Kuwait University

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Engineering Design

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Phase 2 Report

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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 (1).

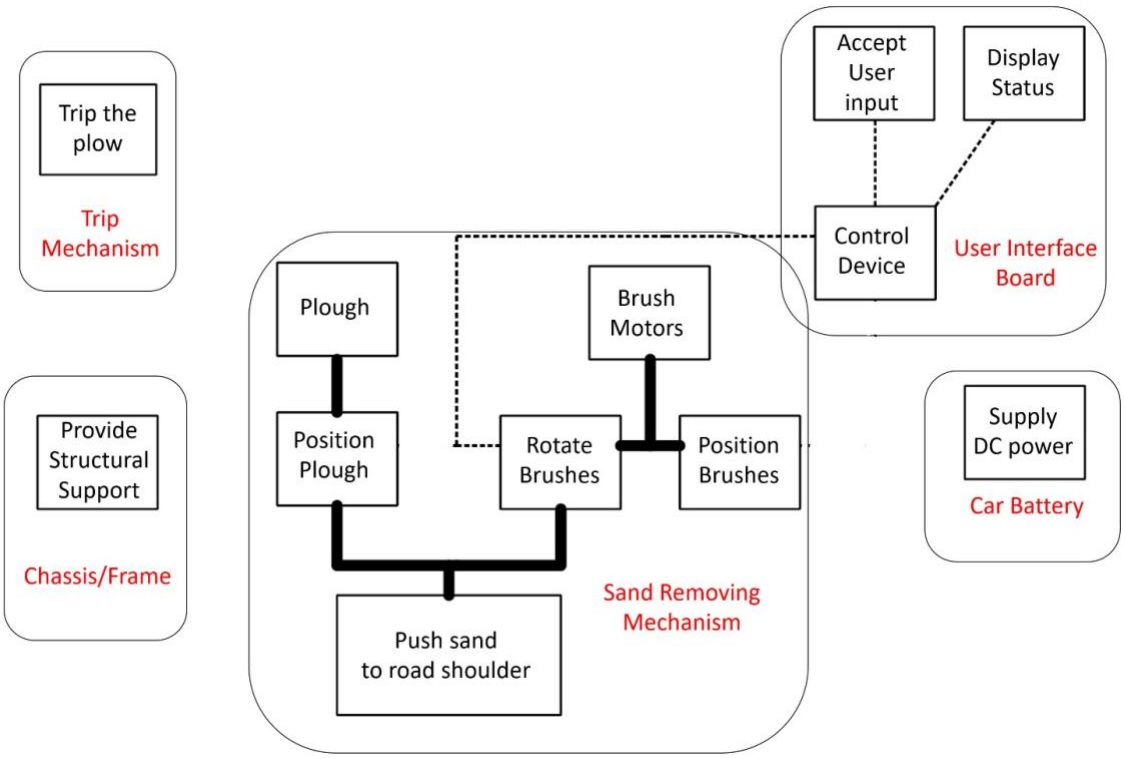

Figure 1: Schematic of The Product

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 (2).

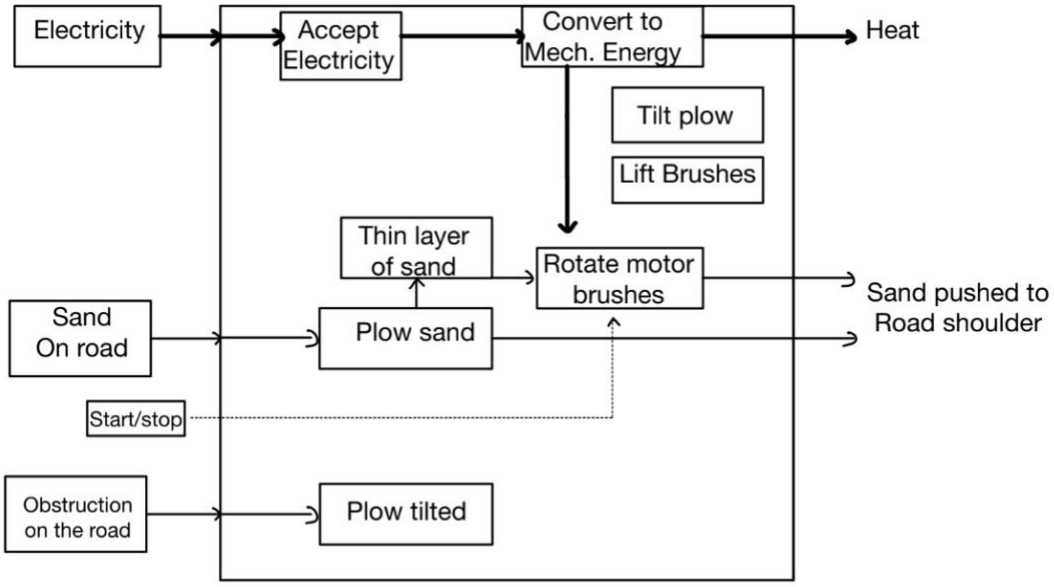

Figure 2: Functional Decomposition

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 (3) and (4).

Figure 3: Trip Edge

Figure 4: Whole Trip

A combination table was made for each of the required functionalities of the intended design. Table (1) shows the concepts for each different functionality.

Table 1: 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 (1). 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 (5).

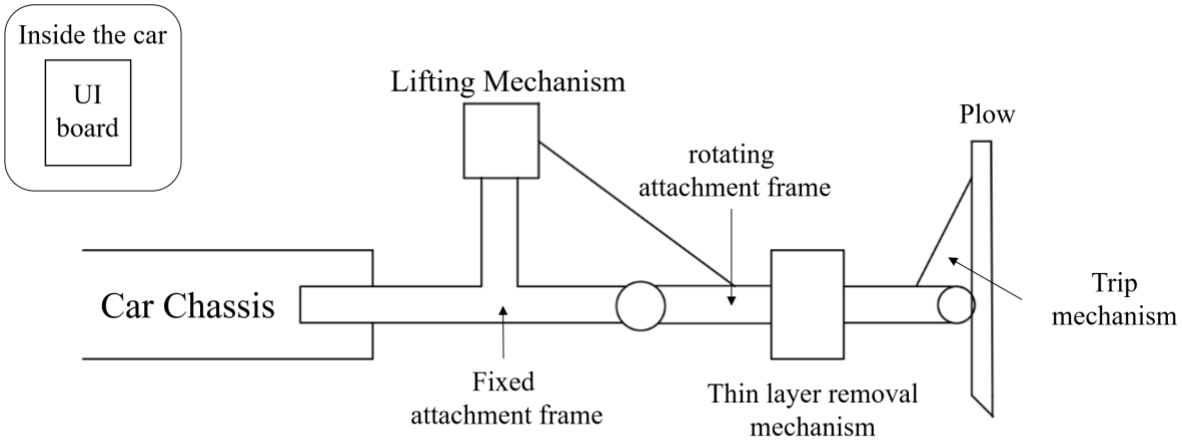

Figure 5:Rough Geometric Layout [1]

Concept A

Table 2: 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 3: 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 4: 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 5: 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 6: 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 (7) 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 7: 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 (7), 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 (7) but with weights on each criterion depending on its importance

Table (8) shows the scoring process for the concepts. It is like Table (8) 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 8: 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 (8) 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 (9) shows concept E which is also Table (9) and has been selected as the final concept for the project.

Table 9: 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 (6) illustrates the front of a GMC Sierra with distinguishable front hooks.

Figure 6: Front of a GMC Sierra

Figure (6) 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 (6).

The Tilting Mechanism and Brushes

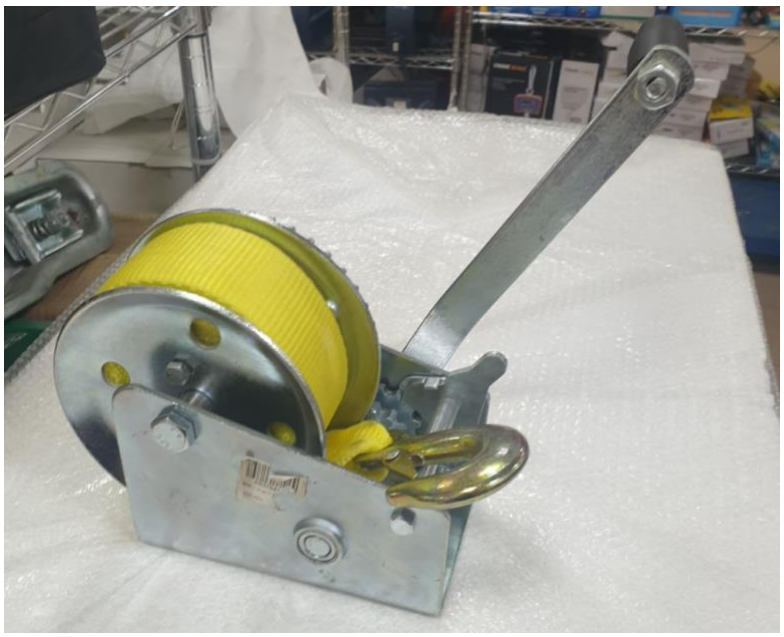

Figure 7: Image of a Manual Winch [2]

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 8: 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 (8) 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 (8)

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 (10) 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 10: 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 (1), (2) and (3) respectively are from Alibaba website, while the prices of the springs are from AliExpress and Bin Nisf websites.

Figure 9: Car Power Inverter [3]

Figure 10: Road Sweeper Brush [3]

Figure 11: Waterproof AC Motor [3]

Figure 12: Extension Spring [5]

Table (2) 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 11: Fixed Costs

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

Table (3) 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 12: 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 :

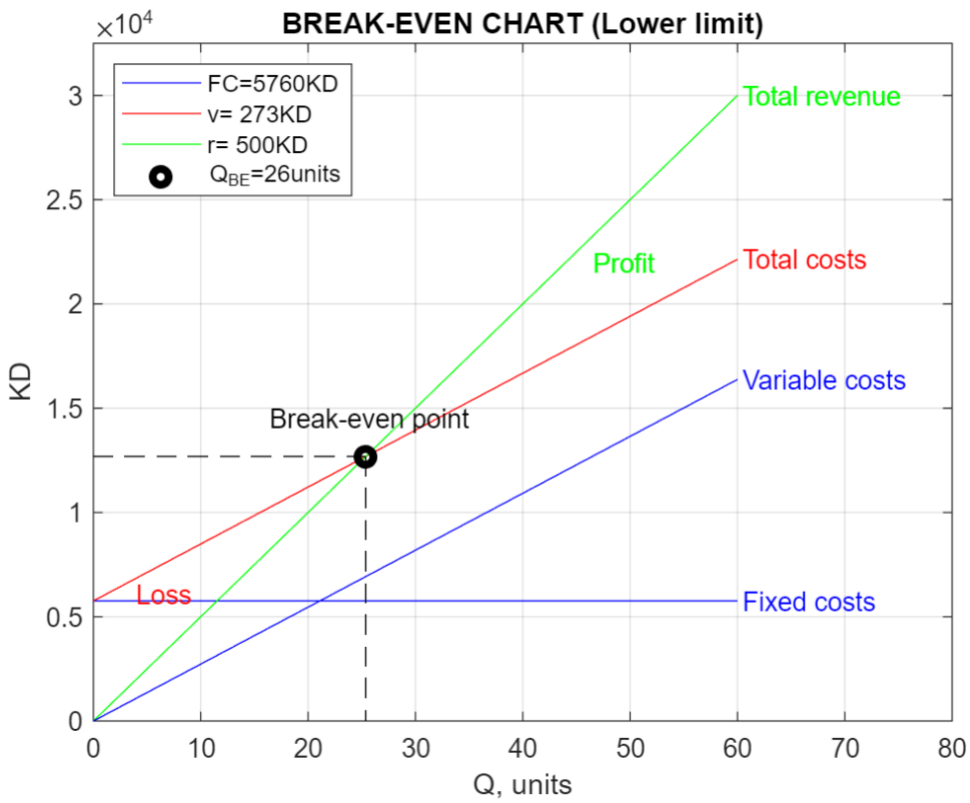

Figure 13: Lower Limit Break-Even Point

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

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

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

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

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

Upper Limit Break-Even Point:

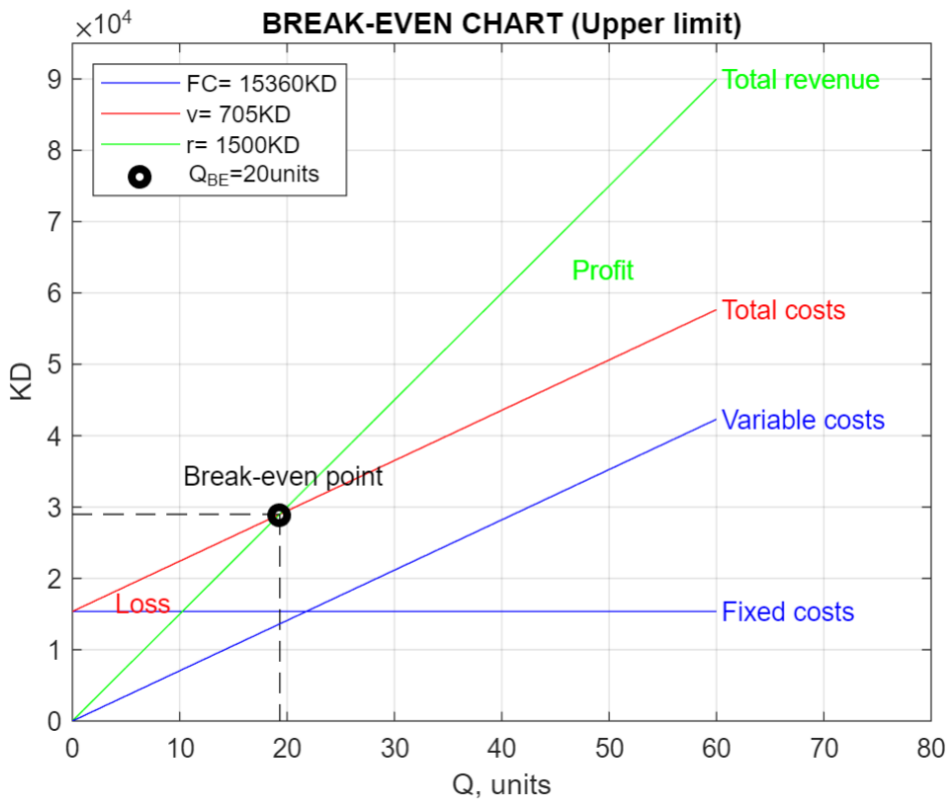

Figure 14: Upper limit Break-Even Point

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

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

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

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

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

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.

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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