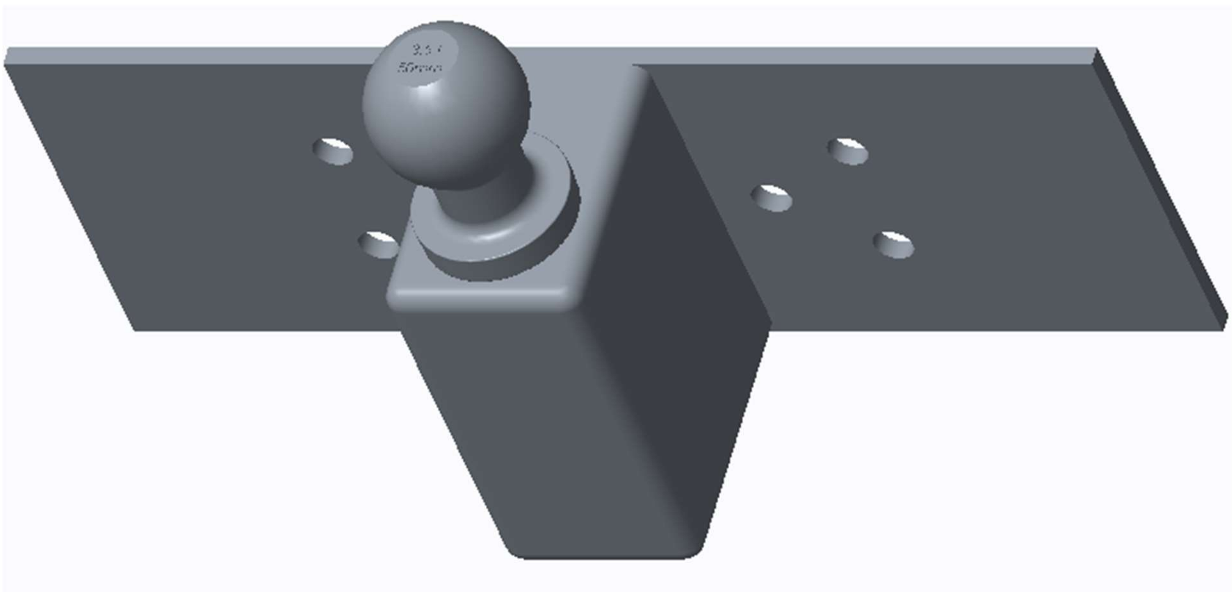

Figure 31. CREO model of tow ball hitch ASM-002.

Hitch force and stress analysis

Our total maximum weight our vehicle can pull is going to be 2000 lbf. We design the hitch to withstand at least a 4G load equivalent to 8000 lbf. The material we are using is A36 steel which has a ultimate tensile strength of 79770.8 psi (550 MPa).

$$F_{max1} := 2000\ \boldsymbol{lbf} \cdot 4 = 8000\ \boldsymbol{lbf}$$

A) The area of a single slot in the plate is 0.696349541 in^2

area of 3 slots in the plate: $A_b := 3 \cdot (0.696349541)\ \boldsymbol{in}^2 = 2.089049\ \boldsymbol{in}^2$

max stress = (F_max1)/A_b $\quad \sigma_b := \dfrac{F_{max1}}{A_b} = 3829.494399\ \boldsymbol{psi}$

This is the max stress our: $\sigma_b = 3829.494399\ \boldsymbol{psi}$

factor of saftey: $\quad FoS := \dfrac{79770.8\ \boldsymbol{psi}}{\sigma_b} = 20.830635$

This max stress is under our ultimate tensile stress of our material A36 steel (79770.8 psi). This gives us a factor of safey of 20.

B) The 4G load was also places in the block of the hitch to assure the same high quality factor of saftey in the block as in the slot welds. The force was placed as a bearing force of 8000 pound force which gave us a maximum shear stress of 3837.7 psi and a maximum von Mises stress of 7017.6 psi, as shown in Figure 32 and Figure 33. This gives the block a saftey factor of 11.

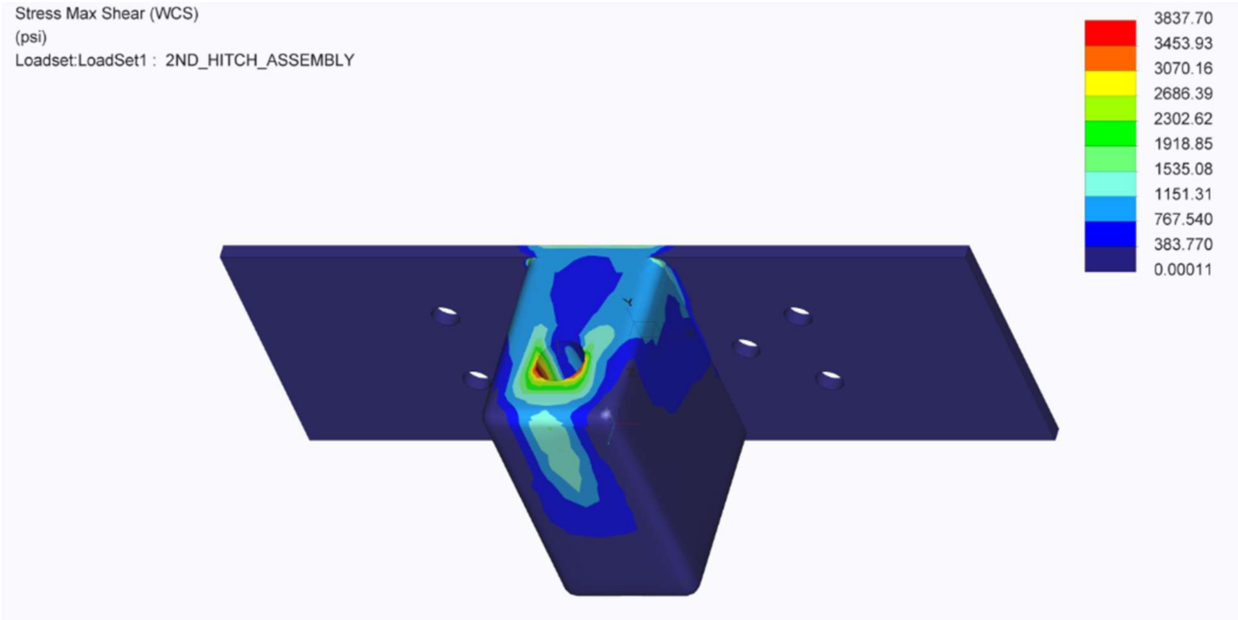

Figure 32. This shows the maximum shear stress of parts DM-0008 and DM-0009 with a 8000 lbf bearing load.

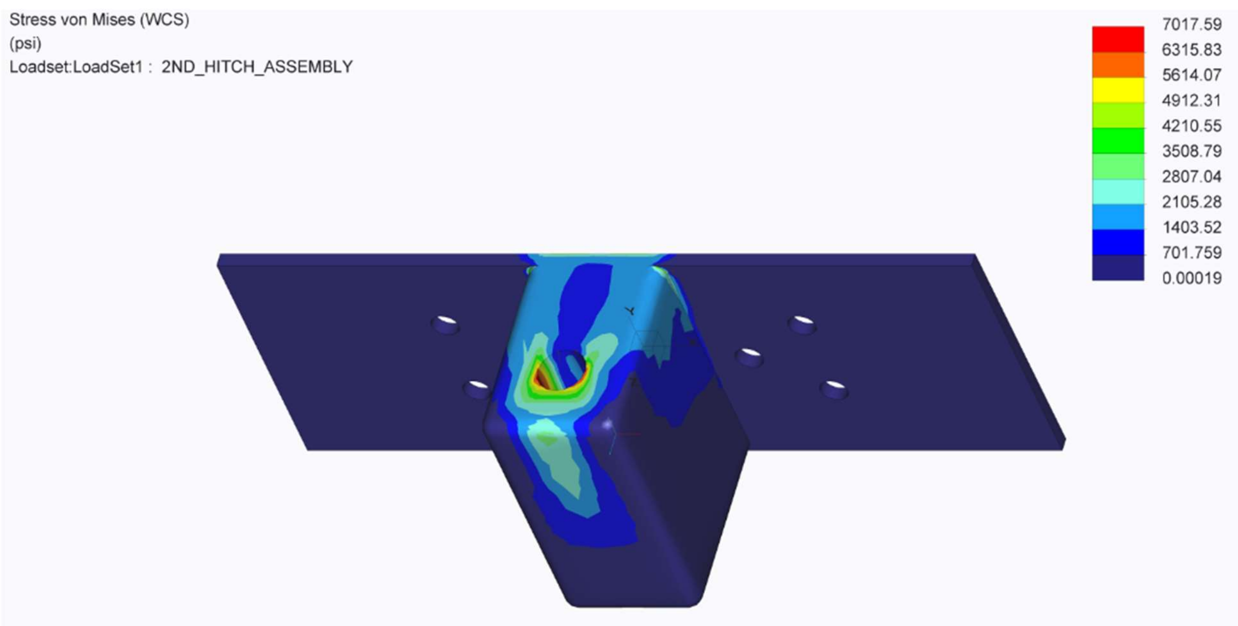

Figure 33. This shows the maximum von Mises stress of parts DM-0008 and DM-0009 with a 8000 lbf bearing load.

The hitch consists of six holes (½" diameter each) that will be used to fit bolts through to fasten it to the frame of the vehicle with nuts. The bolts and nuts will be purchased from BoltDepot.com. This company gives data for each bolt needed to determine the efficient size and grade bolt to order. After calculations, a grade 8 bolt with a minimum diameter of 0.48" will be needed, as shown below.

Hitch Bolt Analysis

The bolts support a 64G load equivalent to 569344 N (127994 lbf). This setup results in each bolt supporting 94891 N (21332 lbf). The bolt we are using is Grade 8 Medium carbon alloy steel, quenched and tempered with a proof load of 827.37 MPa (120000 psi).

$$F_{max4} := \frac{2000\ lbf \cdot 4 \cdot 16}{6} = 21333.333333\ lbf$$

Proof Load: $PL := 120000\ psi$

$$D := \sqrt{\frac{F_{max4}}{\frac{\pi}{4} \cdot PL}} = 0.475766\ in$$

The diameter needed is 0.46 in and our max bolt hole is 0.5 in. We can purchase half inch bolts to satisfy our needs. Also, the length of the bolt should be longer than 1.25 in.

The chosen bolt from BoltDepot is a "Hex bolt, Zinc plated grade 8 steel yellow, ½"-13 x 1-¼"" that cost $2.64 for 6, as shown in Figure 34 [33]. Also paired with these bolts will be "Flange nuts serrated, Zinc plated grade 8 steel yellow, ½"-13" that cost $2.70 for 6, as shown in Figure 35 [34].

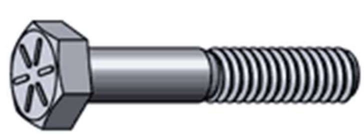

Figure 34. Hex bolt

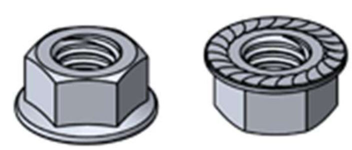

Figure 35. Serrated flange nuts

Finally, the trailer ball will be ordered from CURT manufacturing and will cost $16.72 [35]. The ball is rated up to 12,000 pounds so it will be a perfect selection to complete the hitch. Also if will fit perfectly in the threaded hole that our hitch was designed for as shown in the engineering drawing DM-0009 and ASM-002.

Figure 36. Wire Lock Pin from Home Depot

Roller Frame Design

The roller frame will serve as the main connection between the steel rollers and the vehicle driving them. It will be made completely of A36 structural steel. From CREO Simulate stress analysis (attached at the end of the report), we find that the maximum von mises stress in the frame will be 13 ksi. With a yield strength of 36 ksi, we arrive at a safety factor of 2.7. To further improve stress estimates in the prototype, force tests will be introduced to accurately measure impact forces of mine detonations and roller impact on the frame.

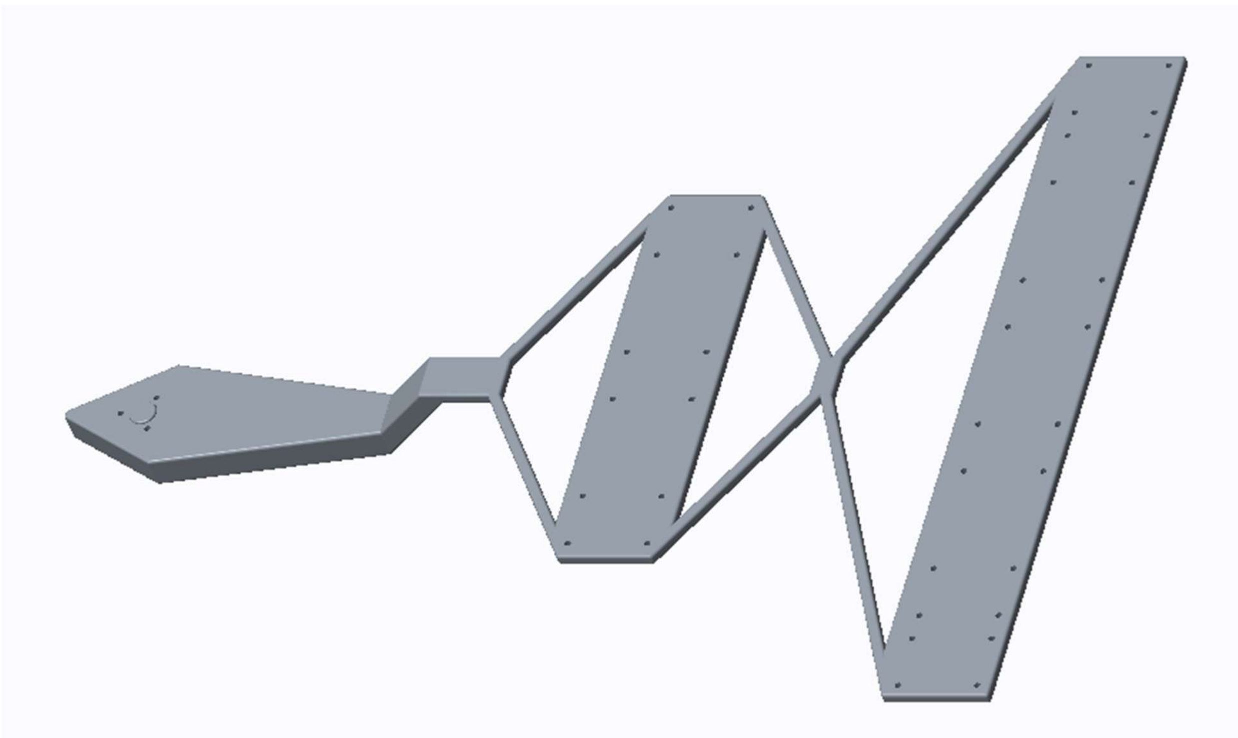

Figure 37. CREO model of frame DM-0001

The frame is designed to accommodate a trailer hitch that we will buy from Croft Trailer Supply. The RAM80071 A-frame coupler has a towing capacity of 8000 lbs.

Figure 48. Female trailer hitch [41]

Armor Design

The armor was designed to be able to protect the selected vehicle and also any other vehicle that is to be pushing the deminer because it will be attached to the frame as shown in Figure 38. Shown below are pictures of the left and right front panel of the armor DM-0010 and DM-0011, the upper support beam DM-0012, the lower support beam DM-0013 and the assembly of the parts ASM-0003 and DM-004, as shown in Figures 39, 40, 41, 42, 43. The total cost of manufacturing the armor is predicted to be $2,000. Full detailed drawing are shown in the engineering drawing section.

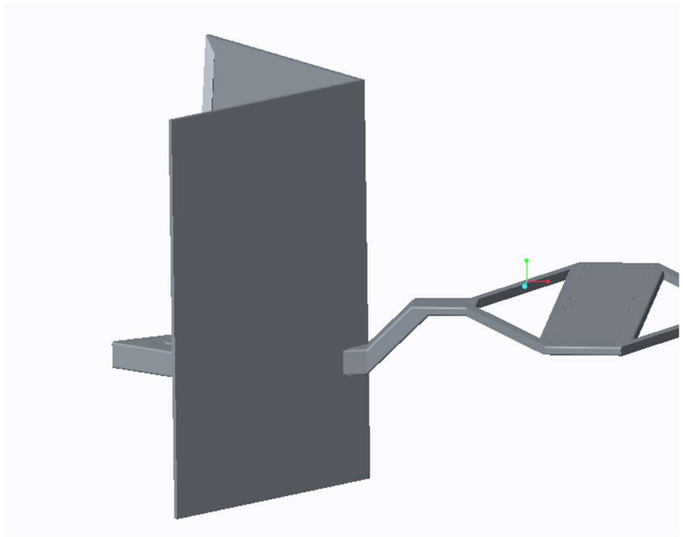

Figure 38. CREO model of armor attached to the frame.

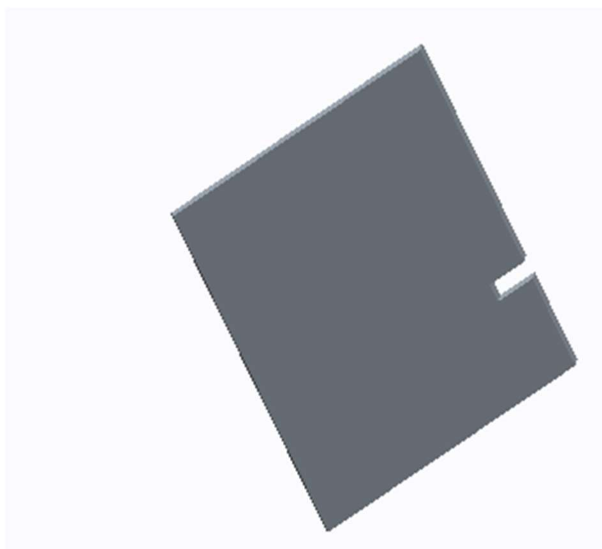

Figure 39. CREO model of left armor panel DM-0010.

Figure 40. CREO Model of Right Armor Panel DM0011.

Figure 41. CREO Model of Armor Upper Support Beam DM-0012.

The upper support beam helps the front panel from bending back or forward to keep it in place. The dimensions help the beam fit perfectly in between the front panel and the frame, as shown in Figure 43 and in the engineering assembly drawing ASM-003 and ASM-004.

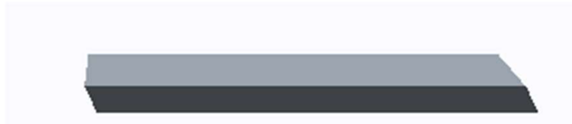

Figure 42. CREO Model of Armor Lower Support Beam DM-0013.

The lower support beam, similar to the upper support beam, helps the front panel front moving back or forward to keep it in place. The dimensions help the beam fit perfectly in between the front panel and the frame, as shown in Figure 43 and in the engineering assembly drawing ASM-003 and ASM-004.

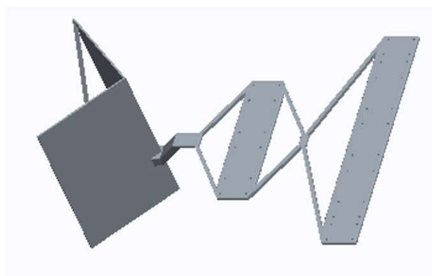

Figure 43. Armor Assembly Attached to the Frame ASM-003 and ASM-001.

This drawing depicts how the armor is placed onto itself and to the frame. The armor fits perfectly before the frame has a lift in elevation, as shown in Figure 43 and in the engineering assembly drawing ASM-003 and ASM-004.

The thickness of the plate and what material to use can be approximated with the fluid jet equation. This equation does not depend on the impact velocity. this fact is a consequence of the assumption of a steady-state one-dimesional flow, neglecting material strength effects.

- L will be the length of the bullet
- P_bullet will the the density of the bullet material
- P_plate will be the density of the plate material
- Depth will be the minimum thickness of the plate needed in that test combination.

Lead bullet vs. Carbon Steel plate (SS400 steel)

$p_{LEADbullet} := 0.4097\ pci \qquad p_{STEELplate} := 0.284\ pci \qquad L_{avg} := 0.25\ in$

$$Depth_{min} := L_{avg} \cdot \sqrt{\frac{p_{LEADbullet}}{p_{STEELplate}}} = 0.3\ in$$

The armor is made of carbon steel which can withstand the impact of a .22 caliber bullet, as shown above. The equations are from “High Velocity Impact Dynamics” by Jones A. Zukas and published by John Wiley & Sons, Inc [38].

Roller Arm Assembly

Fastened to the frame will be two arrays of swivel casters. The caster wheels will be removed and replaced with the roller arm to connect the steel rollers to the frame. This design allows for two degrees of rotation, enabling the rollers to move vertically and rotate independently of each other. The swivel casters will be purchased from MSCDirect.com and they have a load tolerance of 1000 lbs each. There will be a total of 7 swivel casters attached to the frame with 4 bolts and nuts each. They cost about $39 each. It will be attached to the frame by using 4 bolts that are ⅜ inch in diameter and 2 inches long. Each of these bolts costs $3.

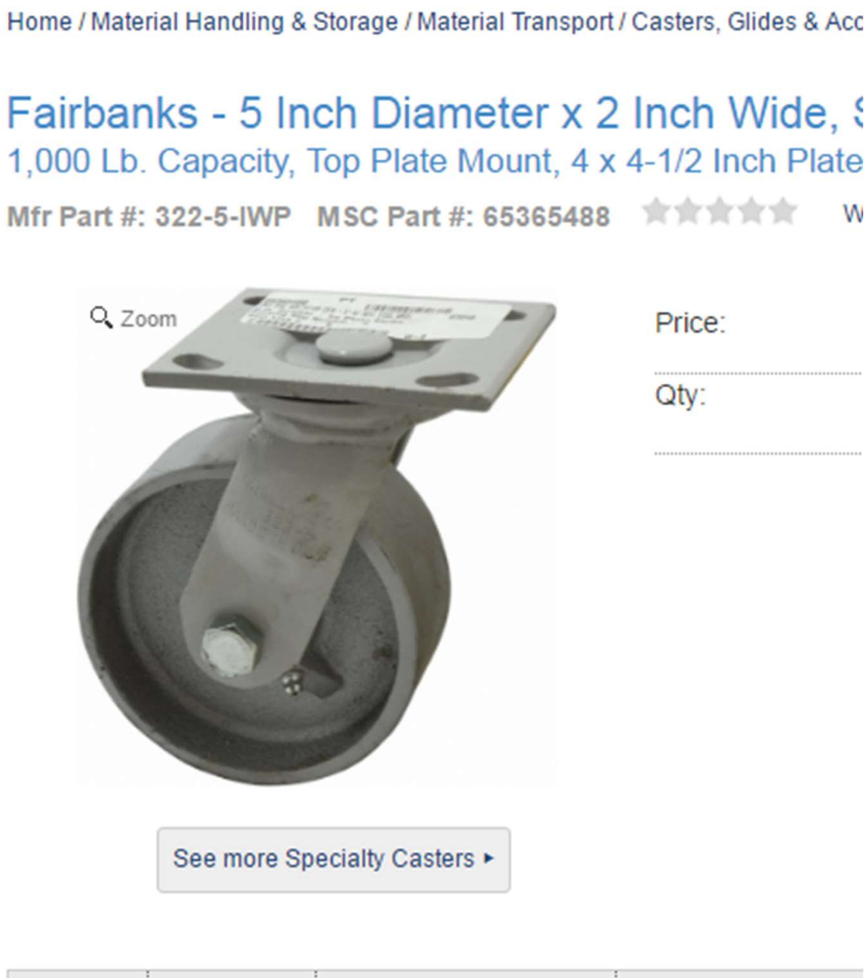

Figure 45. Swivel Caster from MSCDirect.com [39]

Fastened to the front of the frame will be two rigid support rollers. These serve to keep the frame elevated from the ground and to prevent the deminer to roll or tip over while moving. They are fastened to the frame by the same method used with the casters. Applying the entire weight of the frame to the supports using CREO Simulate analysis shows a maximum compressive stress of 4.19 MPa in the support arm. With a compressive strength of 1290 MPa, our design has a safety factor of over 300. We will use the same bolts that were used to secure the hitch to the vehicle.

Figure 46. Support roller arm DM-0002 and DM-0003

Roller Arm Connection

The roller arm has a simple function within the overall design, it serves as a connecting member between the roller disk and the pin connections at the base of the roller frame. It also allows energy to be transferred through it from the disk, performing a lever type motion about the pin axis. These connections will be made with three-eighth inch bolts. How the roller arm is placed into the system can be seen below. The part number for the roller arm is designated DM-0004

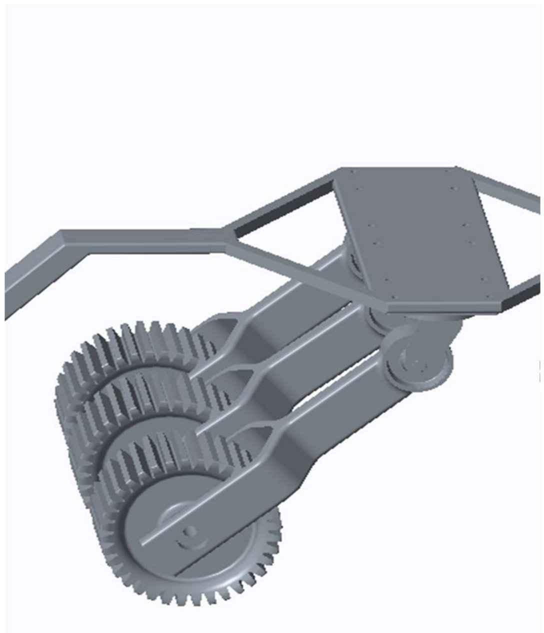

Figure 50. Roller Assembly

Modeling (Roller Arm)

The dimensions of the roller arm were designed according to the design of the frame. With the disk radius being 82 mm and the height of the frame from the ground being 483 mm, the parameters allowed for the roller arm length to be at most 537 mm from hole to hole.

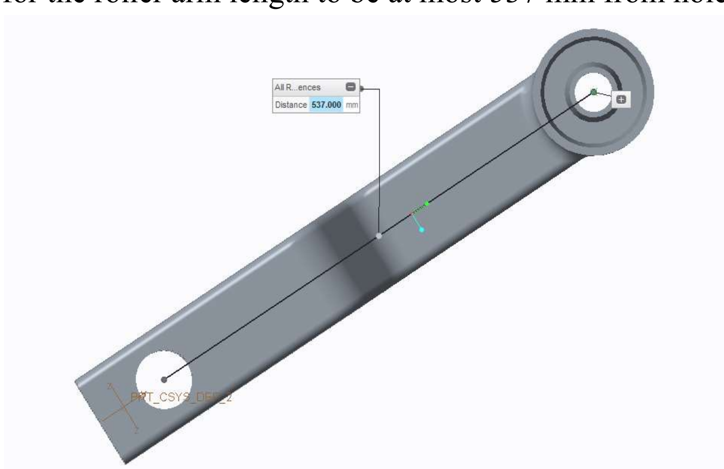

Figure 51. Hole to hole length DM-0004

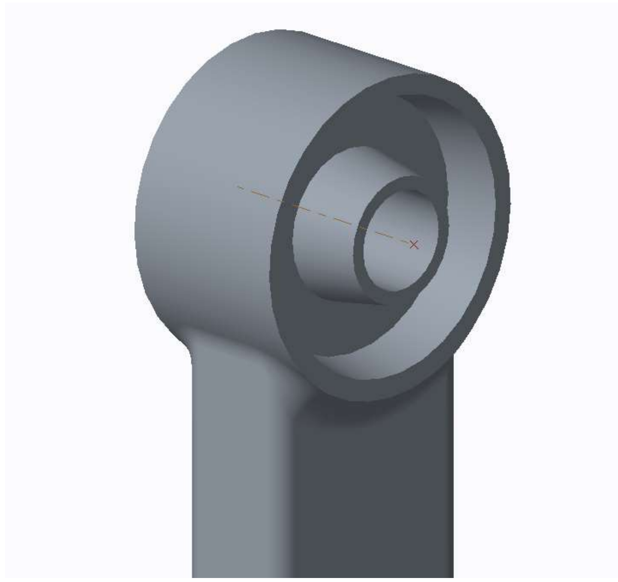

Figure 52. Roller arm head DM-0004-1

The head of the arm has a round, wheel shape to pair with caster attachments beneath the roller arm. This shape will allow the arm to rotate about the caster connection.

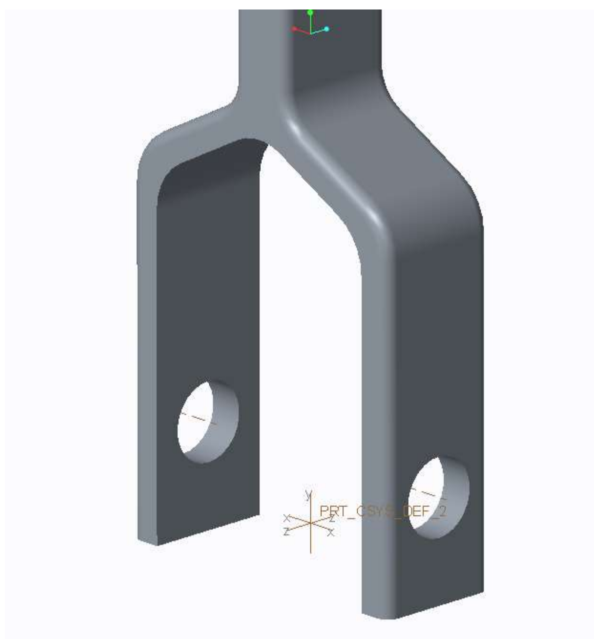

Figure 53. Roller arm fork connection DM-0004

The roller disk fits into the fork connection and connects through the holes. The fork design allows for the forces applied to the arm to be evenly distributed through the arm.

Material Selection (Roller Arm)

The material that will be used to make the roller arm will be ASTM class 60 grey cast iron. It has a relatively low cost, good machinability, and has a low rate of thermal expansion. The silicon within the material will make casting a good option for manufacturing the part. It has lower tensile strength (62.5 Kpsi) and shock resistance than its steel alloy counterparts, but cast iron's compressive strength is comparable to lower tiered carbon steels (187 Kpsi). Plus, its damping capacity is many times higher than steel, which will benefit the roller arm since it will be experiencing high amounts of compressive forces and excessive vibration. Typically, this material is use for brake components, engine blocks, supports, and dimensionally stable tools that undergo temperature variations. [45] [46]

Manufacturing Process (Roller Arm)

A metal casting process, specifically green-sand mold casting, will be used to manufacture these roller arms. Sand-mold casting is a widely used expendable casting process that can accommodate many ranges of sizes. Sand casting is a process that consist of pouring molten metal into a sand mold, allowing the metal to solidify, and then breaking up the mold to remove the casting. Cores can be used to mold the holes that are in the roller arm. Since the mold is sacrificed to remove the casting, a new sand mold must be made for each arm made.

Due to the roller arm's relative geometric simplicity it should be suitable for the san-casting procedure. Also additional machining may be necessary for getting the geometry of the roller head the right size to mate with the roller casters beneath the framework. Therefore, the machine allowance for sand casting should be within the range of 1.5 mm and 3 mm (1/16 in and 1/4 in). [47]

Disk Design:

The roller disk is the part of the Deminer that applies force on the ground to activate the landmines. It must be strong enough to survives the impacts of the detonation. The deminer will have 2 rows that contain 8 disks. Each disk Babbitt-Coated Leaded-Bronze bearing shall be placed in the center of the disk by using a press to force fit it. The bearing shall minimize the disk's rolling friction, and prevent the rollers from skidding. As shown in the analysis (page 55), the roller is well designed enough to withstand the explosion because that the maximum stress occurring in the disk is less than half the compressive strength of the material (1290 MPa).

The rollers are made of ASTM Grade 60 Grey Iron. This iron was found to be an excellent alloy for this application due to its very high compressive strength (1290 MPa) and hardness (HB302). This alloy is also cheap, which reduces the maintenance cost. The material cost about 520 USD per metric Ton.

The roller will be casted to minimize the manufacturing cost and the hub will be machined because it requires higher tolerance. Zerk fitting will be used to lubricate the connection between the roller and the axle that link between the roller and the fork.Zerk fittings are used on cars, trucks and many types of industrial machinery. The operator shall use a grease fitting gun to lubricate the Disks. Lubricating the disks is necessary to ensure a smooth rolling action without skidding.

Figure 54. Zerk fitting similar to the one used in our model [48]

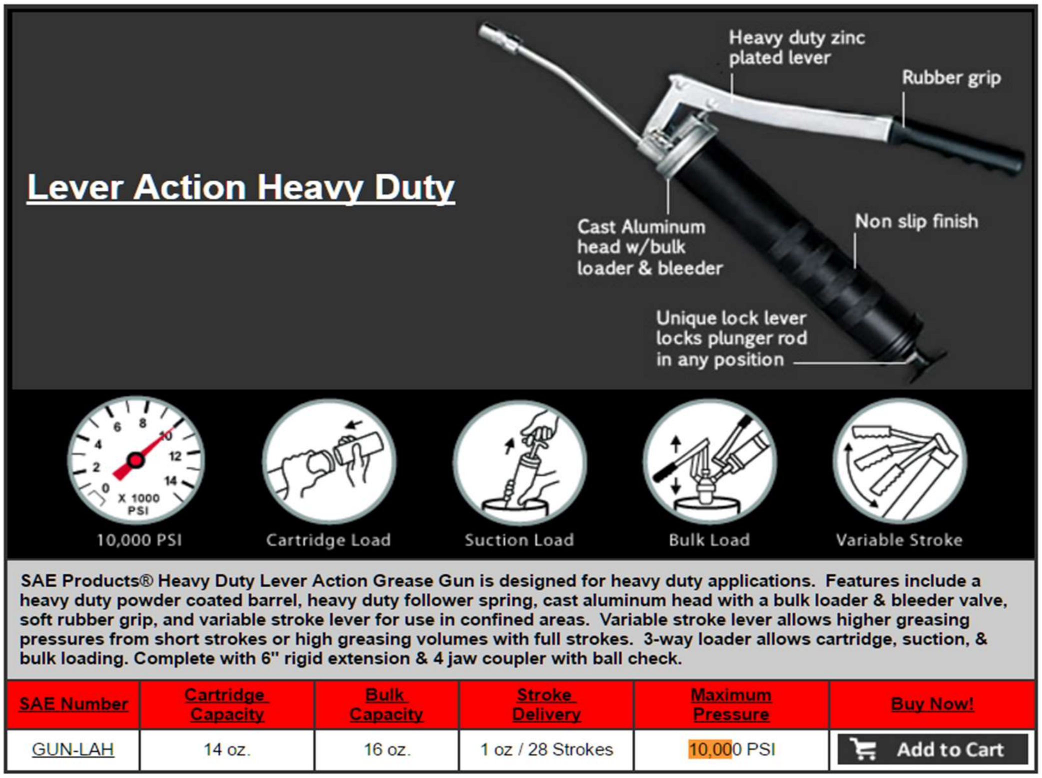

Figure 55. Grease fitting gun used to lubricate the disk [49]

Controller Design

The design, manufacturing and implementation of the remote control system of the deminer will be outsourced to TORC ROBOTICS. TORC ROBOTICS has years of experience equipping various types of vehicles for total control via remote, including heavy duty farming and digging equipment. The estimated cost of purchasing and installing the necessary equipment is around 4000$. Our vehicle controls are simple enough that the most basic of their systems, will suffice.

Figure 49. TORC ROBOTICS Controller [42]

Energy Transition (Roller Arm)

When the roller disk makes contact with a mine, the detonation will cause the disk to move in an upwards direction. This motion causes the roller arm to rotate about the pin, which would be about the x-axis, according the model geometry. The speed at which the roller disk strikes the frame is to be determined.

To find the velocity of the roller disk, the energy of a mine detonation is to be determined first. When calculating the energy balance of the system, two main assumptions are made. The first assumption is that the mine detonation energy can be approximated to be equivalent to the energy of the 20 gauge shotgun shell. The 20 gauge blast has a similar cone shaped blast profile and they both presumably have explosive and focused energy outputs. One source says the muzzle energy of a 20 gauge is 1320 lbf-ft while another source says the muzzle energy is 2475 J (1825.5 lbf-ft) [43], [44], . The muzzle energy of ranges roughly between 1200 to 1800 lbf-ft.

So the energy of a mine detonation is concluded to be 1500 lbf-ft. The second assumption is that, at a maximum, only about one-third of the energy of the mine explosion is actually transferred linearly into the disk. The reason being is he cone shape of the mine explosion, some of the energy is dispersed outward, outside of the area of the roller disk. Also, the roller disk can come into contact with the land mine from various position along the width of the disk, causing the energy distribution to be uneven and varied from to mine to mine. So it is determined that, at most, one-third (λ) of the mine detonation energy will transfer through the roller. So “1/3” will serve as an adjustment factor for the mine detonation energy (1500 lbf-ft).

So,

$\square\square = 1500\ \square\square\square * \square\square = 2033.73\square$

And with the explosion ratio,

$\square = \frac{1}{3}$

So by applying the explosion ratio to the initial kinetic energy.

$\square\square_1 = \square * \square\square$

With these assumptions, the initial angular velocity can be determined with the kinetic energy equation:

$$\square\square_1 = \frac{1}{2} * \square_{\square\square} * \square_1^2$$

With I_{xx} being the moment of inertia of the roller arm/roller disk assembly about the fixed pin axis (which would be the x-axis), and the initial angular velocity is determined to be,

$\square_1 = \sqrt{(2 * \square\square_1)/\square_{\square\square}} = 414.723\ \frac{\square\square\square}{\square}$

With the initial angular velocity found, energy balance can be applied in order to find the final angular velocity.

$\square\square_1 + \square\square_1 = \square\square_2 + \square\square_2$

With KE_1 given before and the initial state of $\square\square_1 = \square * \square * h$ adding up to zero (because h is initially zero). The energy equation becomes,

$$\square\square_1 + 0 = \frac{1}{2} * \square_{\square\square} * \square_2^2 + (\square * \square * h_2)$$

m being the total mass of the roller arm/roller disk (, *g* being the acceleration due to gravity (9.81m/s or 9806.65mm/s), and *h* being the height from the center of gravity of the assembly to the bottom of the frame (being 286mm). The final angular velocity is determined to be,

$$\square_2 = \sqrt{(2 * (\square\square_1 - \square * \square * h)/\square_{\square\square}} = 313.169\ \frac{\square\square\square}{\square}$$

With an hole to hole length of 537mm, linear velocity can be calculated to be,

$$\square = \square_2 * 537\square\square = 2.935\ \frac{\square}{\square}$$

So, with these calculations, it is determined that the roller disk will strike the bottom of the frame at 2.935 m/s. The equivalent drop height can be found using the well known equation of

$$h = \frac{\square^2}{2 * \square} = 0.439\square$$

So, the roller disk hitting the frame would be the equivalent of dropping the roller disk and arm from 0.439m in the air. This is likely to cause some problems in long run with these two components bashing into each other for each mine detonation. So to mitigate this effect, rubber bumpers will be fixed at the striking position of the roller frame. The MathCad document for these calculations can be found in the appendix alongside the references used for 20 gauge energy outputs.

Personnel Duties

Project Schedule

A detailed schedule for the design process of the deminer has been made to cover the span of the 2017 University of Texas of the Permian Basin spring semester. This schedule is organized below in Figure 54. The duties have been assigned equally between all team members and are recorded in Table 7.

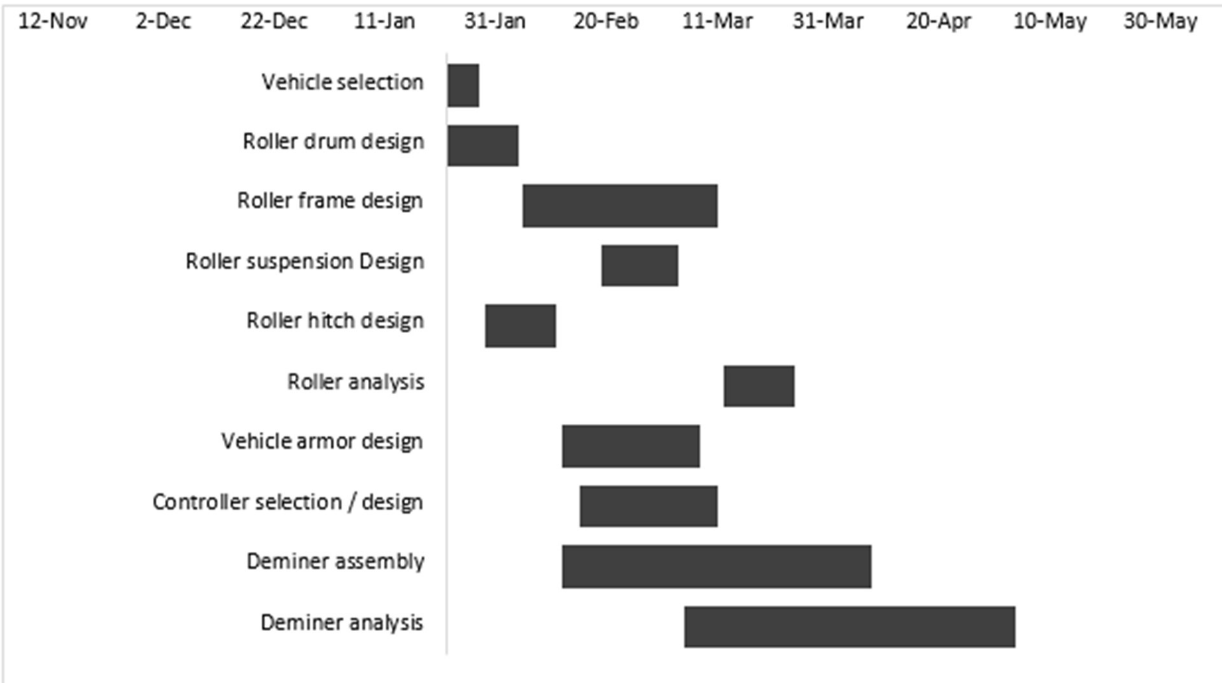

Figure 56. Gantt chart for the humanitarian deminer design schedule

Table 8. Duties list for the humanitarian deminer - spring 2017

Task	Start Date	End Date	Team Member Responsible	Duration
Vehicle selection	22-Jan	28-Jan	Xavier Castillo	6
Roller drum design	22-Jan	4-Feb	Ahmed Mohamed	13
Roller frame design	5-Feb	11-Mar	Dylan Rothganger	35
Roller suspension Design	19-Feb	4-Mar	Daniel Hernandez	14
Roller hitch design	29-Jan	11-Feb	Xavier Castillo	13
Roller analysis	12-Mar	25-Mar	Ahmed Mohamed	13
Vehicle armor design	12-Feb	8-Mar	Xavier Castillo	25
Controller selection / design	15-Feb	11-Mar	Dylan Rothganger	25
Deminer assembly	12-Feb	8-Apr	Ahmed Mohamed	56
Deminer analysis	5-Mar	4-May	Daniel Hernandez	60

Table 9a. Humanitarian Deminer Assembly ASM-001 Parts List

Humanitarian Deminer Assembly ASM-001				
Description	Quantity	Part #	Manufacturer	Cost
Ball Hitch	1	ASM-002	-	$822
Frame, Female Hitch, and Armor Assembly	1	ASM-003	-	$7,058
Support Roller Assembly	2	ASM-005	-	$710
Demining Roller Assembly	7	ASM-006	-	$2,453.42
Armor On Frame	1	ASM-004	-	$0
Vehicle	1	BX2370	Kubota	$11,720
			TOTAL COST	$22,764

Table 9b. Hitch Assembly ASM-002 Parts List

Hitch Assembly ASM-002				
Description	Quantity	Part #	Manufacturer	Total Cost
Hitch Plate	1	DM-0008	-	$300
Hitch Block	1	DM-0009	-	$500
Hitch Ball	1	SKU#40038	Curt Manufacturing	$16.72
Hitch Bolt	6	SKU#641	Bolt Depot	$2.64
Hitch Nut	6	SKU#17637	Bolt Depot	$2.70

Table 9c. Frame Assembly ASM-003 Parts List

Frame Assembly ASM-003				
Description	Quantity	Part #	Manufacturer	Total Cost
Frame	1	DM-0001	-	$5,000
Female Hitch	1	SKU#43-805	Croft Trailer Supply	$24.95
Armor Left Plate	1	DM-0010	-	$500
Armor Right Plate	1	DM-0011	-	$500
Armor Upper Support	2	DM-0012	-	$500
Armor Lower Support	2	DM-0013	-	$500
Female Hitch Bolt	3	SKU#17637	Bolt Depot	$1.32
Frame Bolt	36	SKU#641	Bolt Depot	$15.84
Frame Nut	36	SKU#17637	Bolt Depot	$16.20

Table 9d. Support Roller Assembly ASM-005 Parts List

Support Roller Assembly ASM-005				
Description	Quantity	Part #	Manufacturer	Total Cost
Plate	2	DM-0002	-	$40
Support Roller Arm	2	DM-0003	-	$60
Roller Disk	2	DM-0014	-	$600
Axel	2	DM-0016	-	$10

Table 9e. Demining Roller Assembly ASM-001 Parts List

Demining Roller Assembly ASM-005				
Description	Quantity	Part #	Manufacturer	Total Cost
Caster	7	SKU#65365488	MSC DIRECT	$273.42
Demining Roller Arm Assembly	7	DM-0004	-	$70
Roller Disk	7	DM-0014	-	$2,100
Axel	7	DM-0016	-	$10

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