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Abstract

Sand accumulation on roads and streets is a significant problem facing Kuwait and the nearby countries. The sands impede the movement of vehicles and cause car accidents. Furthermore, it stands in the way of expanding and developing new cities and costs the country thousands of dinars every year. The team’s mission was to find a solution to this problem. An engineering design process was followed during a full academic semester. Starting with setting target specifications obtained from customer interviews and proceeding through concept development and system-level design, in which techniques such as concept scoring and concept screening were used. The design process ended with a detailed design in which CAD software packages were used to determine mechanical stress and specific dimensions for the product. A prototype was manufactured, however, some features were eliminated due to the limited time of the project. The prototype was tested after. The test was successful in most criteria despite having some issues with some features. Finally, an economic analysis was done to study the feasibility of the project from an economic point of view and the project was found to be feasible and profitable.

Phase I

Project Plan and Product Target Specifications

Introduction:

As it is known, Kuwait lies in a harsh desert environment. And regardless of having the black gold living under its sands (oil), Kuwait's economic engine, the desert is causing a lot of trouble to the country both on the health and economic levels. Sand likes to take a breath and fly with the hot summer winds and February's unstable climate, and once it finds an obstacle or a place to live in, it starts to accumulate.

Figure 1: An accident caused by the sand accumulations

Sand accumulation on the roads and streets is a significant problem causing the country to lose millions of dollars, opposing the expansion and development of new cities, and causing accidents. Every year, the sands block the roads, and it impedes the movement of trucks carrying essential goods (i.e., foods, medicines) coming from neighbouring countries on international routes, and the people who live in the new cities; it takes up to two days to clean the road and open the path. Also, those sand accumulations are causing some accidents on the streets **(Figure 1)**, especially for unaware drivers driving at high speed at night. The sand could cover an obstacle or fill a pit, and when the vehicle goes over it, the car flips. Also, the sand stays in between the asphalt aggregate, and when the vehicle moves at high speed, this sand will fly and cause the vehicle in the back to be blinded.

Interview:

An interview was done with an engineer in the ministry of public works (MPW), and in the discussion, three significant parts were discussed. The first part is the problem itself and how the accumulated sands are causing big troubles in the country (introduction part). The second part is about the current solution and how the government deals with the case. And the last part includes the customer's needs and what is the expectation of the new product or solution.

Roads and Affected Areas:

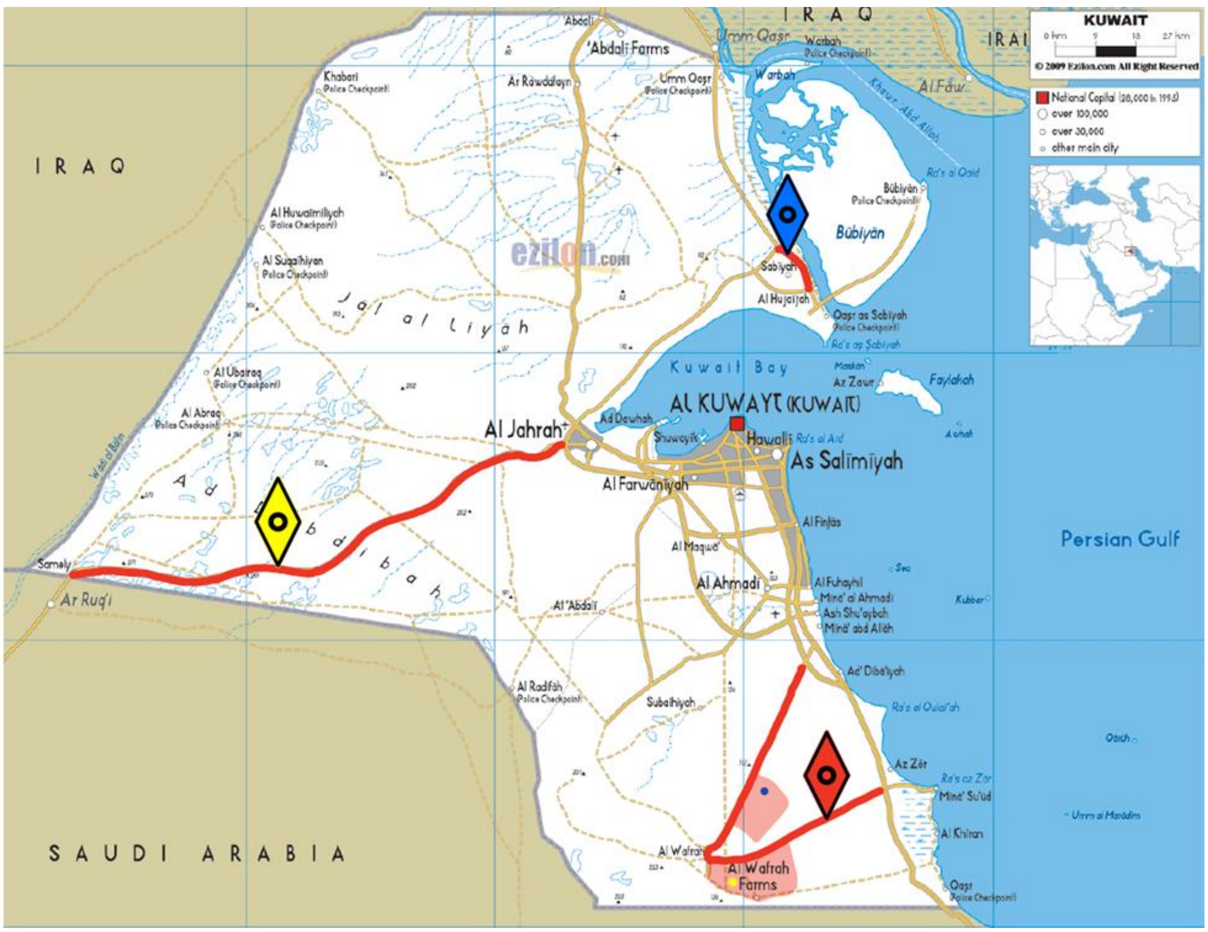

Figure 2: Roads affected by sands accumulations

Figure 3: *Map keys*

The sand accumulation affects many major and vital roads, as shown in **Figure 3**. Al-Salmey motorway is the most affected road; this road serves international transport trucks that carry essential goods such as food and medicine from Saudi Arabia, Jordan, and Syria. Last summer, this road was blocked for more than 48 hours because of the sands, and the military and Kuwait national guards intervened to save the situation. There will be a new city behind Al-Salmey road, Nawaf Al-Ahmad city.

The second and third vital roads are Om Sufag and Sabah Al-Ahmad city roads. These roads serve Sabah Al-Ahmad city residents. Each summer, sand blocks these roads, and the residents are trapped, and their movement is suspended until the road is cleared. Also, the Wafrah farms suffer from this kind of sand.

Winds and sandstorms are very active in February and summer, especially at noon (10 AM) when the sun is vertical.

Current Solution:

Figure 4: Contractor's loader cleaning the road from sands

Each road vital road has its contract with a contractor, which lasts for three years. The contractor is responsible for keeping the road clean and passable, and loaders (**Figure 4**) are used to remove the sands and move them to the road shoulders; and afterwards, the road sweepers clean the remaining sand, which is kept done throughout the year.

Figure 5: Contractor's loader cleaning the road from sands at night

The MPW is a regulator and supervisor only; a three-year contract does everything with a contractor. Most of the time, the contractor takes care of the sand accumulation, but sometimes the MPW uses its vehicles (they are very few). The contractor is paid to place the loaders and road sweepers at a specific point on the road or every particular amount of kilometers. The payment is made to the contractor even if the vehicles are idle and not running.

Disadvantages of the current solution:

The process is very inefficient; it takes up to (48hrs), money, and resources. In addition to that, the loaders cannot remove the sand entirely from the ground; it needs the road sweeper to come after it and remove the remaining sand, making an effort to double. Also, the street level is not constant. It is challenging for the loader's driver to maintain a consistent level from the ground, resulting in contact between the loader and the asphalt, causing the last to be destroyed.

On the other hand, this process is very costly; the MPW pays the contactor even for the idled vehicles, whereas the MPW engineers are paid for doing nothing, just supervising.

The last thing is that the MPW owns thousands of SUVs; these vehicles are often not used in the right way or purpose; many engineers are using them for their personal tasks. So, it is good to take them back to duty.

Estimated Cost:

The rent of the loader is 50KD per day, and if four loaders are needed for every 10km of a 120km road (Al-Salmey Motorway), then it will cost the country around 876,000 KWD. This estimate is not conservative, and it is believed that the need for loaders and road sweepers is much more.

The Mission Statement

Mission Statement: [Devising a way to mitigate sand accumulation on roads by a car attachment]

Product Description	A low-cost light car attachment with road sweeping and bulldozing capabilities, and specialized for removing the accumulated very fine sand on the roads.
Benefit Proposition	• Low cost • Suitable for hot temperatures • Easily attachable • Durable • Light • Fast • Novel approach • Does not damage the road
Primary Market	• Governments with desert climates (GCC, Africa, Mugabi desert (China)) • Construction companies contracted for roads in Kuwait
Secondary Market	• Residents of remote areas • Farm owners • Volunteers
Assumptions and Constraints	• Capable of withstanding the high heat and weather • Capable of removing sand without damaging the road • Capable of removing the sand that is lying between asphalt aggregate. • Materials and parts are available in Kuwait • Manufacturable in Kuwait • There is a maximum velocity for safe removal of sand
Stakeholders	• The producers • Governments • Volunteers • Operators and workers

The Customer needs and Target specifications

From the previous interview, the customer statement in this case the engineer was made into a table and were translated into interpretated needs as illustrated in table (1)

Table 1: Customer statement and interpreted needs

Customer statement	Interpreted need
منتج مصنوع من مادة قوية أن يكون التدعيم قوي	Rigid structure
أن تكون الشفرة بشكل مائل لإزاحة الرمال لجانب الطريق أن تكون الشفرة مائلة من ومقعرة من الأمام	Designed to slide the sand to the road shoulder
أن يحتوي على بروشات في خلف الشفرة	Brushes attached behind plow
أن يكون قابل للطيء ووضعه في حقيبة السيارة	Foldable design
أن يكون خفيف	Light
أن يمكن تركيبه من شخص واحد سهل الفك والتركيب	Easy to attach and detach
صديق للبيئة ، لا يخرج بقايا ب سبب الاحتكاك ويلوث البيئة (البروش)	Environment friendly, strong brush hairs
أن لا يستهلك بطارية السيارة وكهرباء السيارة	Does not consume the car battery
أن يحتوي على انارة تنبيهية (فلشر)	Light indicators
وجودة كاميرا خلف السيارة تبين مدى نجاح العملية ، في الظروف الغبارية	Has a method to check for functionality
أن يمكن تؤدي عملية تنظيف الشارع ب مفردك بأمان	Safe to use
صيانة قليلة	Low maintenance (few parts, few consumable parts)
قابل للتطوير (بزيادة مالية) بحيث يتحول الجهاز الى مكنسة لتنظيف الشوارع	Modular (upgradable to include a vacuum cleaning system)
قيمته تكون في متناول اليد	affordable

The customer statements had some overlapping, and the table shows the multiple customer statements that were interpreted into a single need. These interpreted needs were then organized into a hierarchy relative to importance and grouped into similar categories. With the number of starts noting the importance of need and the exclamation mark noting the triviality.

The plough is easy to attach and store

***Lightweight

**Easily attachable and detachable

*! Foldable design

The plough is safe to use

**Light indicators attached

***Safe to use

**! Does not consume the car battery

Plough removes sand efficiently

*** Able to remove sand from both lanes using multiple ploughs

*** Designed to slide the sand to the road shoulder

*** Brushes attached behind the plough

The plough is very purchasable

**Low maintenance cost

*Modular (upgradable to include vacuum cleaning system)

*** Low cost

*** Strong and durable attachment

The plough is environmentally friendly

Has a method to check for results of the plougher

Metrics were then obtained using the customer needs as references and a table was made with a column after each metric to determine their importance relative a 1-5 numbered scale with 5 being the most important. This is illustrated in table (2)

Table 2: interpreted Needs and their importance

No.	Needs	Imp.
1	Strong and durable attachment	4
2	Designed to slide the sand to the road shoulder	5
3	Brushes attached behind the plough	5
4	Foldable design	1
5	Lightweight	3
6	Easily attachable and detachable	3
7	Environment friendly (i.e., strong brush hairs)	2
8	Does not consume the car battery	1
9	Light indicators attached	2
10	Has a method to check for results of the plougher	3
11	Safe to use	5
12	Low maintenance	2
13	Modular (upgradable to include vacuum cleaning system)	1
14	Low cost	4
15	Able to remove sand from both lanes using multiple ploughs	5

A needs-metrics-matrix was constructed and illustrated in table (3) to identify which metric corresponds to which interpreted need and from that information and table (2) the team can identify and set ideal and marginal values for the various metrics obtained. These can be seen in table (4)

Table 3: Needs-Metrics-Matrix

No.	Needs	Metrics	Strength of Plough	Strength of Brushes	Angle of tilt	Total Mass	Installation time	Cost	Power consumption	Sand removing capacity	Sand height	Maximum car speed	Number of parts	Biodegradable	Camera system	Number of light indicators	Minimum storage space
1	Strong and durable attachment		●			●							●				
2	Designed to slide the sand to the road shoulder				●					●	●						
3	Brushes attached behind the plough									●	●						
4	Foldable design						●						●				●
5	Lightweight					●	●	●									
6	Easily attachable and detachable					●	●										
7	Environment friendly (i.e., strong brush hairs)			●										●			
8	Does not consume the car battery								●						●		
9	Light indicators attached															●	
10	Has a method to check for results of the plougher														●		
11	Safe to use											●					
12	Low maintenance						●	●									
13	Modular (upgradable to include vacuum cleaning system)												●				
14	Low cost							●									
15	Able to remove sand from both lanes using multiple ploughs				●					●	●						

Table 4: Marginal and ideal values for metrics

No.	Need Nos.	metrics	Imp.	units	Marginal Value	Ideal Value
1	1	Strength of Plough	5	MPa	>169	>542
2	7	Strength of Brushes	3	MPa	-	-
3	2,15	Angle of tilt	5	degrees	10<x<40	20<x<30
4	1,5,6	Total Mass	5	kg	<150	<70
5	4,5,6,12	Installation time	3	s	<900	<300
6	5,12,14	Cost	4	KWD	<700	<300
7	8	Power consumption	1	W	<1200	<600
8	2,3,15	Sand removing capacity	5	m^3/s	>2	>8
9	2,3,15	Sand height	3	cm	>2	>10
10	11	Maximum car speed	2	km/h	>10	>40
11	1,4,13	Number of parts	2	#	<10	<5
12	7	Biodegradable	2	unitless	-	-
13	8,10	Resolution of Camera system	3	Pixels/in	>480	>1080
14	9	Intensity of light indicators	4	cd	>0.5	>1
15	4	Minimum storage space	5	m^3	<.423	<.317

The power consumption marginal and ideal values were obtained using a winch has reference with some winches consuming up to 1200 W so the marginal value would be within this value other values were obtained using the same concept and previously mentioned. The target specification and concept development as a whole are not a fixed process and therefore some needs, metric and values may be revisited to ensure that these values are logical. While other metrics such as the strength of brushes has not been established however should be similar the road sweepers and other brushes doing somewhat the same application.

Initial design concept:

After the customer needs were obtained, it was convenient to start working on initial designs. The team searched the internet for designs close to the idea in mind. There were no designs found that could serve the exact purpose of the project (sand removal). However, many products found were close to the idea in mind despite that they were dedicated for snow plowing **Figures (6 & 7)**.

Figure 6: Snowplow attachment

Figure 7: Snowplow attachment side view

The initial design for the project should start from this product and modify it such that it can be used for sand removal as it would be more appropriate to start where others stopped. This product is a snowplow attachment that can be attached to a pickup truck or an SUV. It is attached from the front receiver hitch as shown in **Figure (8)**. It also has a mechanism that lowers and raises the plow which is powered by the car's 12-volt battery.

Figure 8: Attaching with a front receiver hitch

Figure (9) shows a sketch of the suggested modification for the design. It is modified to include sweeping brushes placed behind the plow to sweep the remaining sand that could not be removed by the plow, which was directly stated in the customer requirements. The sweepers would be powered by a 12-volt dc motor, such that it could take its power directly from the car's battery.

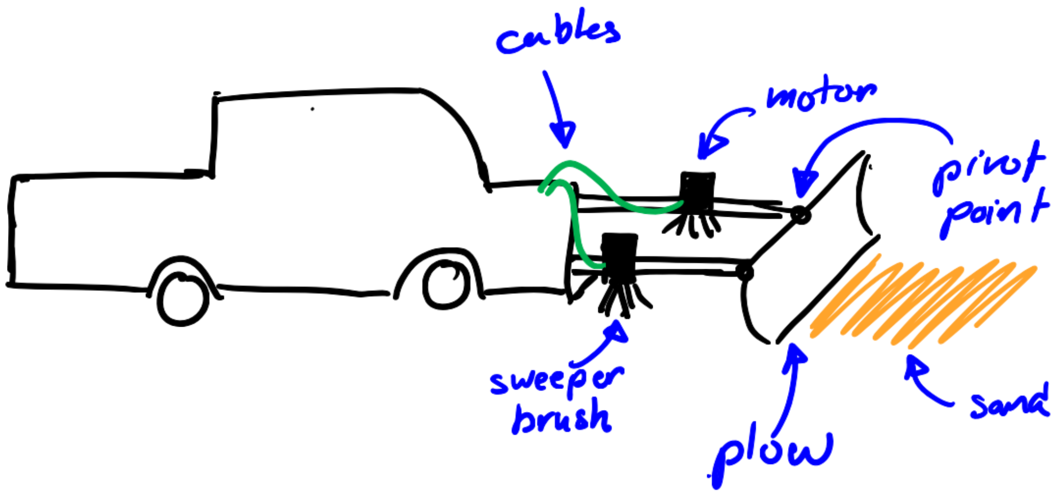

Figure 9: Sketch of the initial design

One disadvantage of this concept is that it is limited to cleaning one lane of the road at a time, and if the sand was accumulated near the concrete road divider, it would be difficult to get it to the other side, where it can be thrown aside of the road. However, these difficulties can be easily encountered by using multiple plowing vehicles instead of one as shown in **Figure (10)**.

Figure 10: Snow-plowing convoy

In order to proceed with this idea, it was necessary to check whether the car battery can supply enough power for the sweepers. To estimate the power needed to sweep the sand, an experiment was done. A broom was attached to an electric drill powered by a 12-volt battery, such that the broom car rotate and sweep the sand. The electric drill managed to sweep the sand which indicates that a motor with the same power rating could serve that purpose. The drill power rating was about 100 Watts. This experiment was not very accurate, however, it gave a rough estimate of the needed power as a start. The device should have about 3-4 sweepers of a larger size than the one that was tested, so an initial estimate for the motor's power is about 600 Watts.

After the needed power was estimated, it was necessary to know how much power the car battery can supply. It was convenient to lookup for benchmarks of car battery-powered devices such as the starting motor and towing winch **Figure (11)**, the starting motor approximately draws around 150 amps for a four-cylinder engine and about 225 amps for a V8 engine, while towing winches' current ratings start at 100 amp and could exceed 300 amps. A 100 amps towing winch powered by a 12-volt battery uses 1200 Watts of power, which is more than the needed power for the project. It can be concluded from the previous discussion that the project is feasible in terms of technical parameters.

Figure 11: Towing winch

The Manufacturing Process:

The investigation in the manufacturing process started with a trip to Shuwaikh industrial area to find a blacksmith workshop that could manufacture the product. After looking in more than 20 different workshops where almost neither of them agreed on cooperating, the instructor suggested checking a specific workshop owned by a manufacturer who had worked with another design group last semester. After contacting that guy, a meeting was scheduled on the 10th of April, at 10 PM, in the workshop located in the Khaitan residential area **(Figure 12).**

Figure 12: The workshop located in Khaitan

Figure 13: Snowplow attachment

After sating down and negotiating the whole design project while showing illustrative pictures of products that have the same function but are used in a different environment, the manufacturer stated the following :

- The density of the sand is way higher than the density of the snow, so designing a product similar to the one shown in **Figure (13)** would be unpractical or even inapplicable, as sand accumulation at the front of the attachment is a much more complex problem to deal with as the attachment might get stuck in the ground.
- In terms of design specifications, if the intention is to manufacture a sand removing attachment, it will be a heavy-duty product. It cannot be a lightweight one as the design group planned it to be.
- Specialists should manufacture it, as it requires a lot of work and the design group is restricted with time while having little experience.
- While working with sand, installing the attachment in the back could be more effective.
- A specific four-wheel vehicle such as the one shown in **Figure (14)** must be selected to take its measurements, do all the analysis required, and design a product that can fit perfectly with this vehicle, as one attachment cannot be suitable for all the vehicles since it is a heavyweight product as mentioned previously, and the heavier it gets, the more restricted the cars options will be.

Figure 14: The car provided by the manufacturer to test the product

Phase II

Concept Generation and System-Level Design

Functional Decomposition:

After the team set the aims of the project, the next step was to determine how the product could fulfil these aims. The team listed all necessary functions of the product in order to generate concepts that could achieve these functions. The list of components for Functional decomposition is shown below:

1. Attachment Method
2. Tilt Mechanism
3. Brush lifting mechanism
4. Remaining sand removal
5. Obstacle avoiding
6. Handling Method

Because the product is going to be attached to a car, an attachment method is needed. The attachment method should provide the required structural support and allow the device to be detached when it is not needed. A tilting mechanism is needed as the device should allow for plough height adjustment so that the plough can be raised when it is not in use because it would be dangerous to have a heavy metallic object touching the ground when the vehicle is moving at highway speeds.

The sand removal process could not be done at one stage. The plough would be able to remove most of the sand, however a thin layer of sand would still be left, for that reason, the device should have a method to remove that remaining sand layer. It is inevitable that the device will encounter some obstacles in the road while plowing the sand, so it is necessary that the device can avoid these obstacles safely. The device is expected to have a large mass, and it would be difficult to handle it without any support, so a handling method should be considered when designing the product.

After all the important functions were obtained a schematic of the product was made to better understand the chunks and components of the product which is shown in Figure (15).

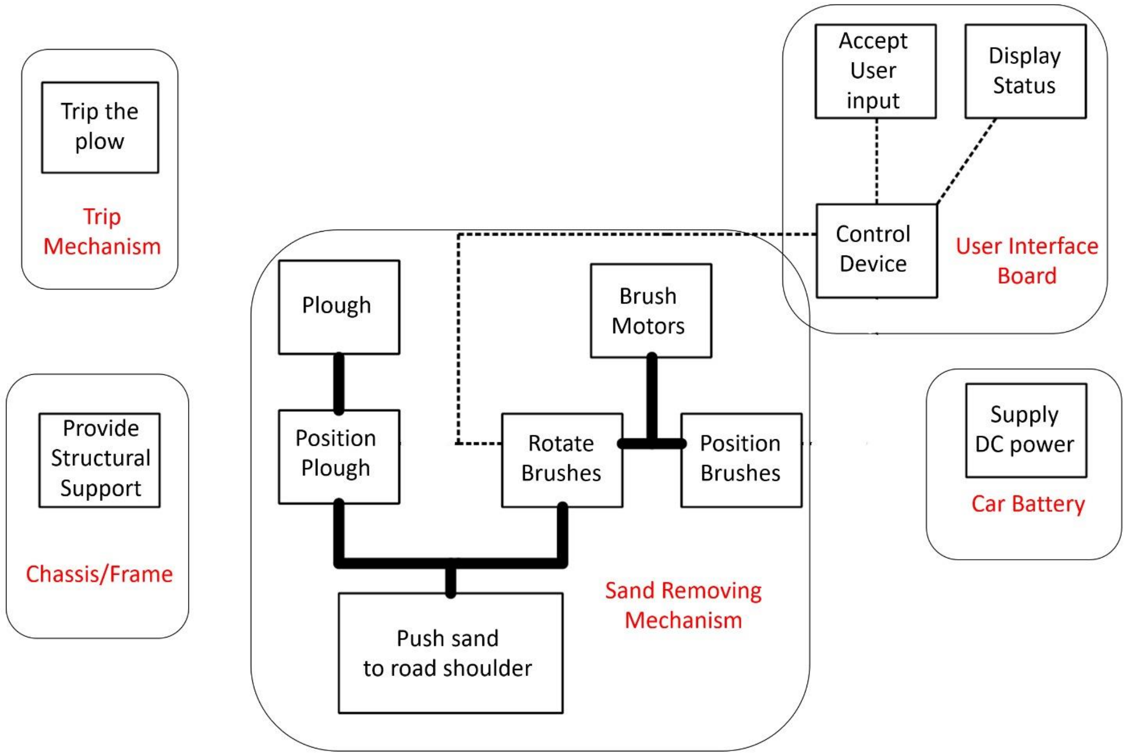

Figure 15:Schematic of The Product

The schematics provide the team with a clear view of the important functionality of each chunk. Frame, Mechanism, UI and the car battery. After creating the schematic, a rough geometric layout was made to visualize the design with each of its functional components and where they will be placed relative to each other.

Finally, with regards to the concept generation, a functional decomposition was done for the product as is shown in Figure (16).

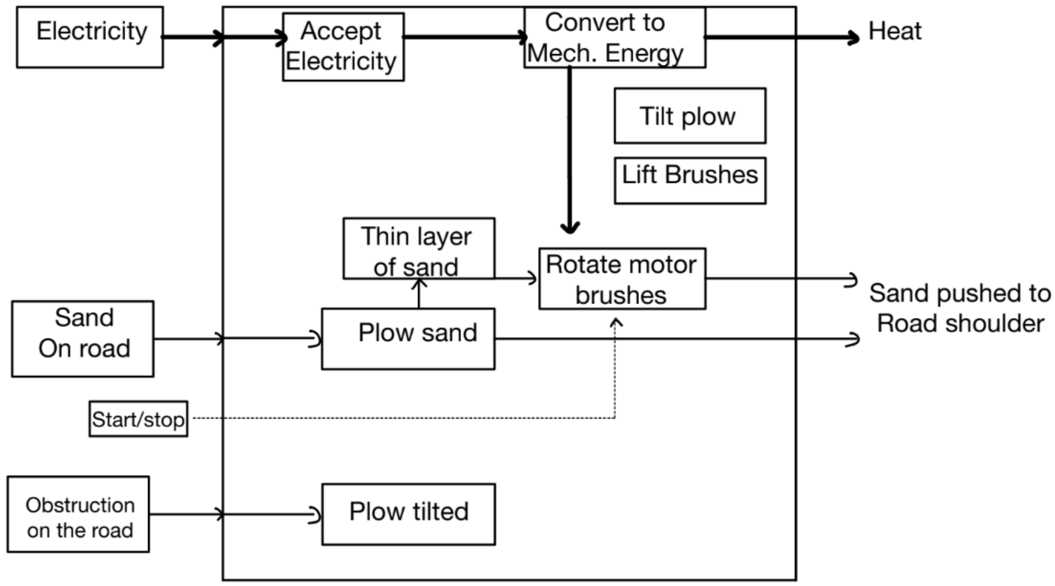

Figure 16: Functional Decomposition

Concept Generation:

Each function of the product must have a working concept. The team viewed each system's functionality separately and tried to generate as many concepts as possible until good ideas are reached.

Starting with the attachment mechanism, there were two methods. The first is to use a front receiver hitch and the second is to use the towing hooks. The towing hooks are not designed for such a purpose, but they can be easily removed, and an appropriate attachment device can be placed. For the tilt mechanism, the choices were between using an electric winch, a manual winch, manually tilting the plough without mechanical aid, using a power screw and using a hydraulic cylinder. Regarding the thin sand layer that remained after the plough passed, it was either to remove it by blowing air on it or to use brushes with a motor to rotate them, power will be taken from the car battery in all these cases.

For obstacle avoidance, the team looked for solutions applied on snowplowes. The team found that most snowplows use a spring mechanism used to force the plough to tilt forwards in the case of any obstruction in front of the plough that cannot be moved without causing a large amount of stress on the frame and car. There are two concepts for these trip mechanisms, full trip, where the whole plough trips forward, and trip edge, where only the bottom of the plough trips. These two concepts are shown in Figures (17) and (18).

Figure 17: Trip Edge

Figure 18: Whole Trip

A combination table was made for each of the required functionalities of the intended design. Table (5) shows the concepts for each different functionality.

Table 5: Combination Table

Attachment Method	Tilt Mechanism	Brush lifting mechanism	Thin layer sand removal	Trip Mechanism	Handling Method
Front Receiver Hitch	Electric winch	Electric power screw	Stepper motor	Whole plow	Tires installed
Hook Attachments	Manual winch	Manual power screw	DC motor	Bottom plow	External cart
Both	Manual	manual	Blower		
			A/C with inverter		
	Power screw	Attached with the tilt mechanism			
	Hydraulic				

Concepts were generated by using different combinations of ideas using Table (5). The project is of a car attachment and therefore the overall design of each concept does not differ but only the components change. Therefore, a rough geometric layout was made to better visualize each component of the whole attachment which is shown in Figure (19).

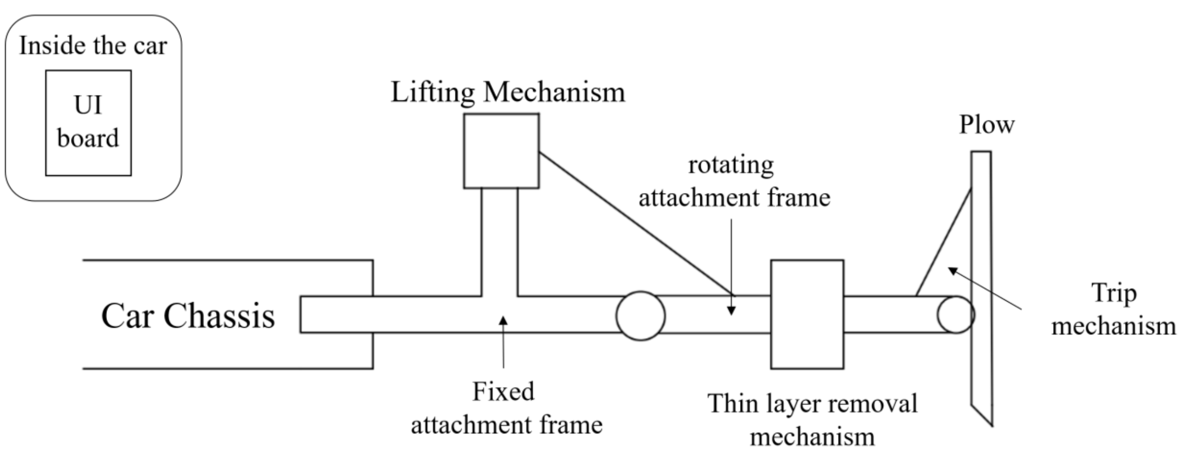

Figure 19:Rough Geometric Layout [1]

Concept A

Table 6: Concept A

Attachment Method	Tilt Mechanism	Brush lifting mechanism	Thin layer sand removal	Trip Mechanism
Front Receiver Hitch	Electric winch	Electric power screw	Stepper motor	Whole plow
Hook Attachments	Manual winch	Manual power screw	DC motor	Bottom plow
Both	Manual	manual	Blower	
			A/C with inverter	
	Power screw	Attached with the tilt mechanism		
	Hydraulic			

Concepts A utilizes the front receiver hitch that is like the DK2 snowplow which is the benchmark for this project. The idea of concept A is to automate most of the components. Therefore, the tilting lifting and blower can all be controlled remotely from the driver seat. Similar to the front receiver hitch the trip mechanism used in the concept is like the DK2 snowplow.

Concept B

Table 7: Concept B

Attachment Method	Tilt Mechanism	Brush lifting mechanism	Thin layer sand removal	Trip Mechanism
Front Receiver Hitch	Electric winch	Electric power screw	Stepper motor	Whole plow
Hook Attachments	Manual winch	Manual power screw	DC motor	Bottom plow
Both	Manual	manual	Blower	
			A/C with inverter	
	Power screw	Attached with the tilt mechanism		
	Hydraulic			

As opposed to the automation of concept A, concept B was generated to test the idea of making the design mostly manual. The attachment is the same but the tilt and lifting mechanisms are manual. Also, the thin layer sand removal uses an A/C motor instead of a blower. The trip mechanism that is used for this concept is to make the bottom of the plow rotatable to absorb shock and rotate when any obstruction is present on the road.

Concept C

Table 8: Concept C

Attachment Method	Tilt Mechanism	Brush lifting mechanism	Thin layer sand removal	Trip Mechanism
Front Receiver Hitch	Electric winch	Electric power screw	Stepper motor	Whole plow
Hook Attachments	Manual winch	Manual power screw	DC motor	Bottom plow
Both	Manual	manual	Blower	
			A/C with inverter	
	Power screw	Attached with the tilt mechanism		
	Hydraulic			

Concept C was thought of to ensure that the attachment is strong, and the stress is more evenly distributed. The concept is very similar to concept A, but the thin layer removal uses an A/C motor. This concept is likely to be on the expensive side of all the concepts but is conceived to be extremely safe to use.

Concept D

Table 9: Concept D

Attachment Method	Tilt Mechanism	Brush lifting mechanism	Thin layer sand removal	Trip Mechanism

Front Receiver Hitch	Electric winch	Electric power screw	Stepper motor	Whole plow
Hook Attachments	Manual winch	Manual power screw	DC motor	Bottom plow
Both	Manual	manual	Blower A/C with inverter	
	Power screw	Attached with the tilt mechanism		
	Hydraulic			

Concept D tries to minimize the cost of the project by combined the tilt and lift mechanism into one and reduced the parts needed. Also, it uses an attachment that is already on most trucks therefore a separate attachment is not needed, and a DC motor is used instead of an A/C motor so that the need of an inverted is no longer a problem. The trip mechanism uses the same idea of concept B.

Concept E

Table 10: Concept E

Attachment Method	Tilt Mechanism	Brush lifting mechanism	Thin layer sand removal	Trip Mechanism
Front Receiver Hitch	Electric winch	Electric power screw	Stepper motor	Whole plow
Hook Attachments	Manual winch	Manual power screw	DC motor	Bottom plow
Both	Manual	manual	Blower A/C with inverter	
	Power screw	Attached with the tilt mechanism		
	Hydraulic			

Concept E focuses more on the simplicity of manufacturing and the availability of the components. The difference between E and D are the thing sand removal and trip mechanism. An A/C motor is chosen since it is more readily available in the market than a DC motor that meets the specifications of the project. Similarly the trip mechanism chosen is also easier to manufacture than the uses of only the bottom of the plow reacting to obstructions.

Concept Selection:

After the concept generation, the concept selection follows. A structured approach was made to make for a more effective decision on the final concept. All the concepts that were generated went through a concept screening and scoring method to obtain the relatively best concept. The screening process filters out obvious redundant concepts and later onto a scoring process to acquire a more qualitative outcome using weighting scoring by using specific selection criteria.

Using the DK-20 Snowplow as a reference the screening process was made by comparing all the concepts with the reference using the selection criteria to notice whether the concept is better than the reference for each criterion.

Table (11) shows the concept screening for the different concepts of the design with the DK-20 Snowplow being the reference. The first column represents the selection criteria which is mostly the metrics that were obtained in the first phase of the project. The rest of the columns are each concept and the reference.

Table 11: Concept Screening

	Attachment methods					
Selection Criteria	**A**	**B**	**DK-20 Snowplow (ref)**	**C**	**D**	**E**
Ease of handling	-	-	0	-	-	-
Durability	+	+	0	+	+	+
Power Consumption	-	0	0	-	0	0
Installation time	0	-	0	-	0	0
Ease of manufacture	0	+	0	-	+	+
Sand Removing capacity	+	+	0	+	+	+
Portability	0	0	0	0	0	0
Number of Parts	-	+	0	-	0	0
Strength of Plow	0	-	0	0	-	0
Cost	-	-	0	-	-	-
Sum +’s	2	4	0	2	3	3
Sum 0‘s	4	2	10	2	4	5
Sum – ‘s	4	4	0	6	3	2
Net Score	-4	0	0	-4	0	1

Rank	3	2	2	3	2	1
Continue?	No	Yes	No	No	Yes	Yes

From Table (11), the concepts A and C fall far below the allowed reference that was used. Only three out of the five concepts passed the screening which are concepts B, D and E. To decide on which concept to develop the concepts will be scored using the same selection criteria as in Table (11) but with weights on each criterion depending on its importance

Table (12) shows the scoring process for the concepts. It is like Table (12) however includes an extra column for the weighting and for each concept there includes two columns for the rating and weighted score. The rating system will be used to rate each concept for its specific criteria with a rating of one being far lower than the standard of the reference and a rating of five being much better than the reference.

Table 12: Concept Scoring

		Trip Mechanism					
		B		D		E	
Selection Criteria	**Weight (%)**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Ease of handling	**10**	2	0.20	2	0.20	2	0.20
Durability	**10**	4	0.40	4	0.40	5	0.50
Power Consumption	**15**	3	0.45	3	0.45	3	0.45
Installation Time	**5**	2	0.10	3	0.15	3	0.15
Ease of manufacture	**20**	4	0.80	4	0.80	5	1.00
Sand Removing Capacity	**15**	5	0.45	5	0.45	5	0.45
Portability	**5**	3	0.15	3	0.15	3	0.15
Number of Parts	**5**	4	0.20	3	0.15	3	0.15
Strength of plow	**10**	1	0.10	1	0.10	5	0.50
Cost	**5**	2	0.10	2	0.10	2	0.10
	Total Score	2.95		2.95		3.65	
	Rank	1		2		2	
	Continue?	No		No		Develop	

Table (12) shows the weighting for each criterion. The most important factors that were considered were the power consumption, ease of manufacture and sand removing capacity. The power consumption had a high weight since the design is limited to a car battery which supplies only 12 volts therefore a design that consumes a minimal amount of power is desired. The other factor is the sand removing capacity this is obviously an important factor since the whole result of the design is the ability to remove sand off the road. Finally, the highest weighting is the ease of manufacturing. This factor has the highest weighting since the team is very limited with where it can manufacture the product and some of the components may not be available in the market. With all this taken into consideration concept D and B were overshadowed mainly due to the strength of the plow. The first two concepts use a trip mechanism that would decrease the strength of the plow and thus makes E the better concept.

The Final Concept

Table (13) shows concept E which is also Table (13) and has been selected as the final concept for the project.

Table 13: Combination Table With Final Concept Highlighted

Attachment Method	Tilt Mechanism	Brush lifting mechanism	Remaining sand removal	Trip Mechanism
Front Receiver Hitch	Electric winch	Electric power screw	Stepper motor	Whole plow
Hook Attachments	Manual winch	Manual power screw	DC motor	Bottom plow
Both	Manual	manual	Blower	
			A/C with inverter	
	Power screw	Attached with the tilt mechanism		
	Hydraulic			

The Attachment Method

Figure (22) illustrates the front of a GMC Sierra with distinguishable front hooks.

Figure 20: Front of a GMC Sierra

Figure (22) shows where the desired location of attaching the frame of the plow. As opposed to the other concept of using a front receiver hitch. This was chosen as the better option since a front receiver would have been designed from scratch and firmly attached to the front of the car which would increase the cost of the project, and this would take longer than designing an attachment to a car which already has the required joints shown in Figure (22).

The Tilting Mechanism and Brushes

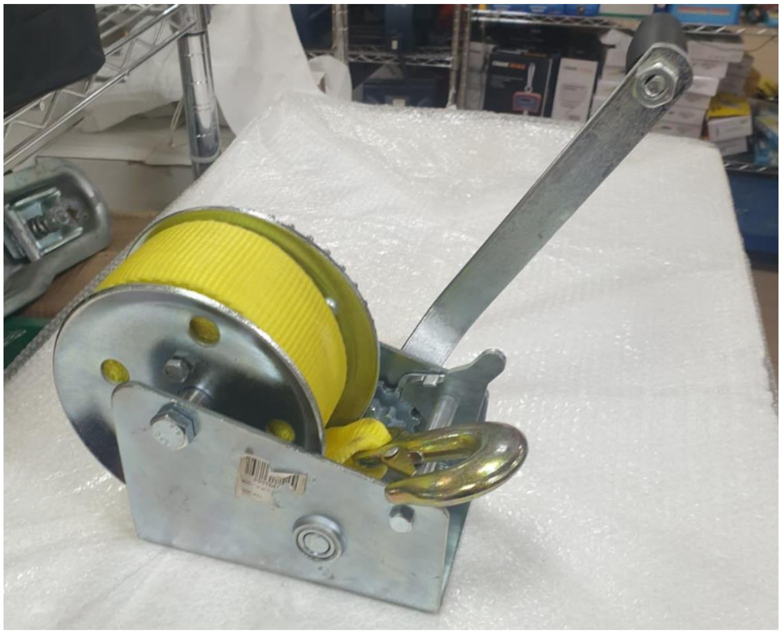

Figure 21: Image of a Manual Winch [2]

To ensure that the plow is well above the road level tilted upwards away from the road. As previously mentioned, there are several ways to do this, however the manual winch will be utilized for case of the project. Since the rotating body may be too heavy for a person to tilt a winch will more than likely do the trick. However, the choice of whether to use an electric winch or not was decided due to the lack of variety in the market and the gap in their prices. An electric winch with a load capacity of 150 [kg] is more expensive and larger than that of a manual winch which can withstand a load of 800 [kg]. Therefore, the logical choice would be a manual winch. As for the brushes the choice is to attach them to the rotating frame thus making it a less complicated design as opposed to designing a separate lifting mechanism that acts independently.

Trip Mechanism

Figure 22: Image of Trip Springs for the DK-20 Snowplow

There were only two choices for how to design a trip mechanism which were proposed and have been previously mentioned. Figure (22) illustrates the choice that will be used for the final concept which is the rotation of the whole plow. This was chosen mainly because the second choice is weaker than the concept chosen this is due to the use of a movable lower piece of the plow to absorb the shock. It is also a relatively more complex design. Therefore, the trip mechanism will be nearly identical to that shown in figure (22)

Thin Layer Removal

The sole decision as to why the A/C motor with an inverter was picked was that it is the most accessible motor in the market. As for the use of a blower, does not ensure for a more efficient way of removing sand unless a very strong blower was used and another reason for the use of a motor with a brush was that the road sweepers utilize the same thus making it easier to be used as a reference.

Economic Analysis:

A break-even analysis was done to know how many units of the product have to be sold to cover the fixed and variable costs of the project and, based on that, have a better understanding of whether it would be feasible to lunch the product or not.

Table (14) shows the estimated bill of materials for the final concept selected. The 1st column represents the item number. The 2nd column shows the part name, while the 3rd column shows the quantity of each part. The last two columns are the upper and lower limits for the prices.

Table 14: Bill of Materials [3]4][5]

	Part Name	Quantity	Lower Limit	Upper Limit
1	Steel	174 kg	35 KD	53 KD
2	Motors	3	18 KD	90 KD
3	Brushes	2	2 KD	12 KD
4	Springs	2	2 KD	12 KD
5	Inverter	1	8 KD	30 KD
6	Winch	1	8 KD	8 KD
Total			73 KD	205 KD

Since Kuwait rely mainly on importing, Kuwait steel prices increased 50% in 16 months during the Coronavirus pandemic [4]. The upper and lower limits for steel prices were set based on the prices before and after the pandemic. In the current stage of the design process, the product weight is estimated to be around 174 kg, and the estimated price range is from 200 to 300 KD.

$$\frac{200\ KD}{1000\ kg} = \frac{Steel\ price}{174\ kg}$$

$$Steel\ price \approx 35\ KD$$

Prices of the inverter, brushes and the waterproof AC motor shown in Figures (23), (24) and (25) respectively are from Alibaba website, while the prices of the springs are from AliExpress and Bin Nisf websites.

Figure 23: Car Power Inverter [3]

Figure 24: Road Sweeper Brush [3]

Figure 25: Waterproof AC Motor [3]

Figure 26: Extension Spring [5]

Table (15) below shows the project's fixed costs, consisting of only each design group member's research and development costs. These costs are calculated with a labor cost of $8\ KD/hr$ and a project completion time of 3 months as follows :

$$\boldsymbol{Research\ and\ development\ costs}\ (\boldsymbol{lower\ limit}) =$$

$$\frac{8KD}{hr} \times \frac{3hr}{day} \times \frac{5day}{week} \times \frac{4week}{month} \times\ 3months\ = 1440\ KD$$

$$\boldsymbol{Research\ and\ development\ costs}\ (\boldsymbol{upper\ limit}) =$$

$$\frac{8KD}{hr} \times \frac{8hr}{day} \times \frac{5day}{week} \times \frac{4week}{month} \times\ 3months\ = 3840\ KD$$

Table 15: Fixed Costs

Source	Labor Cost	Lower limit (3hr)	Upper Limit (8hr)
R&D costs	8 KD/hr	5760 KD	15360 KD

Table (16) shows the total material costs along with the upper and the lower limit estimates of the manufacturing costs per product, representing the project's variable costs. The values obtained for the manufacturing costs are from a trip to Shuwaikh Industrial Area workshops.

Table 16: Variable Costs

Source	Quantity	Lower limit	Upper Limit
Materials	6 items	73 KD	205 KD
Manufacturing	1 product	200 KD	500 KD
Total		273 KD	705 KD

Lower Limit Break-Even Point :

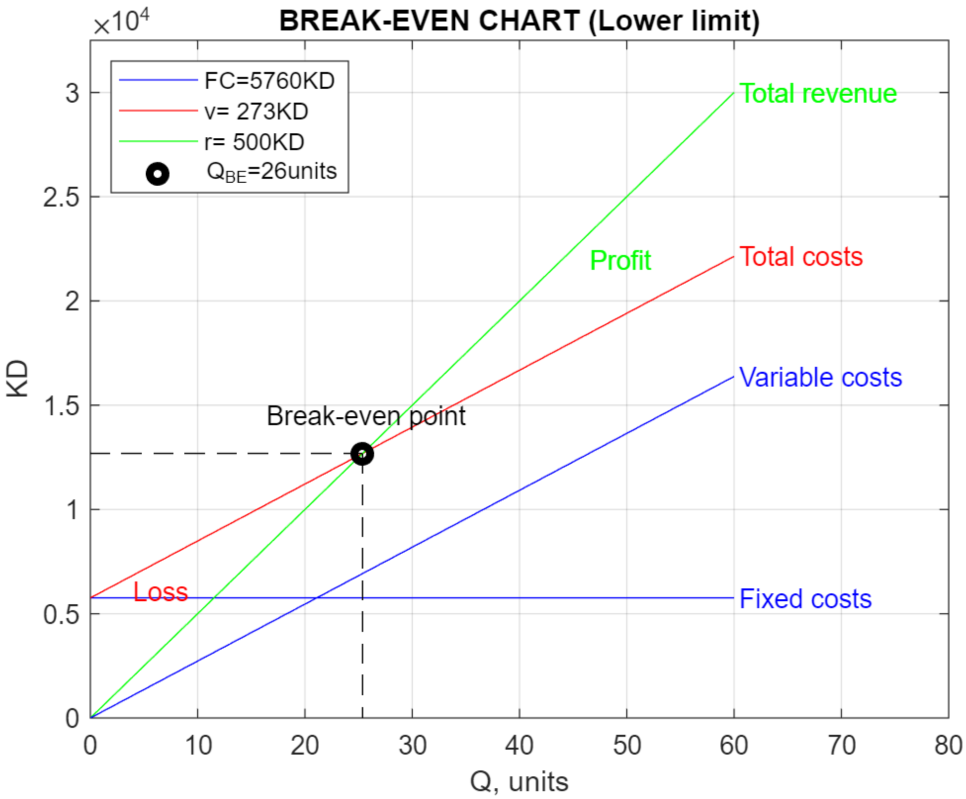

Figure 27: Lower Limit Break-Even Point

$$Q_{BE} = \frac{FC}{r - v}$$

$$Fixed\ costs\ (FC) = 5760KD$$

$$Variable\ costs\ per\ unit\ (v) = 273KD$$

$$Revenue\ per\ unit\ (r) = 500KD$$

$$Break - even\ point\ (Q_{BE)} = \frac{5760}{500 - 273} \approx 26\ units$$

Upper Limit Break-Even Point:

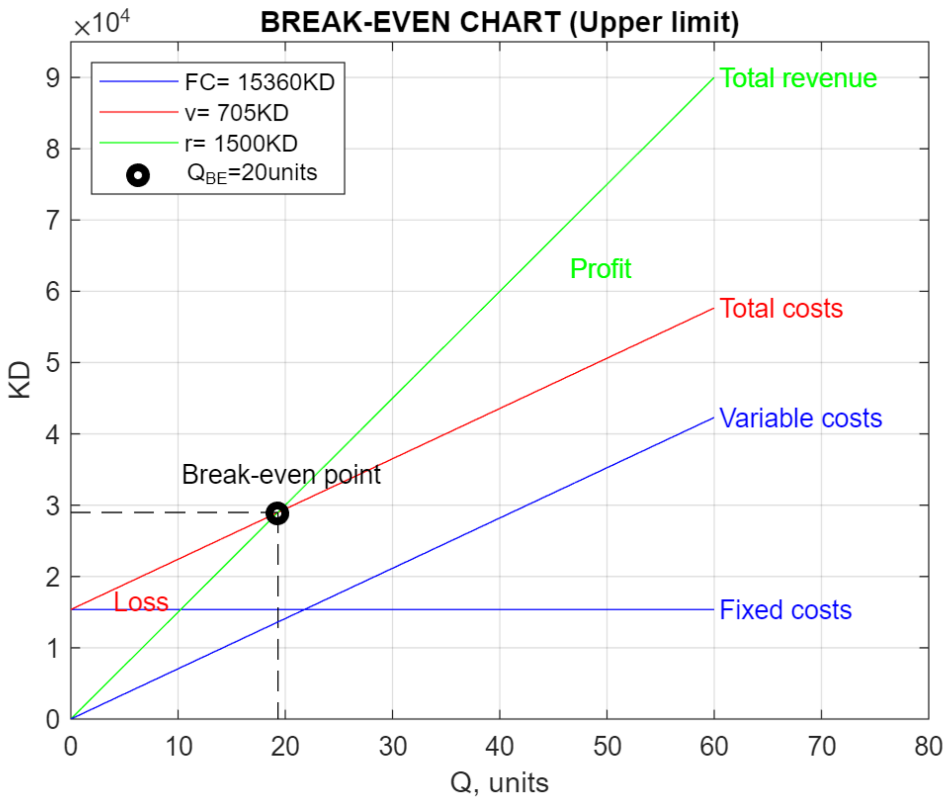

Figure 28: Upper limit Break-Even Point

$$Q_{BE} = \frac{FC}{r - v}$$

$$Fixed\ costs\ (FC) = 15360KD$$

$$Variable\ costs\ per\ unit\ (v) = 705KD$$

$$Revenue\ per\ unit\ (r) = 1500KD$$

$$Break - even\ point\ (Q_{BE)} = \frac{15360}{1500 - 705} \approx 20\ units$$

Both the upper and the lower limits price ranges show that the project will break even after selling around 20 units which is a minor number considering that the problem the product is going to solve is widespread in many countries around the region and the expected unit sales are actually much higher.

Phase III

Detail Design, Manufacturing and Testing

The detailed design will be discussed below. But, first, the design will be simplified for the sake of the analysis. The material used in our analysis is Steel AISI 1020, and the study was based on the worst scenario: no tires to curry the frame and the car attachment carries all loads. Therefore, all stresses were obtained are the von misses stress.

Detailed Design:

Feasibility:

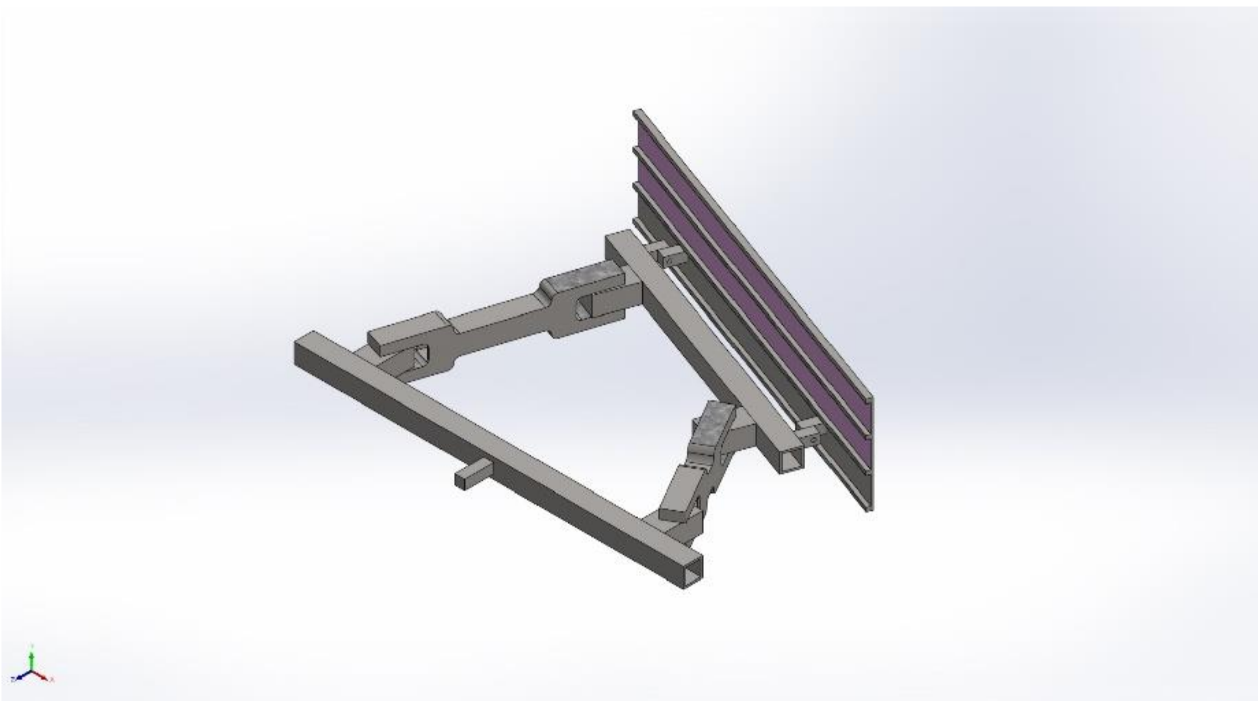

Figure 29: First CAD Design

We started with this initial design Figure (29) to ensure the feasibility of the project. The design was started with this simplified model to know the maximum sustainable load; the beams used were 10cmx10cmx2cm. The two arms in the middle were made to rotate, to study all angles

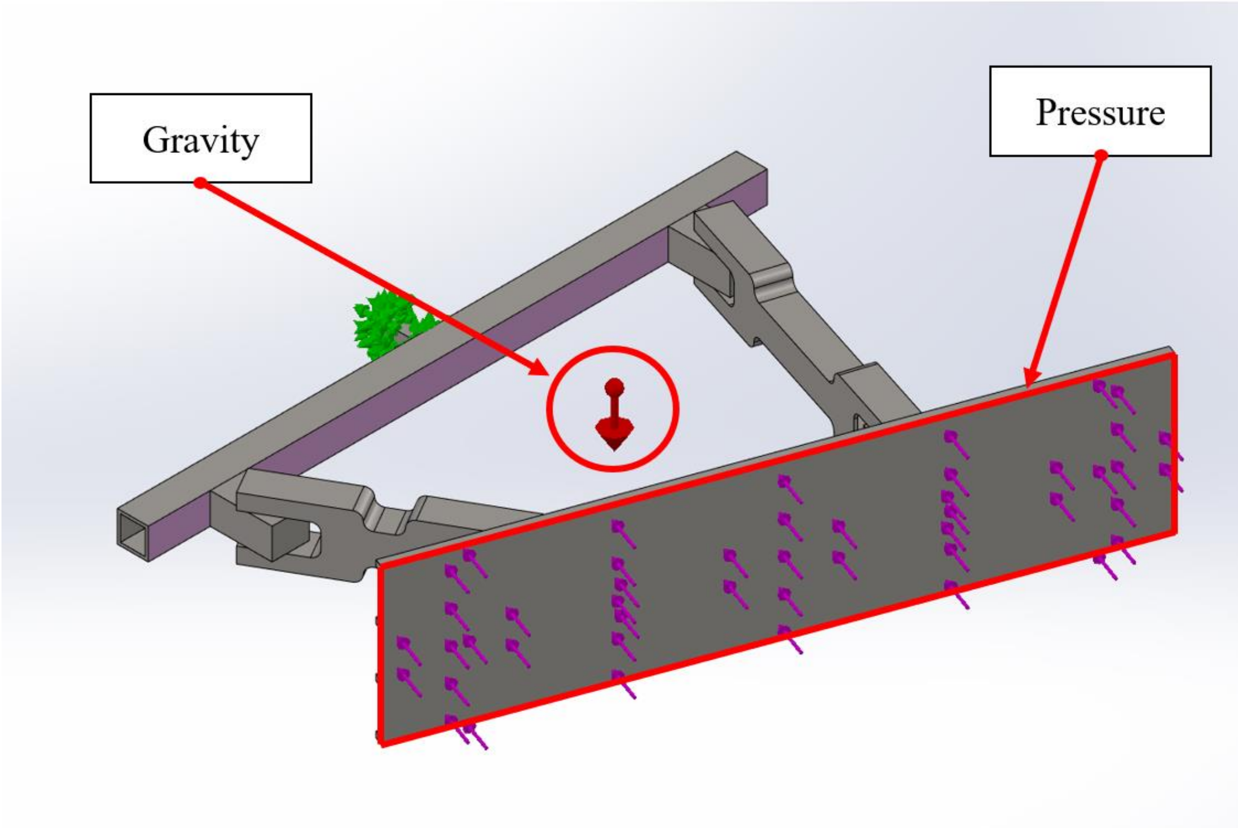

Figure 30: Type of Loads

There were two loads in the feasibility study, the gravity and the frame weight caused the first load, and the second load is sand Pushing.

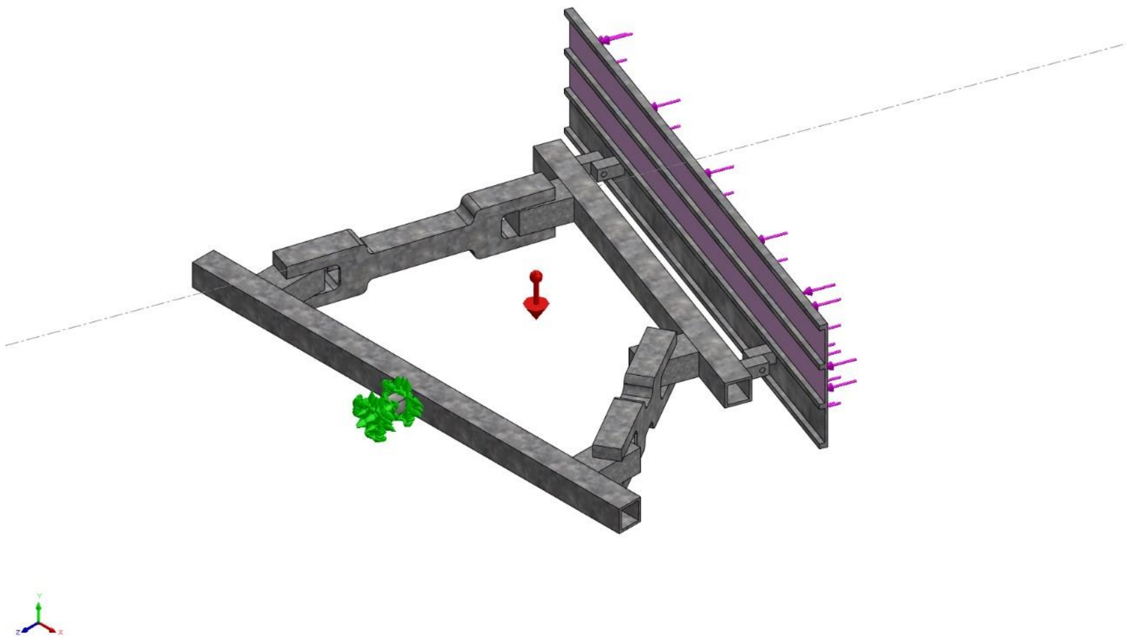

Figure 31: Distributed Load on the Plow

A distributed load of 21000N was applied on the surface of the plow, and the plow size was 2mX0.5mX1cm.

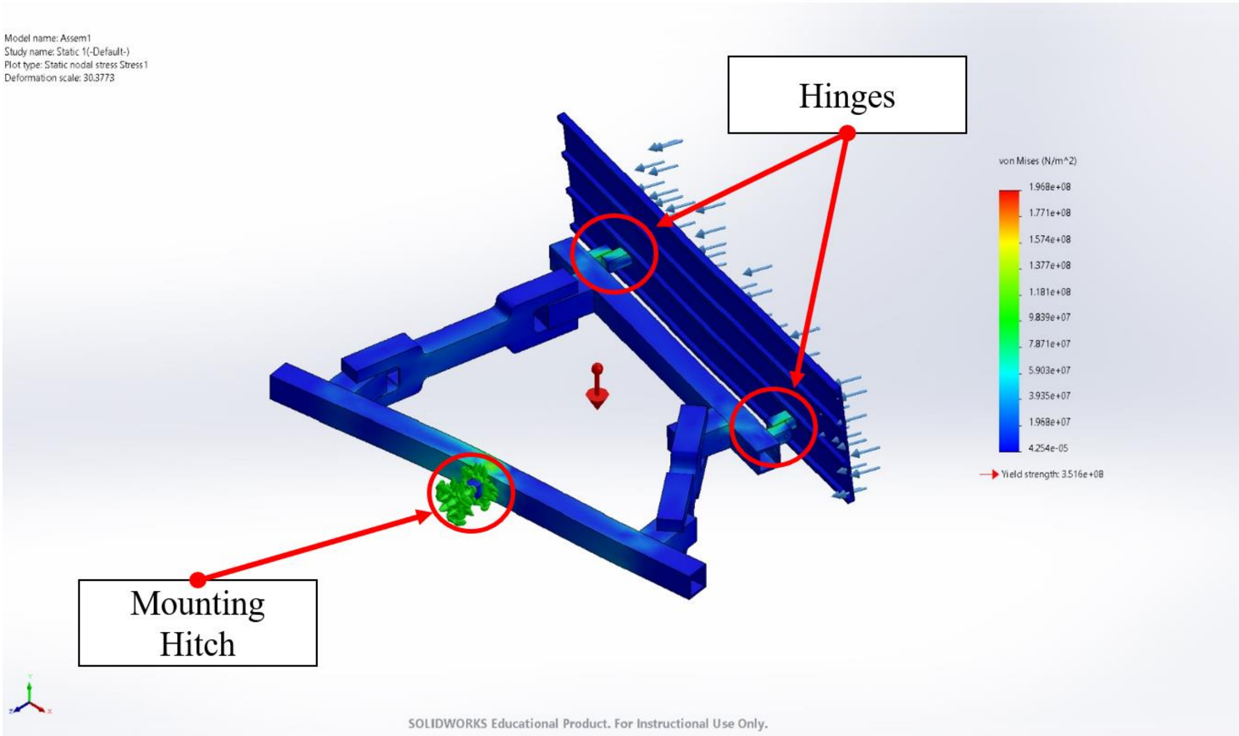

Figure 32: Locations of the maximum stresses

It was found that the maximum von mises stresses Figure (32) were on the plow hinges and the car mounting (front hitch). Hence, these locations must be supported.

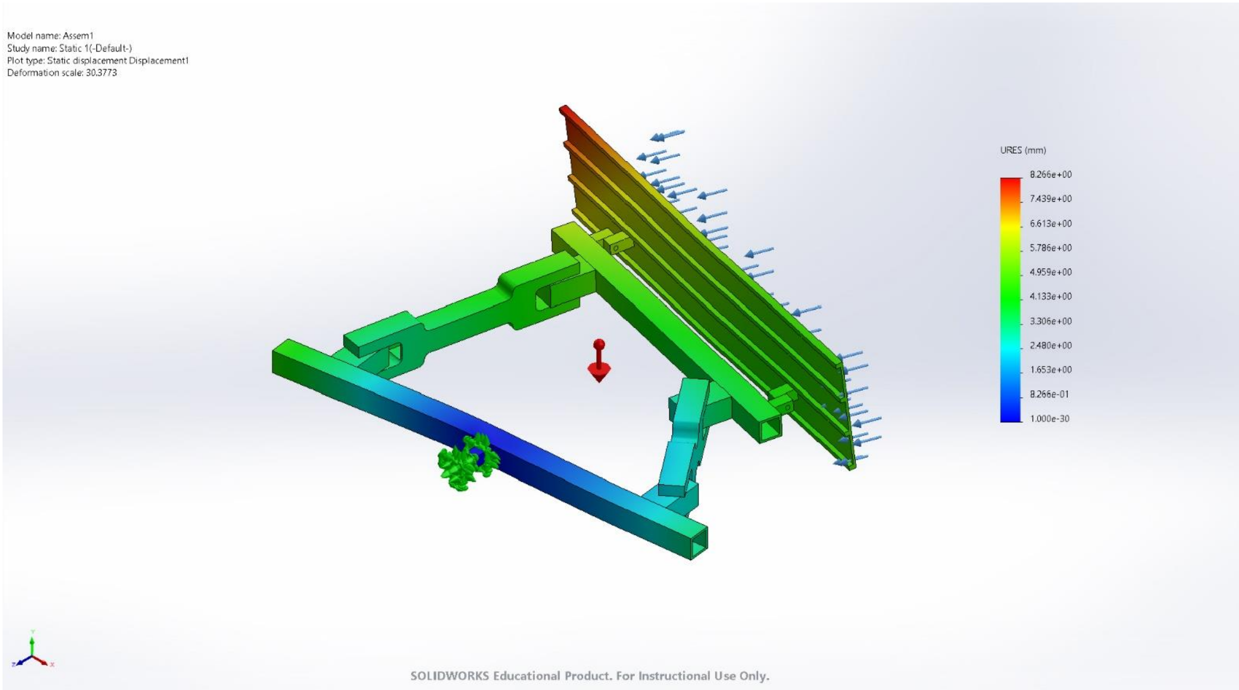

Figure 33: Maximum deflection point in the system

The maximum displacement Figure (33) was on the plow's left edge at 8mm, which is very low for that high load.

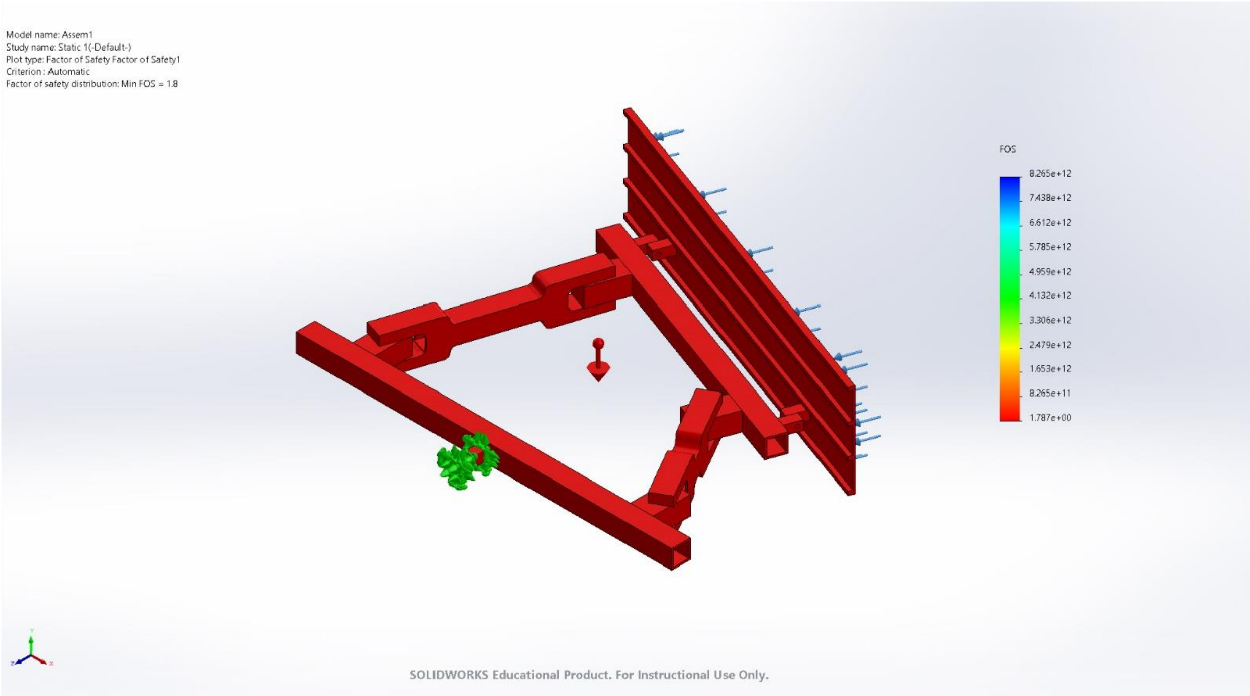

Figure 34: System's factor of safety

The factor of safety Figure (34) was 1.787; hence, the maximum load is 37527N. So, this tool is overdesigned, and the thickness of the beams needs to be decreased. The table below summarizes the results.

Table 17: Feasibility study summary

Quantity	Value
Applied Load	21,000 N
FOS	1.787
Maximum Load	37,527 N → 3825 Kg (Small elephant)

Changing to smaller dimensions:

As seen in the previous section, the system was overdesigned, with a very high beams thickness and weight. Also, the last beam dimensions do not meet the stock beams available in the market.

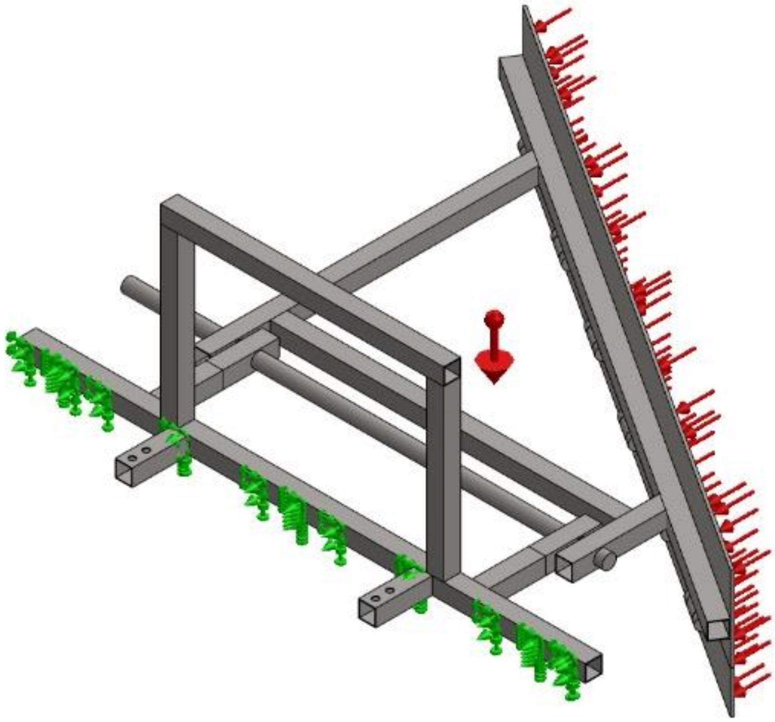

Figure 35: The frame with the new dimensions

A list of all the available beams in the stock has been obtained from the HADIDCO company. All beams in the frame were changed to meet the stocks. Also, the plow hinges were removed, and the plow was welded to the frame directly since the team decided to use the edge trip mechanism rather than rotating the plow entirely. By doing this step, the team gets rid of the plow stresses in the previous section. The disturbed load was decreased to 7000N, and the team made many iterations until the best size was reached. The last iteration size was 50mmx50mmx5mm.

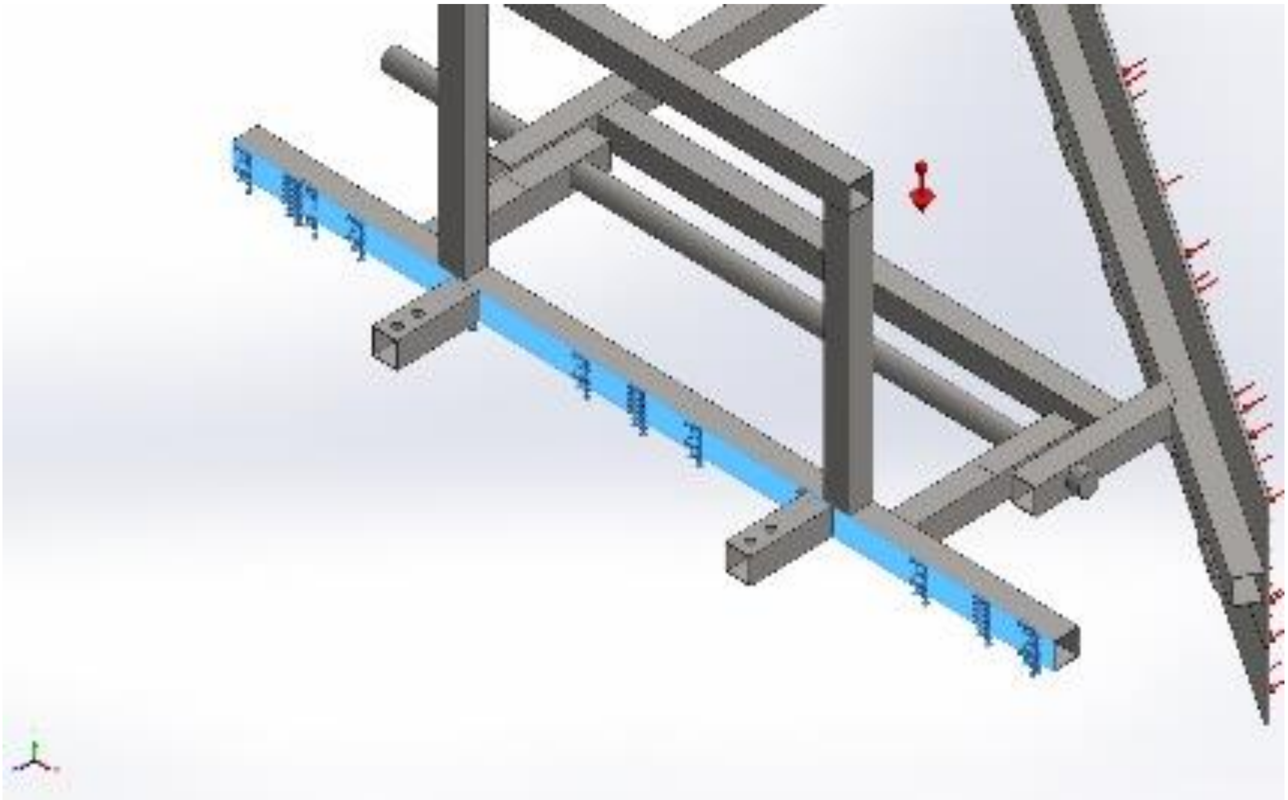

Figure 36: Frame Fixation

The frame was fixed at the back edge Figure (36), as shown in the blue since it was decided to design the car attachment later, and the team wanted to focus on the frame itself.

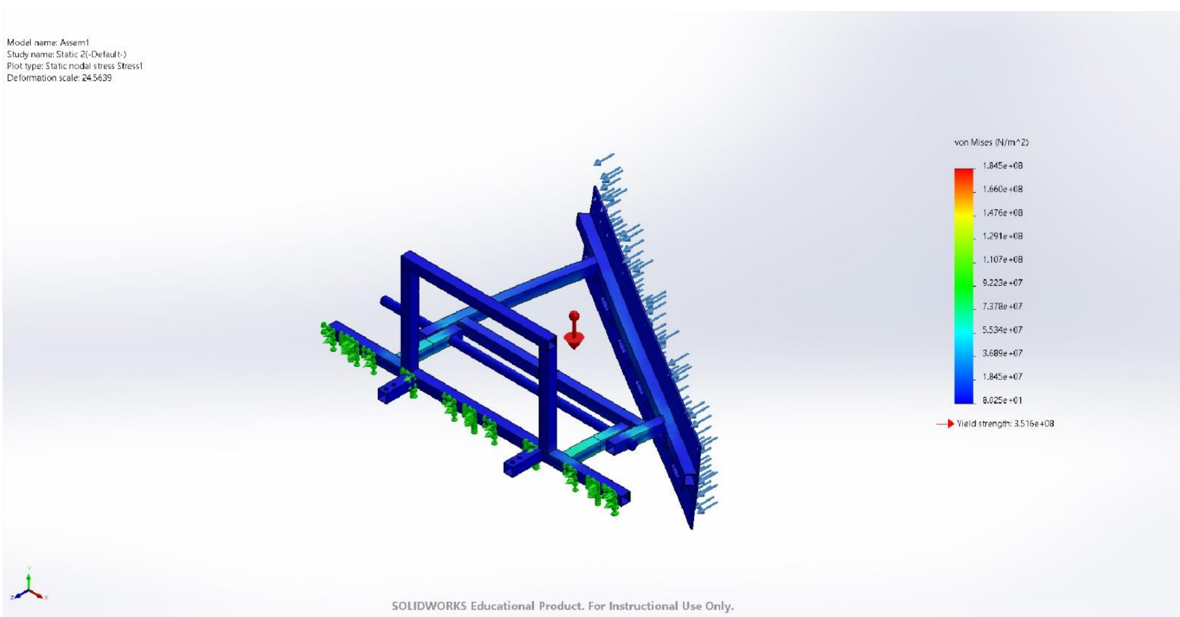

Figure 37: Stress analysis after changing the dimensions to 50mmX50mmX5mm

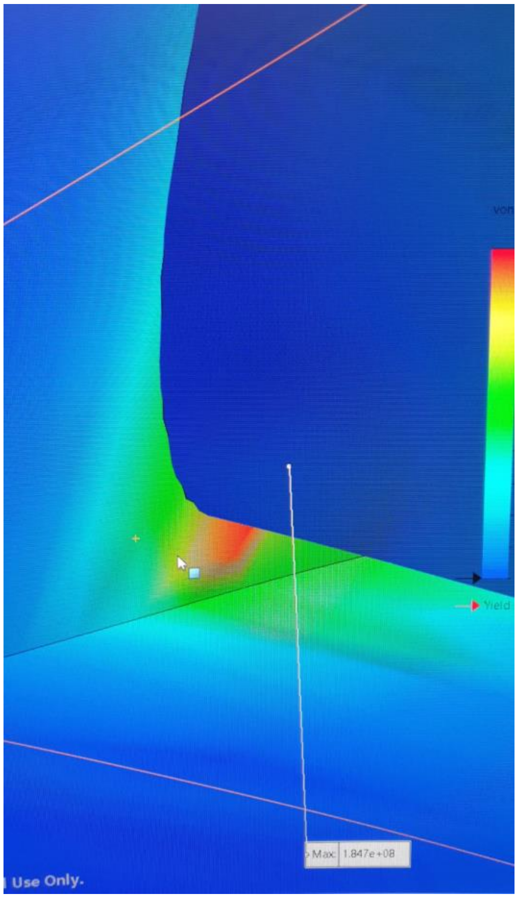

Figure 38: Location of the maximum stress

As shown in Figure (37) and Figure (38), the maximum stress was 185.5 [MPa], and the bearing stress of the cylinder allowed the half front of the frame to rotate. However, the stress still does not exceed the maximum allowable stress, and the safety factor is perfect and equal to 1.9 Figure (39) below; hence, the last iteration's thickness is suitable.

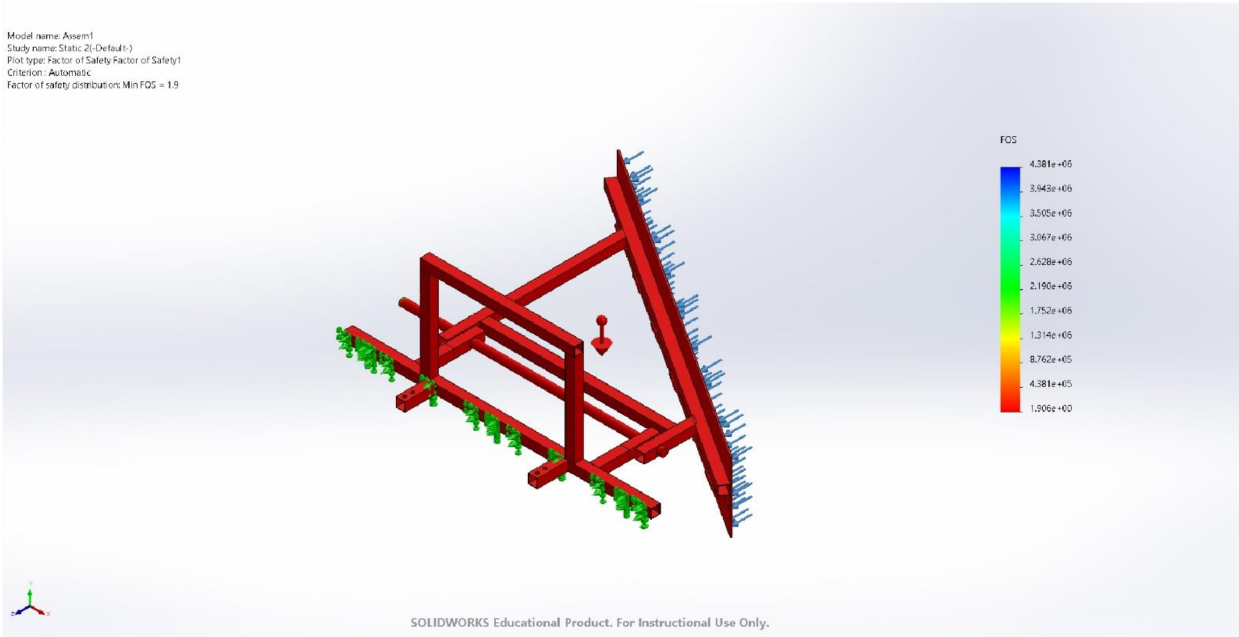

Figure 39: Factor of safety after changing the dimensions to 50mmX50mmX5mm

Adding a third bar:

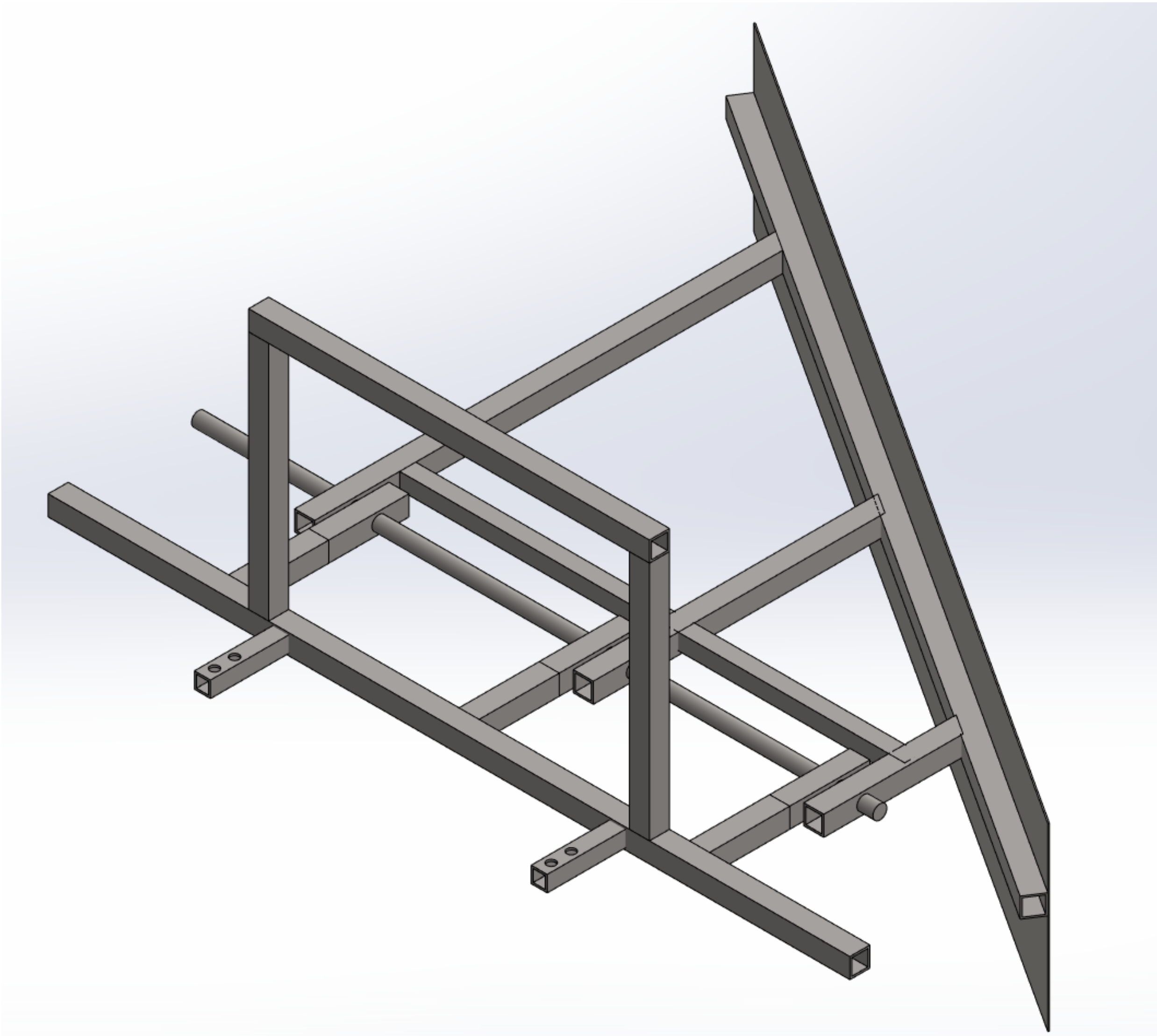

Figure 40: The frame after adding the third bar

The safety factor in the last iteration is only suitable for static loading; however, in this case, the load is dynamic, and the car's acceleration significantly impacts the system. The load could be higher than the static load if the acceleration were high; therefore, the team decided to add a third bar in the middle to double the safety factor.

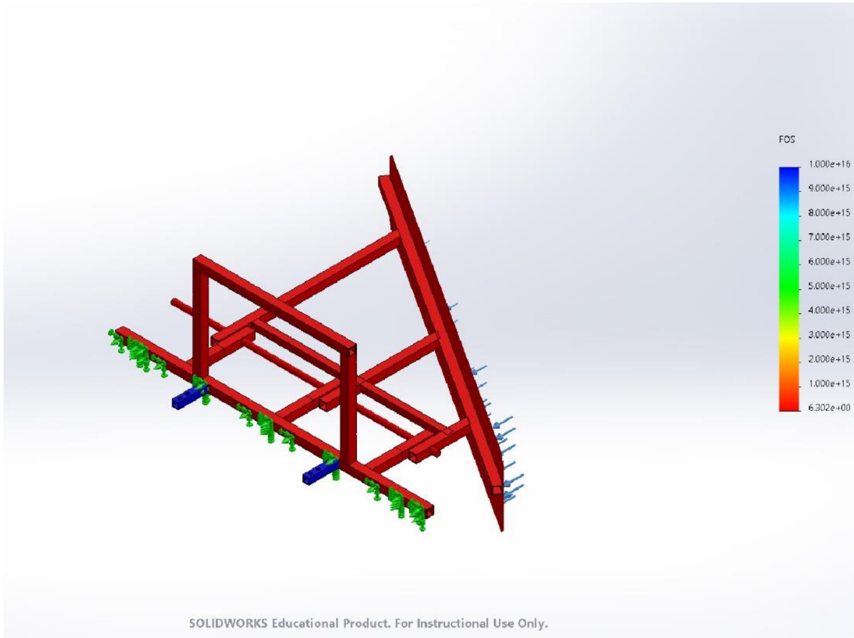

Figure 41: The factor of safety after adding the third bar

A third bar in the middle was added Figure (41) with the same size as the other bars, and the safety factor increased dramatically from 1.9 to 6.3. This change will ensure that the dynamic load will not break the frame at its stress concentrations.

Changing the Plow Shape:

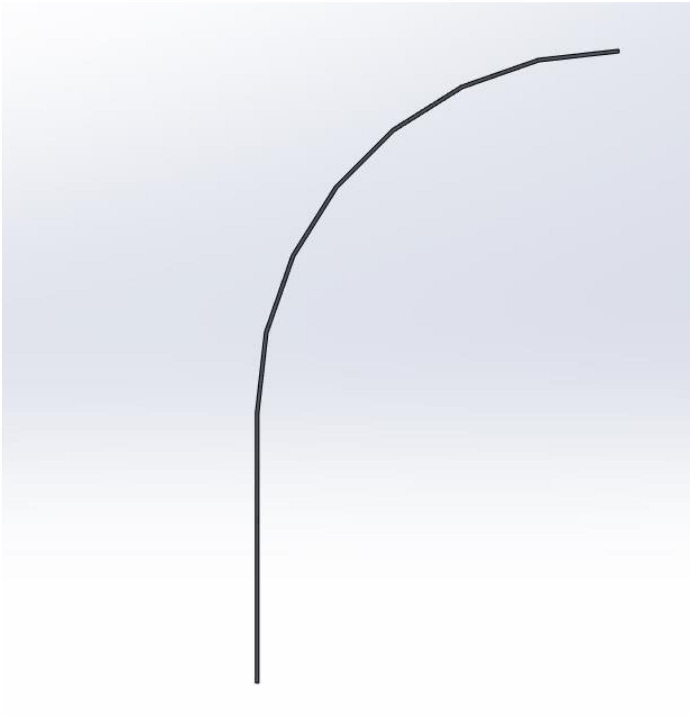

Figure 42: Plow with a curved half top (1)

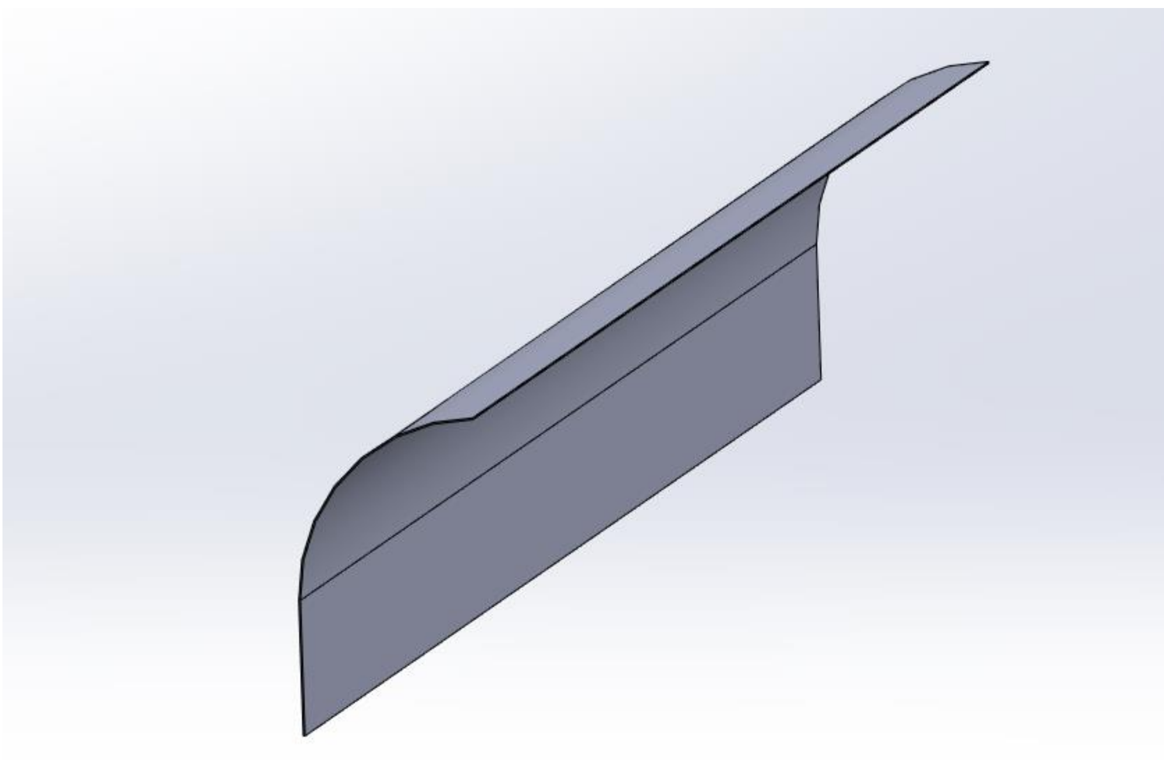

Figure 43: A plow with a curved half top (2)

As shown in the above Figure (42), the plow was designed to be curved on the half top since the sands will start to accumulate and build up, and if there is no curvature, the sands will cross the plow from the top. The analysis of this shape takes much time due to the mesh complexity; more than one day is needed to analyze the system when this plow is used.

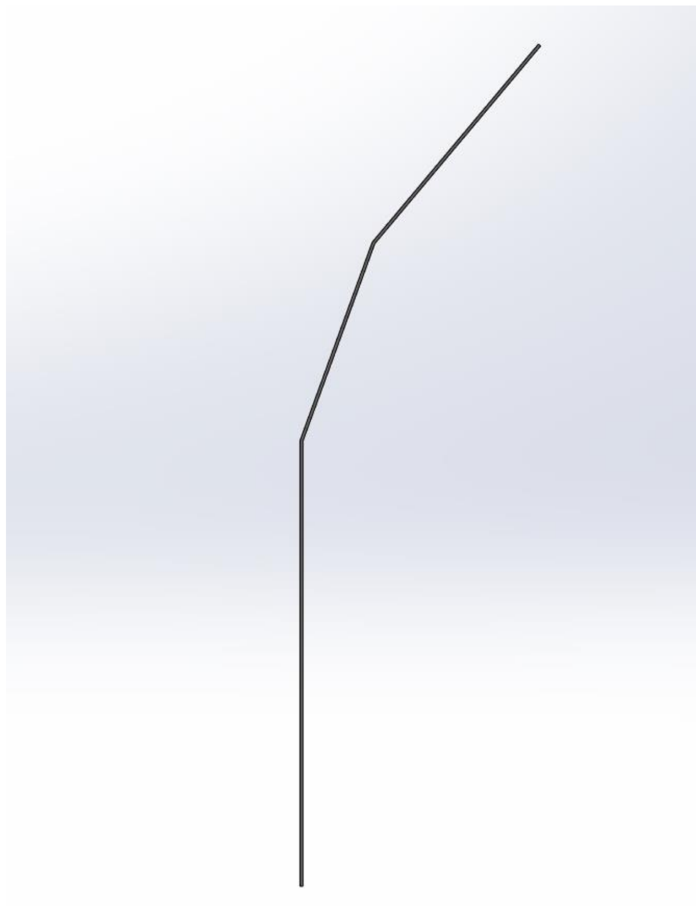

Figure 44: A plow with an angled top (1)

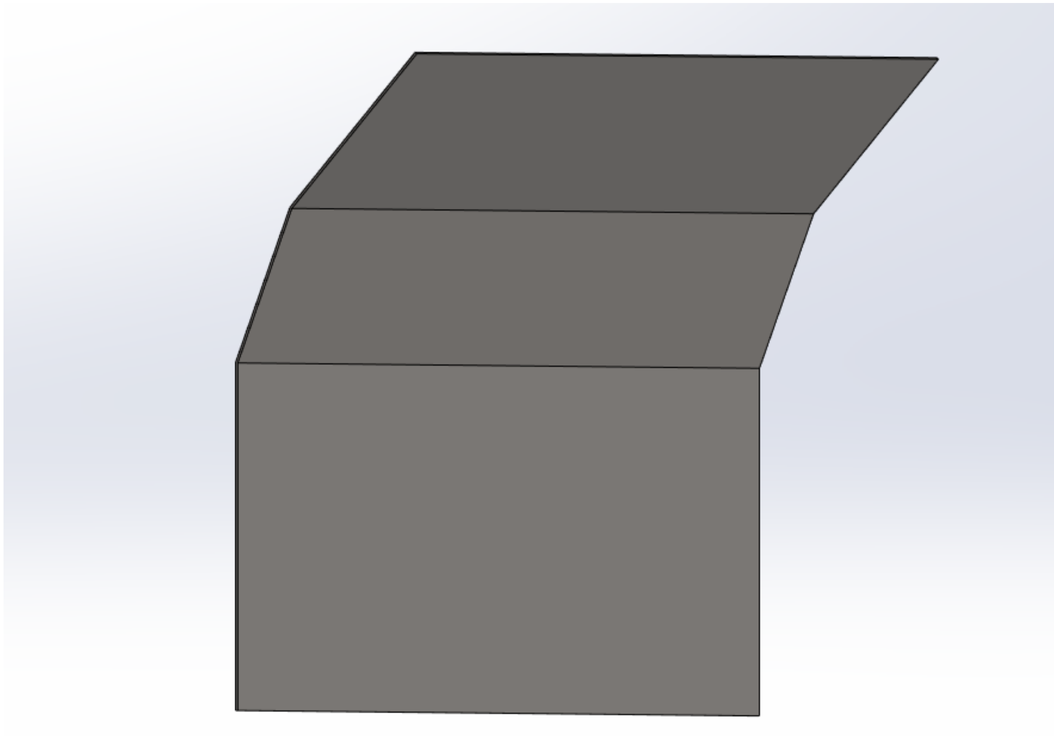

Figure 45: A plow with an angled top (2)

The team decided to simplify the curvature and make it double angled. The first angle is 20 degrees, and the second one is 40 degrees. The analysis ran successfully after this simplification.

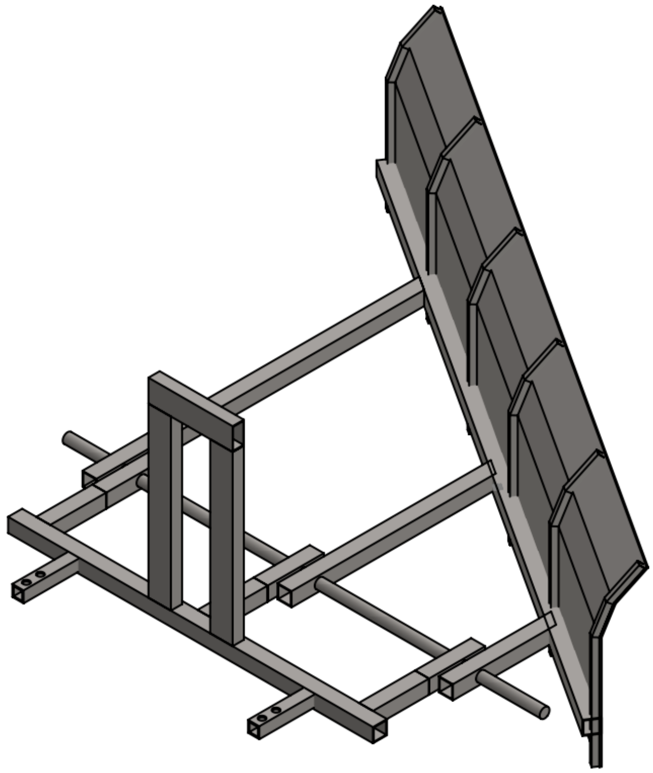

Figure 46: The frame with the new plow (1)

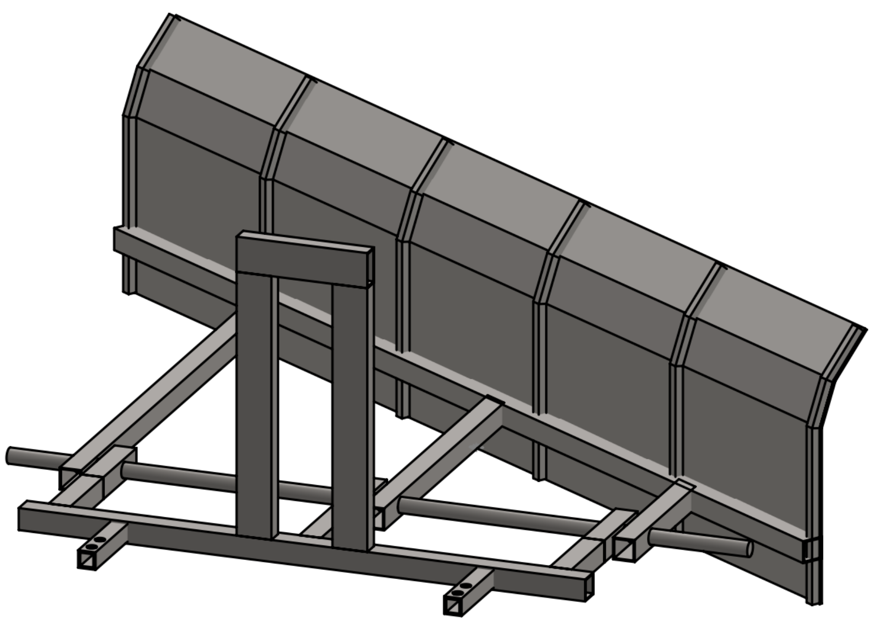

Figure 47: The frame with the new plow (2)

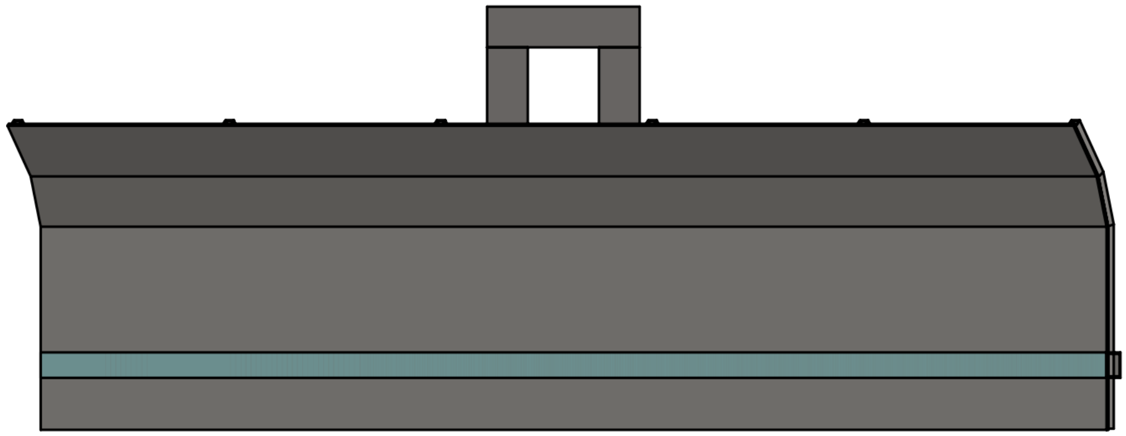

Figure 48: The frame with the new plow (3)

The system with the double angled plow is shown in the above figures, and this is the nearly final shape of our design.

System Dimensions:

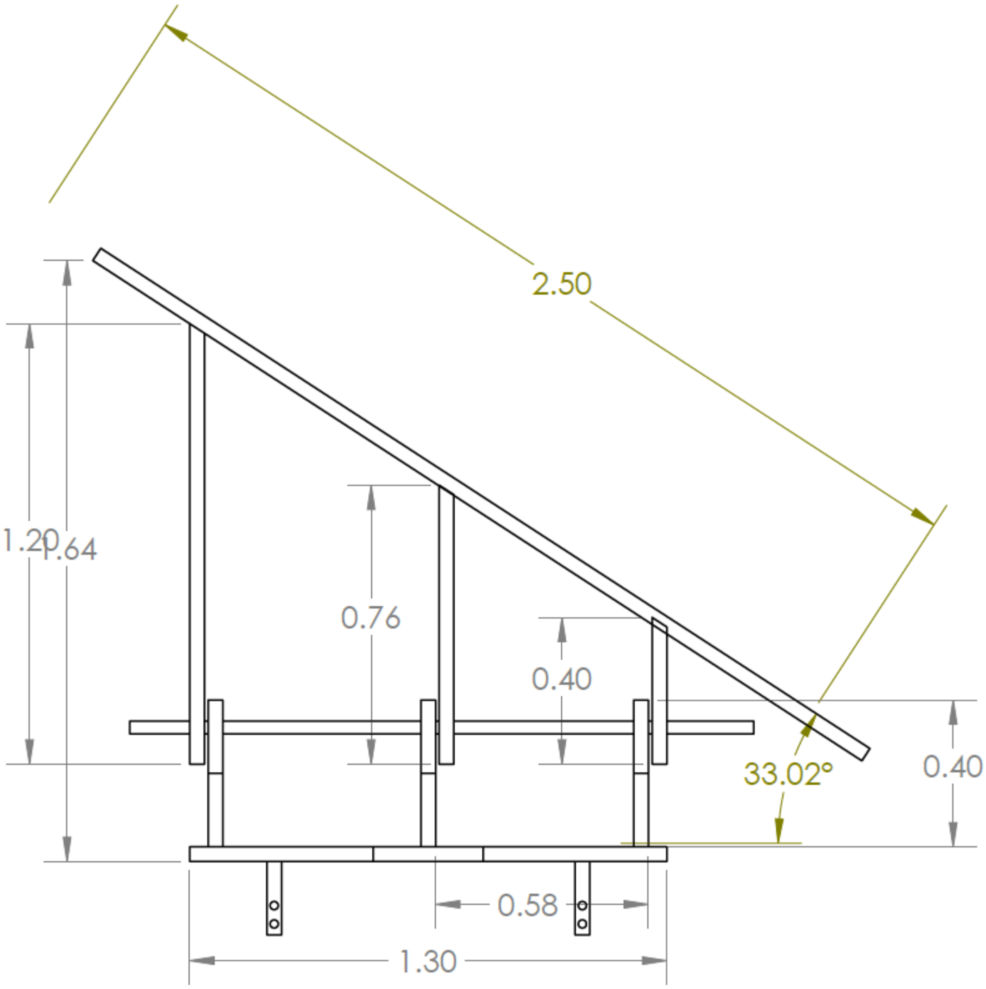

Figure 49: System dimensions

The figure above Figure (49) shows the final dimension of the frame after doing the analysis (previous sections).

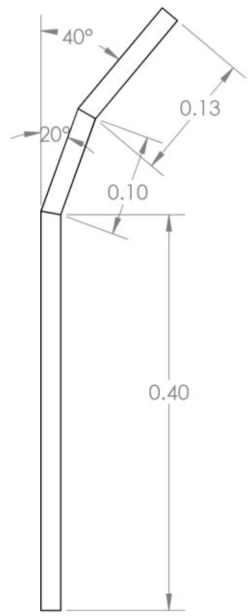

Figure 50: Dimensions of the double angled plow

Figure (50) above shows the dimensions of the plow and the back supports.

Blade Release Mechanism:

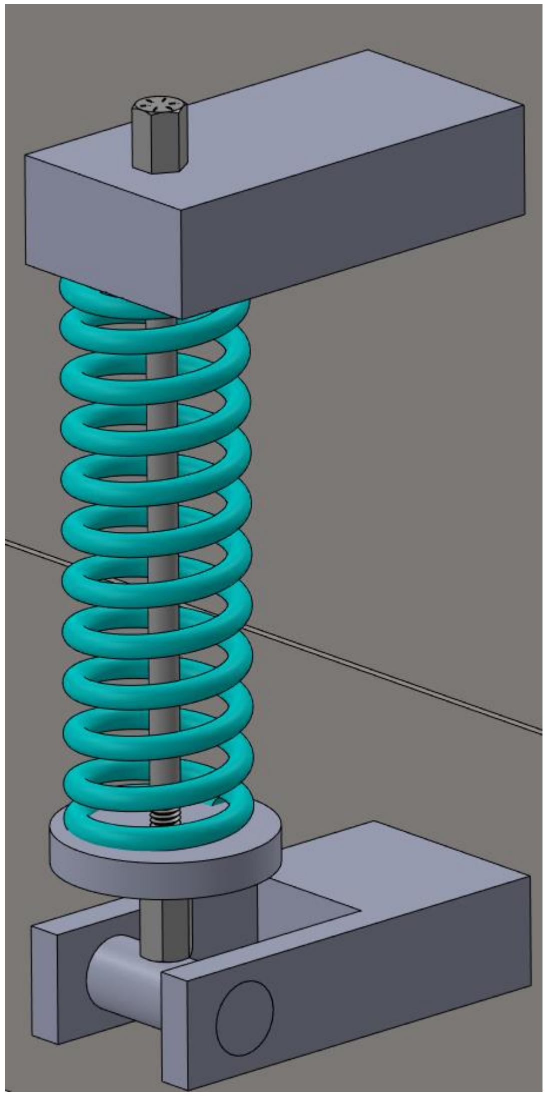

Figure 51: Plow edge mechanism

The figure above shows that the plow edge mechanism consists of a spring, rod, rotating cylinder, and screws. When a certain amount of force (it depends on how much the spring is pre-compressed) is applied to the edge of the plow, the edge will start to rotate, and the spring will be compressed. The middle bar helps the spring to remain vertically; however, the spring will tilt a little bit, and a larger hole on the top is needed.

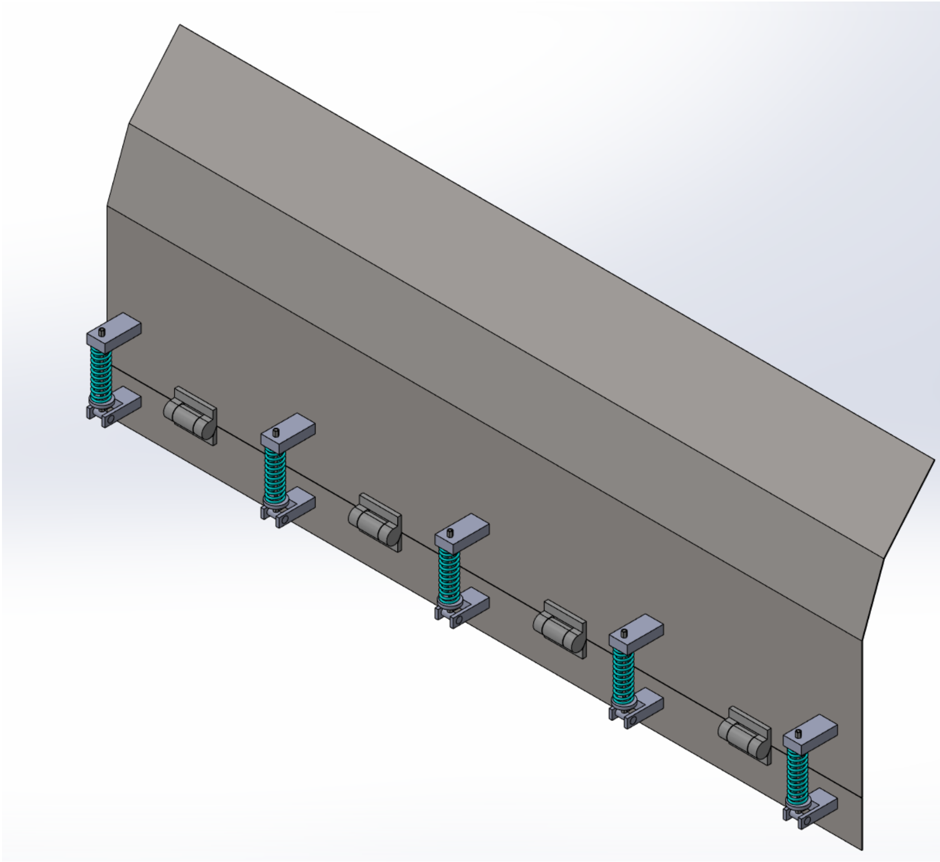

Figure 52: The plow with its edge mechanism

The figure above shows the plow with its edge mechanism, and the team decided to add five springs to it to reduce the need for larger springs.

<u>Car Mounting:</u>

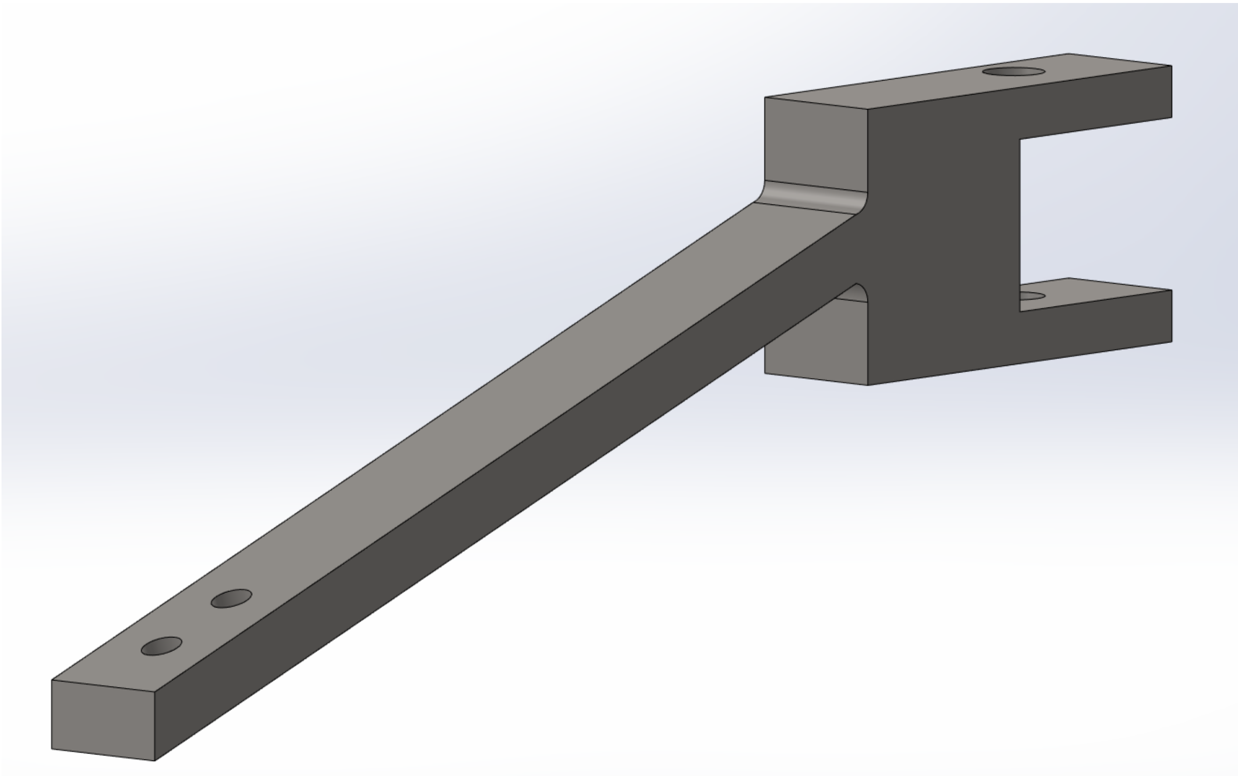

Figure 53:Car Mounting

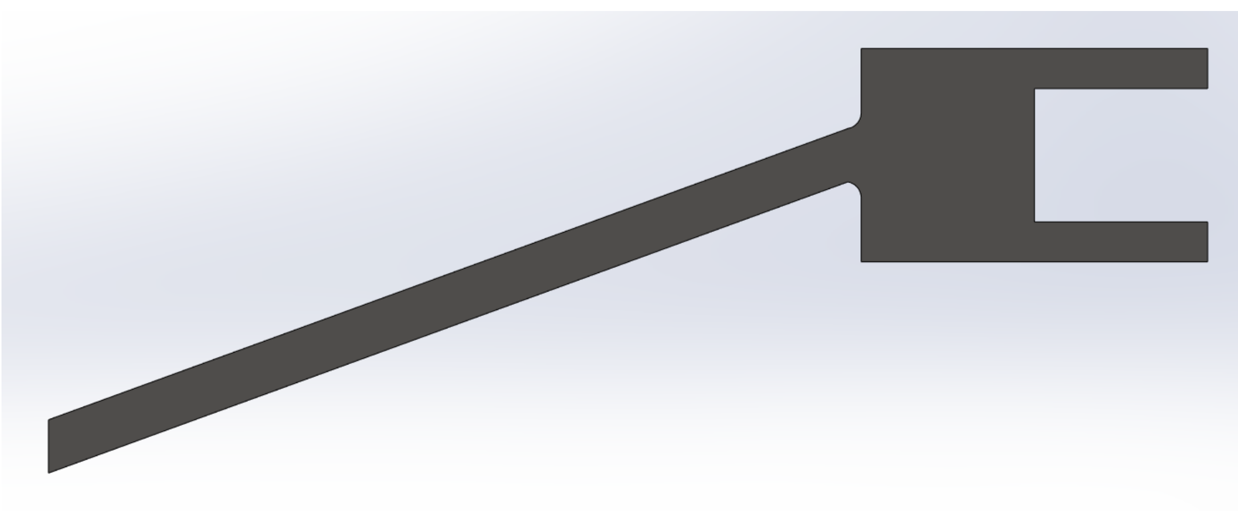

Figure 54: Car Mounting side view

Figures (53 and 54) above show the hook that will be attached to the SUV, the two bolts will be attached to the chassis, and the front square has a size same as the frame; hence this hook will act as a male and female attachment, and the frame bar will set inside the square.

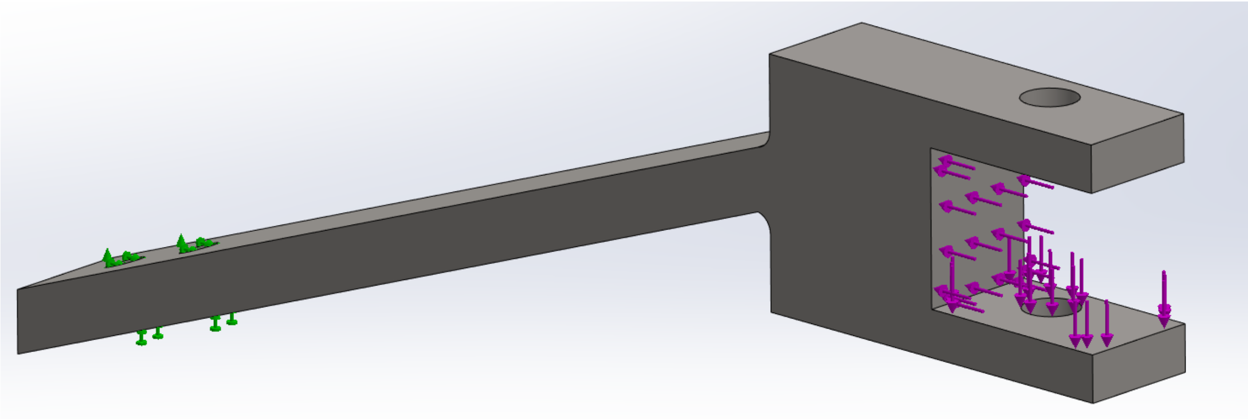

Figure 55: Load on hook

The hook is the most critical part of the project; if it fails, the whole project fails; hence, it was decided to overdesign it with very high loads and unrealistic scenarios. Two loads were applied to the hook figure (55), a vertical load of 300kg, double the weight of the whole system, and a horizontal load of 1000kg, which is almost one and half of the real sand plowing load. The two bolts were assumed to be fixed, and the analysis was done.

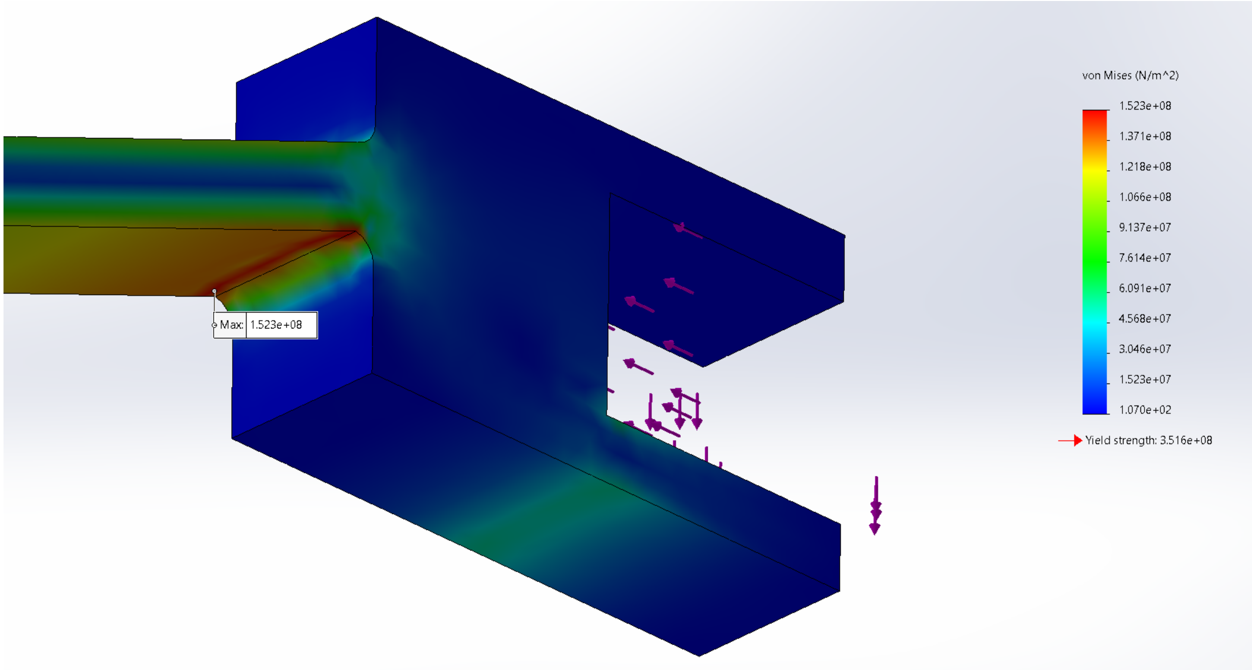

Figure 56:Stress contour plot

The maximum stress figure (56) occurred at the fillet, which is a stress concentration. Therefore, the maximum stress does not exceed the yield stress, and the safety factor equals 2.31, as shown in figure (57) below.

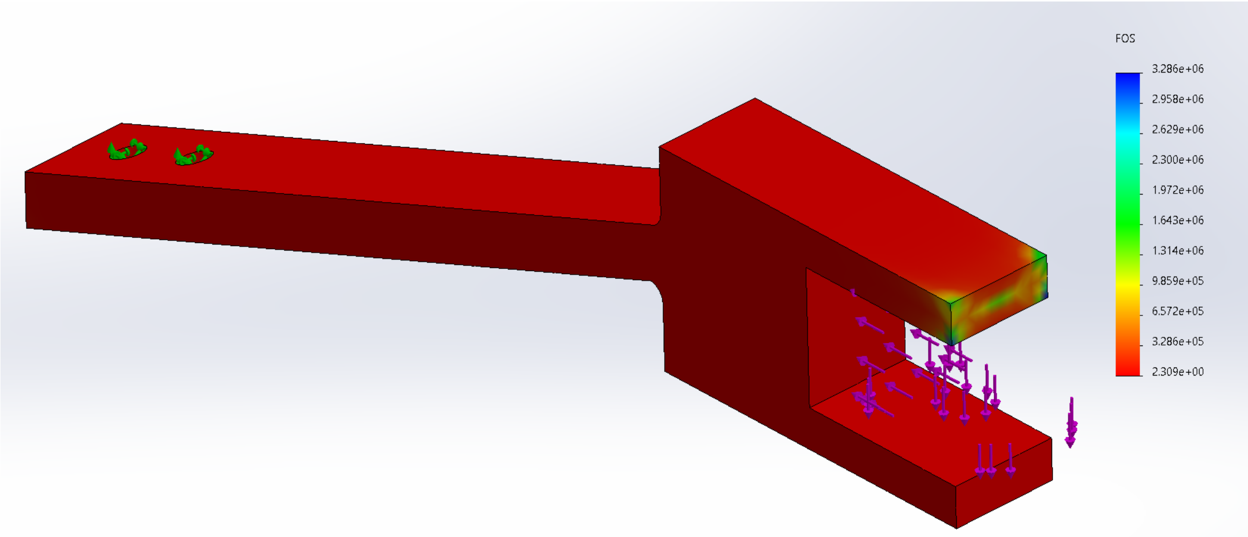

Figure 57: The factor of safety of the hook

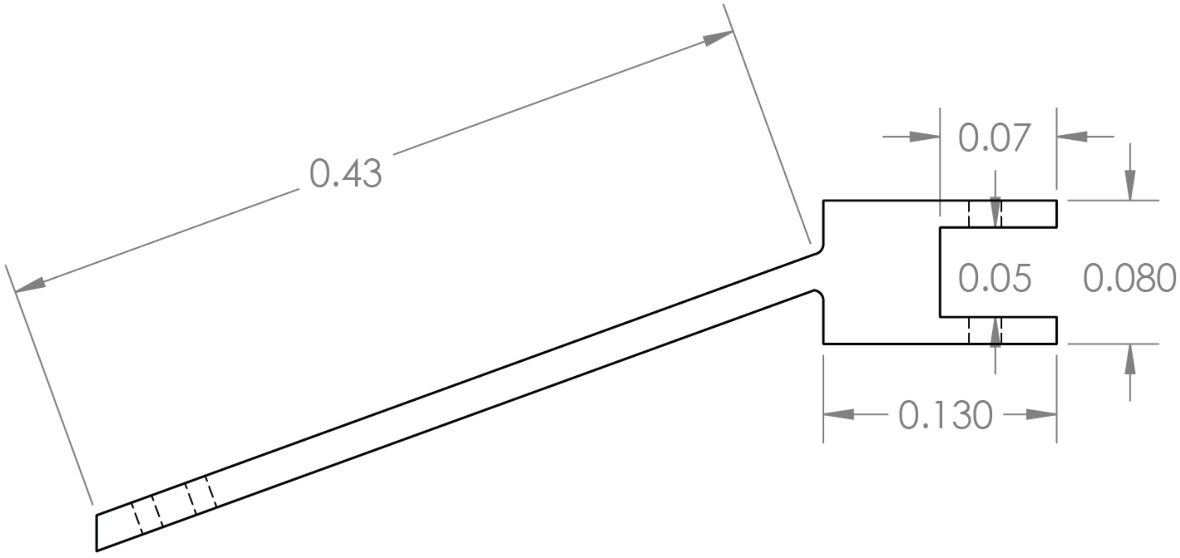

Figure 58: Hook's Dimensions

Figure (58) above represents the dimensions of the hooks. The bolts' sizes are not included since it depends on the user and the used car.

Manufacturing

In this section the detailed manufacturing process for the prototype will be discussed. It should be noted that not all the components that were desired from the concepts have been implemented into the prototype due to time constraints. The manufacturing was outsourced and done by BMB workshop in Shuwaikh due to the fact that the prototype required skilled labor to manufacture.

The available materials that were used for the prototype were:

- AISI 1020
- Hollow square tubes 5x5 [cm] with a thickness of 3[mm]
- Solid Cylinder with a radius of 1.5 [cm]
- Sheet metal with a thickness of 3 [mm]

The manufacturing CAD.

Figure (59) illustrates an accurate representation of the desired end product of the manufacturing process.

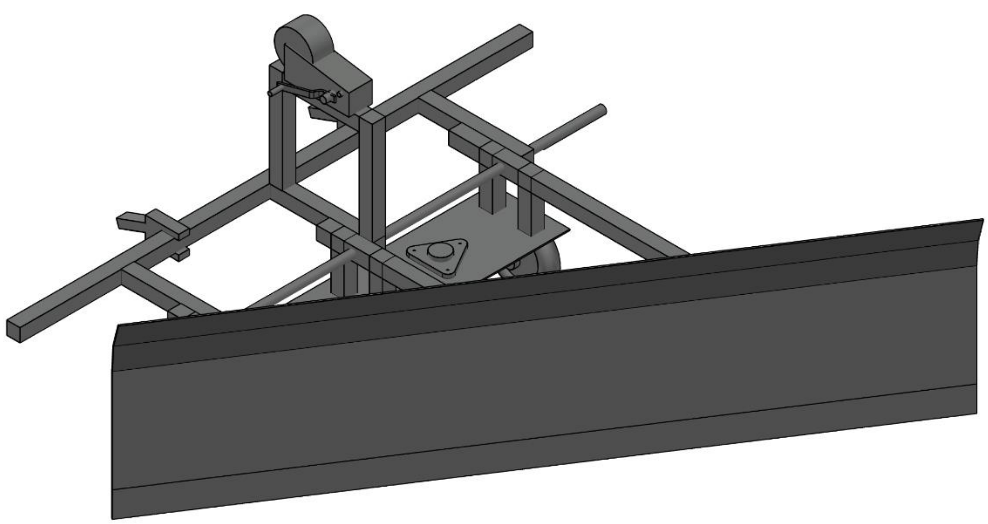

Figure 59: Manufacturable Design

Figure (60) is an exploded view of figure (59).

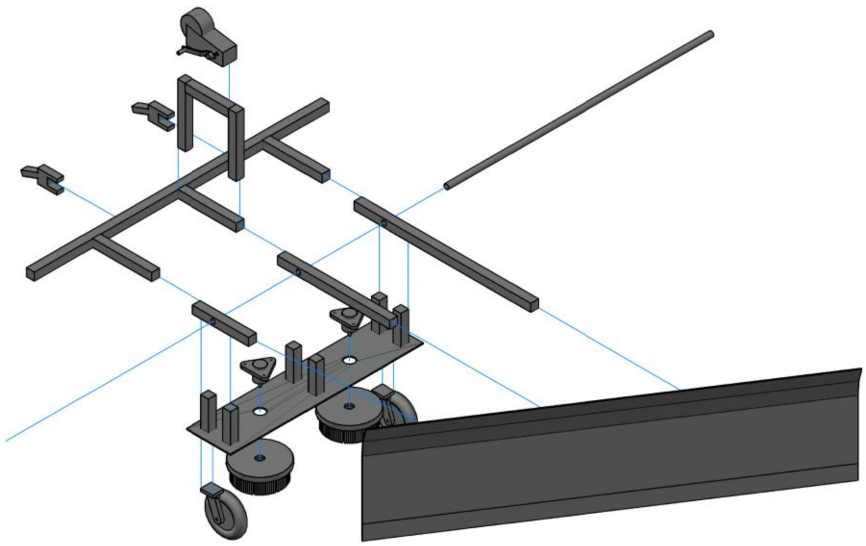

Figure 60:Exploded view of manufacturable design

The process

To start the manufacturing efficiently, the prototype was categorized into four subassemblies; ready-made items; the plow; the frame; and finally, the car joints. This was done to keep track of the manufacturing easily and to also allow for parts to be done in parallel as the main issue with the prototyping was that the team had a time limit that had to be met. The manufacturing started on the 28th of May.

Figure (61) represents the division of the prototype into subassemblies for ease of manufacturing

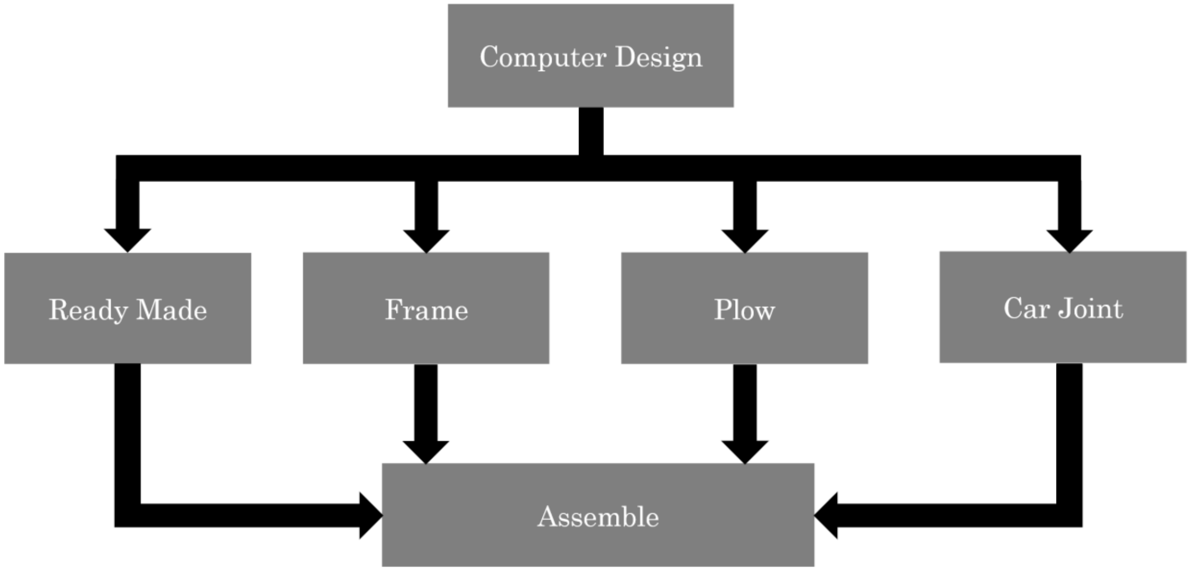

Figure 61: Division of components

The Ready-made items

There were four ready made items for the prototype:

- The manual winch
- The AC motors
- The Tires
- The Street brushes

The manual winch and the tires were both found in the Jawad Al-Saffar store located in Shuwaikh near the workshop. And can be seen in figures (62 and 63).

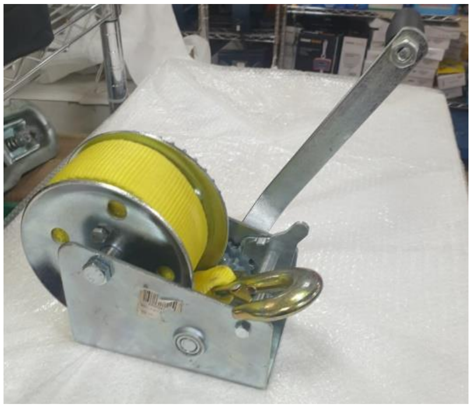

Figure 62:Manual Winch

Figure 63:Tires

The AC motor was obtained in the electronics store in Hawally, Al-Qamar Intl.

Figure 64: The AC motor

The final ready-made item was the street brush this was in the Marafie cleaning company however the issue with the brush was that the AC motor shaft does not match the hole of the street brushes. An attachment had to be made for the motor shaft to fit for the brush. The company also handled the manufacturing of the special attachment since they work with their own workshop that has lathe machines that can create these specially made items.

Figures (66) and (65) illustrate the brush with and without the special motor shaft attachment installed.

Figure 66:Brush without attachment

Figure 65:Brush with attachment

The Frame

The frame was split into two components called the chassis and the motor cage. The chassis is the supporting part of the frame while the motor cage is as the name suggests a resting mount for the motors and brushes.

The chassis

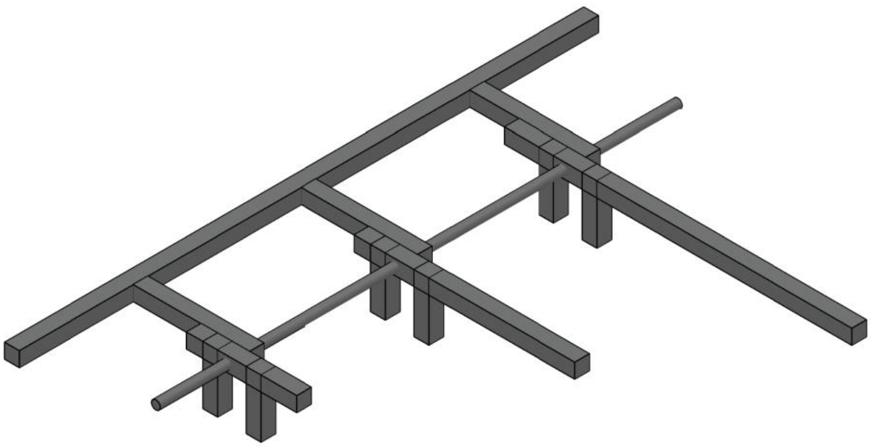

Figure 67: CAD of the chassis

The chassis is composed of two main materials. The hollow square beams and the solid cylinder that allow for rotation. Relevant beams are first drilled using a drill bit for the cylinder to fit in the assembly of the component. Then the beams are joined together using welding and finally the cylinder is adjusted with a cylindrical metal bush in the joints. This allows for smoother rotation.

Figure 68: Finished assembly of the chassis

The motor-cage

The brushes are not able to reach the ground if attached straight at the chassis. Therefore, the motors should be mounted closer to the ground and that is the reason for the designing of the motor cage. A by product of this design is to also create a point of stable attachment for the tires.

Figures (70) and (69) depict the motor cage in isometric view and side view respectively.

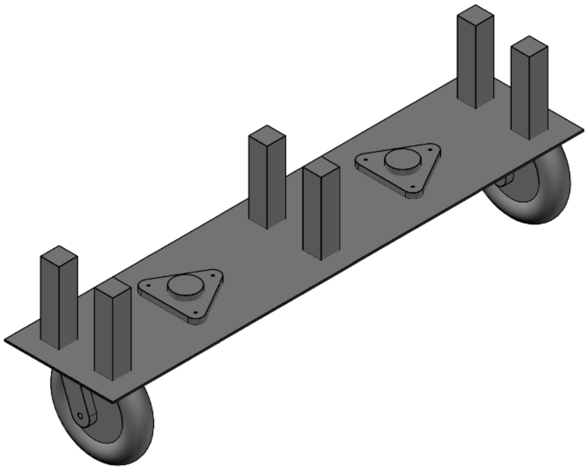

Figure 70: Isometric view of CAD for the motor cage

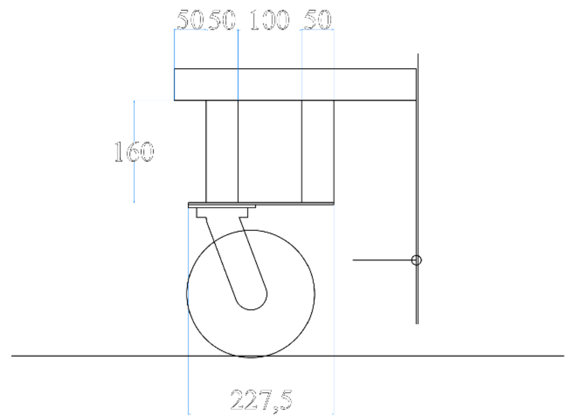

Figure 69:Side view of the motor cage

The cage was manufactured using the same beams for the chassis and were joined by welding as well. As for the motors, a sheet metal was used to have a place for mounting the motor in place. This sheet metal had been punched out using a punching machine to be able to mount the motors.

Figure (71) shows the final assembly for the motor cage when it is attached to the chassis.

Figure 71:Final assembly of the motor cage

The Plow

The metal is simply sheet metal that has been bended using a bending machine. With small sheet metal welded behind the plow for support.

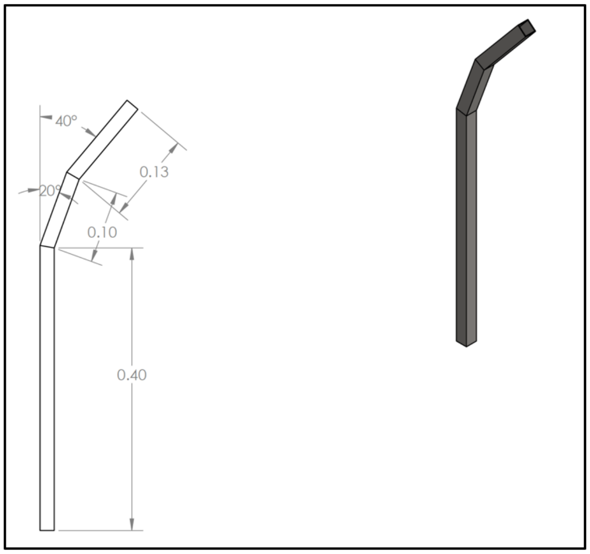

Figure 72: Side view of the plow

Figure (72) shows the bending machine used for manufacturing the plow.

Figure 73:Bending equipment

A problem was encountered with manufacturing the plow subassembly. It was desired to implement a trip mechanism at the bottom of the plow which incorporates a trip spring system. However, due to complexity in the manufacturing and the lack of obtaining the correct springs for the applied force. It was not implemented into the subassembly.

Figure (75) and (76) illustrate the back and front of the plow, respectively.

Figure 75:Back of the plow

Figure 74:Front of the plow

The car joints

The car joints that were designed and analyzed on the SOLIDWORKS software are shown in figure (77). The dimensions that were required were solid steel with a thickness of 5[cm]. However, the workshop tasked with manufacturing the prototype did not have the appropriate machines that can create this component. Therefore, it had to be made outside of the workshop and the only workshop available that could complete it in the appropriate time was a workshop that utilizes water jets for material removal processes. The problem that was encountered was that the machine could only cut a maximum of 2 [cm]. Therefore, through improvisation, the joints were cut as 4 pieces of 2[cm] thick car joints.

Figure (77) shows the required dimensions for the car joints that were obtained when using the CAD software.

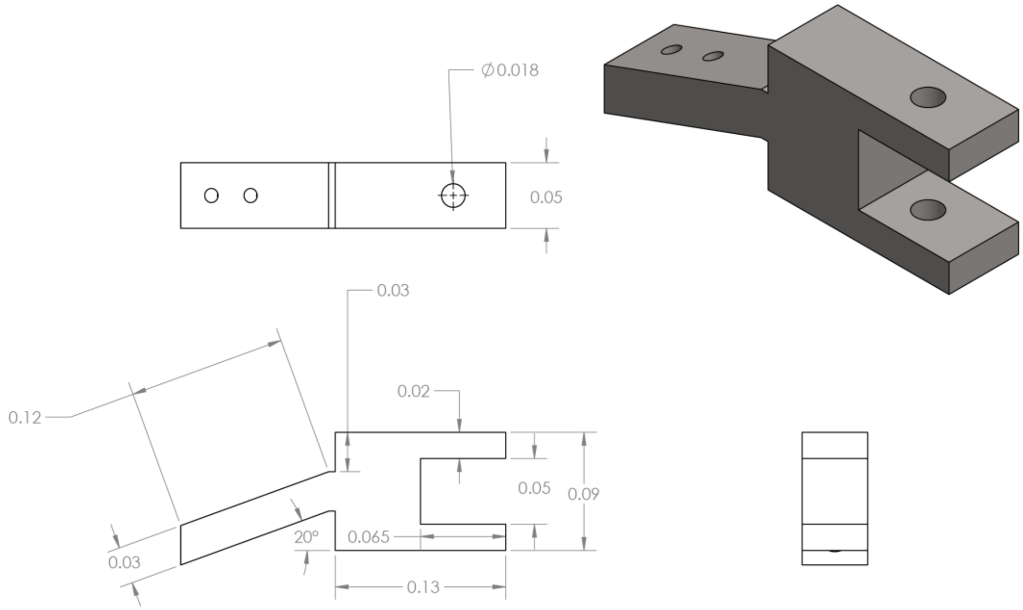

Figure 77: Car joint dimensions

Figures (76) and (78) show the single car joint and the welded pair, respectively.

Figure 76: Single car joints

Figure 78: Welded pair of car joints

These parts shown in figure (76) were then welded together to obtain a final attachment with a thickness of 4 [cm]. This can be seen the figure (78)

When it came to testing the car joint it was later found that the length of the joint was too short, and the bumper of the car was obstructing it. Therefore, the length of the car joint was increased. This can be seen in figure (76)

Figure 79: Car joint attached to the car

The Assembly

After all the subassemblies were made and ready, all that was left was to assemble each of them and complete the manufacturing process. The motor cage, chassis and plow were all assembled by welding and the car joint was attached using bolts and pins.

Figure (80) shows the completed prototype that is ready for testing.

Figure 80: Manufactured prototype

Prototype testing:

After the prototype was manufactured and assembled, it was loaded on a half lorry to transport it to the testing location in Alwafra. The main plan was to test the prototype on a highway affected by sand accumulation, so the team headed to Alwafra police station to request a police car to accompany the team during testing, in order to ensure the safety of the team and the road users. However, the team did not get any help from the police station, so the other plan was to test the product in an isolated place.

The prototype was attached to the car successfully as shown in figure (81) and the motors were connected to the inverter which is connected to the car battery. The inverter was placed inside the car hood, this place made it catch heat from the engine very quickly, which led to overheating the inverter and stopping it from working properly, so the testing was done without using the motors and the brushes. However, the motors and the inverter were tested in the workshop and they proved to be working properly when the inverter was properly cooled.

Figure 81: Prototype attached to the car

The team then tested the strength of the car mounting by raising the plow to the maximum height such that the tires do not touch the ground as shown in figures (82 and 83). The mounting was strong enough to carry the plow by itself without needing support from the tires, which indicates that the mounting is very strong and meets the design goals.

Figure 82:Car mount testing (side view)

Figure 83: Car mount testing (front view)

After that, the team tested how the plow pushes the sand to the road shoulder. The team tried two levels of sand, the first is shown in figure (84) and the second is shown in figure (85). The plow was effective two push the sand away for the two levels of sand.

Figure 84: Plowing medium-level sand

Figure 85: Plowing low-level sand

The product was successful in all tested aspects except the thin layer removal mechanism due to inverter overheating issues.

Economic Analysis:

After the team manufactured the prototype, the team had a better understanding of the project's costs. For that reason, the break-even analysis was done again to know how many units of the product have to be sold to cover the fixed and variable costs of the project.

Table (18) below shows the project's total costs, which consist of materials and the manufacturing costs as variable costs and the research and development costs as fixed costs.

Table 18: Total costs

Source	Quantity	Cost
Materials (VC)	8 items	90 KD
Manufacturing (VC)	1 Sand Sweeper	490 KD
Total Costs Per Unit		**580 KD**
R&D (FC)	4 Engineers	4800 KD
Total Project Costs		**5190 KD**

(FC = Fixed costs ; VC = Variable costs ; R&D = Research and Development)

Table (19) shows the bill of materials for the final prototype. The 1st column represents the item number. The 2nd column shows the part name, while the 3rd column shows the quantity of each part. The 4th column represents the total costs of the prototype components, and the last column shows the same components' total costs if they are bought from the original suppliers.

Figure 86: Manual winch from Hebei Junda Hoisting Machinery Manufacturing Co., Ltd.

Figure 87: A brush from Anhui Youchuan Brush Industry Co., Ltd.

Figure 88: A wheel from Yangjiang Xingyang Industry & Trade Co., Ltd.

Figure 89: AC motor from Zhejiang Electrical Co., Ltd.

Table 19: Bill of materials

	Part Name	Quantity	Cost (Kuwait)	Cost (China)
1	Motors	2	12 KD	5 KD
2	Brushes	2	20 KD	12 KD
3	Springs	6	22 KD	4 KD
4	Inverter	1	17 KD	7.5 KD
5	Winch	1	8 KD	6 KD
6	Wheels	2	6 KD	1 KD
7	Fasteners	-	0.5 KD	0.5 KD
8	Hinges	6	4.5 KD	1 KD
Total			**90 KD**	**37 KD**

Break-Even Point:

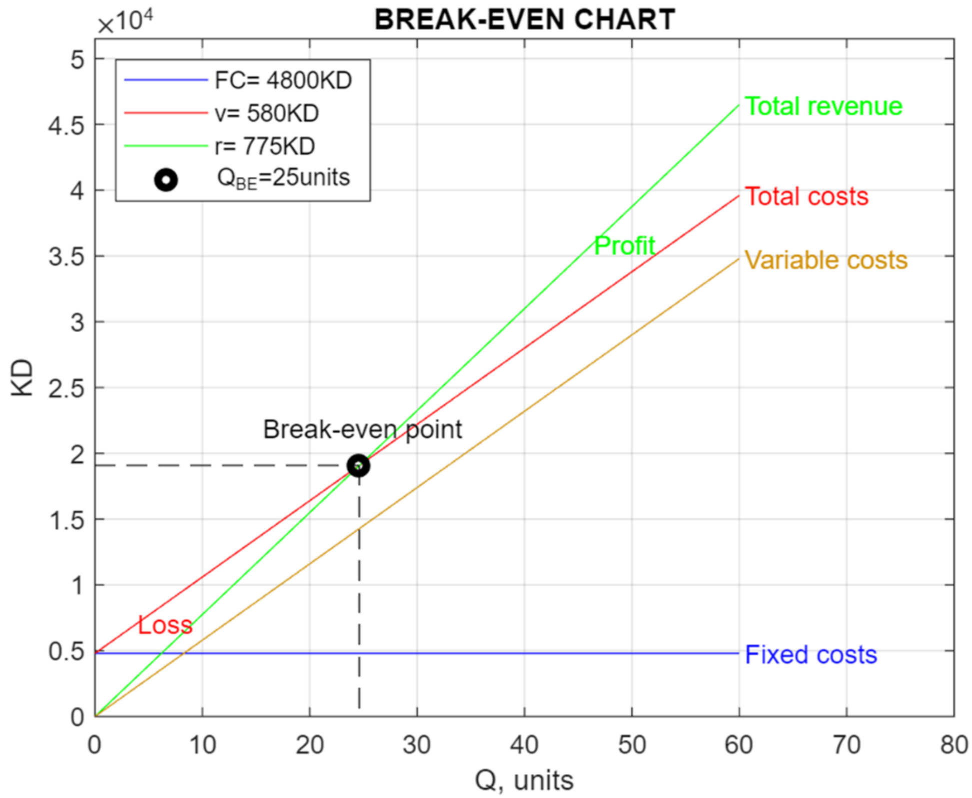

Figure 90: Upper limit Break-Even Point

$$Q_{BE} = \frac{FC}{r - v}$$

$$Fixed\ costs\ (FC) = 4800KD$$

$$Variable\ costs\ per\ unit\ (v) = 580KD$$

$$Revenue\ per\ unit\ (r) = 775KD$$

$$Break - even\ point\ (Q_{BE)} = \frac{4800}{775 - 580} \approx 25\ units$$

Figure (90) above shows that the project will break even after selling around 25 units which is a minor number considering that the problem the product is going to solve is widespread in many countries around the region, as shown in Figure (91) below, and the expected unit sales are actually much higher.

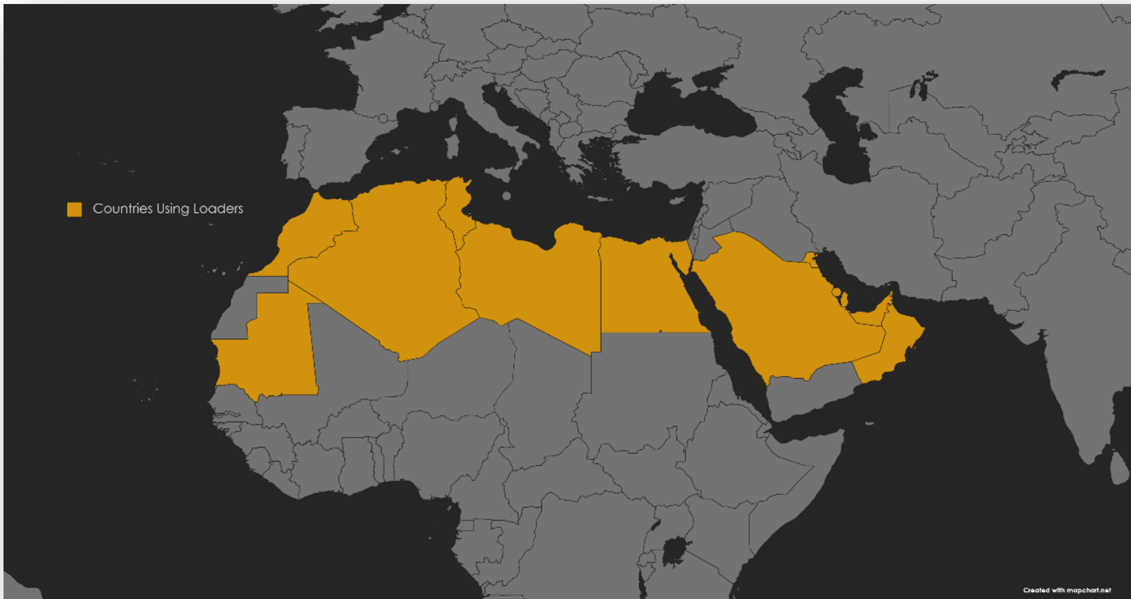

Figure 91: Countries with reported cases of sand accumulation

References:

[1] Figure (5): 2022 GMC Sierra 1500: Choosing the Right Trim

https://www.autotrader.com/comparisons/2022-gmc-sierra-1500-choosing-the-right-trim

[Accessed on: 16/5/2022]

[2] Figure (7): “Detail K2 (DK2) avalanche snow plow kit” December 2020

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