Journal of Applied Mechanical Engineering
OPEN ACCESS Freely available online
Research Article

Design and Modeling of Cereal Crop Reaper Machine

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ABSTRACT

Harvesting by using traditional method is time consuming; it needs much labor force and result in much grain loss. For developing nations like Ethiopia, importing combine harvester is too expensive and not affordable for small scale farmers. The aim of this project was to design and model cereal crop reaper machine that is easily available and operated by small scale farm holders. The designed reaper was manually guided and powered with diesel engine for cutting cereal crop stems. With the help of pulley-belt arrangement, drive power is transmitted from engine to gear mounted shafts. A bevel gear arrangement is used to transmit motion at certain angle. One end of bevel gear shaft was connected to slider crank mechanism which converts rotary motion of shaft into reciprocating motion of cutter bar. Reciprocating cutter bar slides over fixed bar and created scissoring action between cutter blades which are responsible for cutting the crop stems. Integrating mechanism consist of flat belt with collecting lugged plates bolted on it. This machine can give a cost saving of 99.89 USD/hectare. This means one farmer can save 99.89 USD/hectare compared to manual harvesting machine.

Keywords: Reaper; Mechanization; Design; Modeling; Quality Function Deployment (QFD)

INTRODUCTION

Nowadays in Ethiopia, agriculture has facing serious challenges like scarcity of agricultural machinery in peak working seasons but also in normal time. This is mainly due to labor cost increment during harvesting time and lowers the production rate in terms of quality and quantity. Currently, almost all Ethiopian farmers used conventional method for crop harvesting i.e., cutting crop manually using labor but this method is very lengthy and time consuming [1].

Mechanization helps small farms to implement different technologies in the production, processing and transporting of agricultural produces. Generally, mechanization has a positive overall effect on the development of rural areas. However, owing to the land conditions of Ethiopian smallholder what is most important is selective use of mechanization technologies that could increase the technical efficiency of the smallholder through increasing the labor and land productivity. So, from the review it is possible to conclude that mechanization of agriculture bears undisputed truth for improving food security, creating employment opportunities, increasing productivity, reducing loss and promoting economic gender empowerment while maintaining environmental degradation to lower levels [2]. The main problems observed in most of Ethiopian farmers during harvesting season are: Poor quality product (several defects in the process), High grain loss (up to 30%) in the process and shortage of labor force in peak harvesting seasons and increment of labor wages in peak times.

OBJECTIVES

The general objective of this project is developing conceptual framework, design and modeling of cereal crop reaper machine for reaping of cereal crops (wheat, barley and rice). Specific objectives include:

- Developing conceptual mechanism by taking the voices of customers (Farmers)
- Selection of best mechanism and geometric analysis for each component of the machine.
- Appropriate material selection.
- Detail analysis of force, stress concentration area and check factor of safety.
- Prepare 2D and 3D blue prints for parts and assembled reaper components.
- Estimating the cost of the reaper machine and making cost benefit analysis.

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Received: August 28, 2019, **Accepted:** May 28, 2020, **Published:** June 06, 2020

Citation: Alemu N, Yilika K, Manaye W, Tilahun Y (2020) Design and Modeling of Cereal Crop Reaper Machine 9:326. doi: 10.35248/2165-7556.20.9.326

MATERIALS AND METHODS

As any scientific paper, this project followed a scientific methodological process. Mainly, we used secondary data for an input to the design and detail mathematical analysis has been conducted to design each component of the machine.

Data collection

We took voices of customers specifically farmers who are ready to use agricultural machines. This voice of farmers can be taken as a primary data but they are the inputs for our design. We also collected secondary data from reviewing journal, articles, text books, machinery hand books and standard books. In addition, annual and quarterly reports from agricultural bureau were taken as secondary data sources.

Data analysis

We used quality function deployment (QFD) as a tool to translate customer voices to engineering specifications. The result of the QFD analysis has been taken as an input for our design and as a quality characteristic. Depending on the collected secondary data, we applied different mathematical computations, analyzed the work flow by setting main specifications. We used free hand sketches to analyze mechanisms and conducted detail mathematical analysis. We also used Soliwork software to model each part and assembly of the machine.

CONCEPTUAL DESIGN

The step by step process of concept development through QFD has been shown as follows:

Step 1-We took voices of customers: What requirements will farmers demand from us? 10 repeatedly demanded requirements have been taken (Table 1).

Step 2-Competitive analysis graph: Even though there are no as such sufficient suppliers for cereal reaper machine, there are some few competitors. As a result, based one farmers' requirement, competitive analysis graph has been developed as shown in Figure 1.

Step 3-Developing the relationship matrix: In this part we did relate the voice of customers with some engineering specifications. The relation between 10 customer requirements and 13 engineering specifications were conducted using the relationship matrix (one of the houses of quality) and we came up with the following matrix (Table 2).

Step 4-Correlation matrix: In this part we have seen the correlation between 13 engineering specifications and the relations will be positive, negative or no relationship (Table 3).

Step 5-Summary of quality characteristics/design requirements: Based on the results of the above four steps we summarized our design requirements with their importance (Table 4).

The QFD analysis shows us the most important design requirements and their relative importance respectively. As shown above, machine efficiency, mechanism of the machine, strength, **design** simplicity, ease of assembly and made of easily available materials are the most important ones. Based on these results, we proposed a simple sketch of the machine which is power operated with one gear box mechanism. The sketch is shown in Figure 2.

RESULTS AND DISCUSSION

Design analysis results

After detail analysis and consideration of several factors, we came up with the following design results for each respective components of cereal reaper machine (Table 5).

Working principle of self-propelled reaper machine

- The 2.2 kW recoil start type of diesel engine is selected as the driving force to operate the cutting and conveying mechanism of the machine.
- The 3000-rpm developed by the diesel engine is reduced to 1067 rpm by the v-belt connected to pulley mounted on the main shaft B (Figure 3).
- This large pulley mounted on the main shaft B causes the shaft to rotate at 1060 rpm.
- The 1060 rpm of the main shaft B reduced to 600 rpm for the cutter bar by bevel gear that mounted between the main shaft A and the intermediate shaft B
- The crank mechanism mounted on the intermediate shaft B is responsible for transferring this 600-rpm cutting speed to the movable cutter bar used to accomplish the cutting action.

Table 1: Customer requirements.

Row Number	Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Weight/Importance	Relative Weight	Competitive Analysis (0=Worst, 5=Best)			
				Our Current Product	Company x	company y	Company z
1	Reduce harvesting time	10	19.23	5	4	5	1
2	Reduce man power used	10	19.23	3	2	1	4
3	Reaper easy to operate	4	7.69	4	2	1	2
4	Easy to manufacture	5	9.62	4	1	4	
5	Easy to maintenance	3	5.77	4	3	5	2
6	Easy to transport/move	3	5.77	3	4	3	3
7	Easy replacement of worn parts	3	5.77	3	5	1	1
8	Having minimum loss of grain	5	9.62	3	4	2	4
9	Affordable by small scale farmers	5	9.62	4	3	3	4
10	Be light in Wight	4	7.69	3	2	3	3

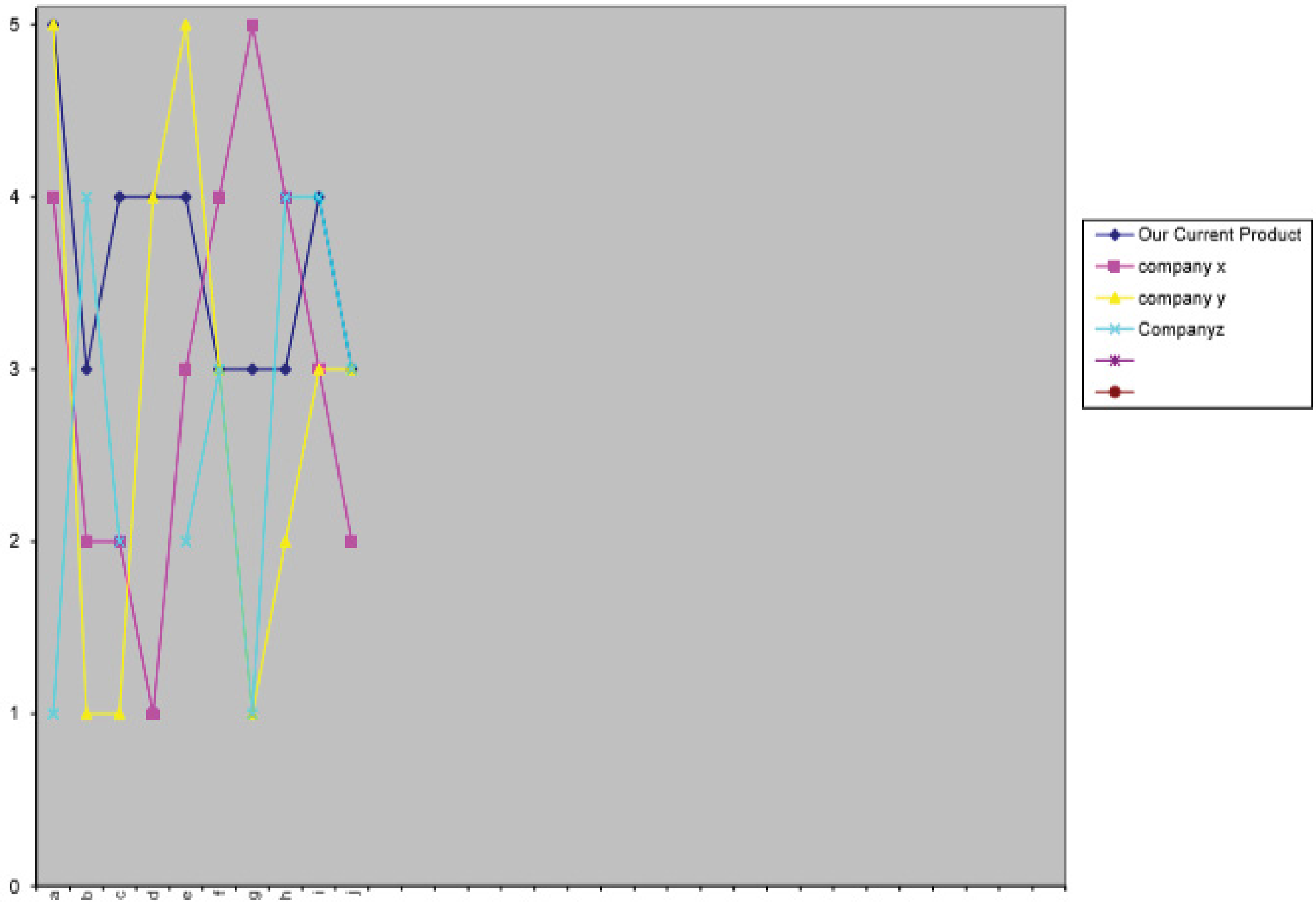

Figure 1: Competitive analysis, a-reduce harvesting time, b-reduce manpower used, c-reaper easy to operate, d-easy to manufacture, e-easy to maintain, f-easy to transport, g-easy to replace worn parts, h-minimum grain loss, i-affordable to poor, j-light weight.

Table 2: Relationship matrix between customer requirements and engineering specifications.

Column Number				**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Max Relationship Value in Column				9	9	9	9	9	9	3	9	9	9	9	9	9
Requirement Weight				140.38	346.15	190.38	248.08	432.69	86.538	57.692	121.15	207.69	109.62	86.538	105.77	207.69
Relative Weight				6	14.79	8.13	10.6	18.49	3.7	2.47	5.18	8.87	4.68	3.7	4.52	8.87
Difficulty, (0=Easy to Accomplish, 10=Extremely Difficult)				10	8	7	8	8	9	10	9	8	7	6	7	9
Minimize (▼), Maximize (▲), Target (x)				x	▲	▲	▲	▲	▲	x	x	▲	▼	▼	▼	▲
Row Number	Max Relationship Value Row	Relative Weight	Quality Characteristics (a.k.a."Functional Requirements" or "How's")	driving wheal	1 gear box mechanism powered by engine	material availability	strength	efficiency	design for manufacturability	ergonomically designed	guided by human	design simplicity	light weight	low cost	minimum vibration	easy for assembly
			Demanded Quality (a.k.a. "Customer Requirements" or "What's")													
1	9	19.23	reduce harvesting time	3	9		3	9		3			3		1	
2	9	19.23	reduce man power used		9		9	9				3				
3	9	7.69	Reaper easy to operate	1						s		9				9
4	9	9.62	easy to manufacture			9			9			3				9
5	9	5.77	easy to maintenance			9						9				
6	9	5.77	easy to transport/ move	9							9		9			

7	9	5.77	easy replacement of worn parts			9	3									9
8	9	9.62	having minimum loss of grain					9							9	
9	9	9.62	affordable by small scale farmers											9		
10	9	7.69	be light in Wight	3									9			

Table 3: Correlation matrix for engineering specifications/quality characteristics where Correlation positive (+), Negative (-).

Variables	Column number	1	2	3	4	5	6	7	8	9	10	11	12	13
Row number	Quality characteristics (functional requirements) 'how's"	driving wheal	1gear box mechanism powered by engine	material availability	strength	efficiency	Design for manufacturability	ergonomically designed	guided by human	design simplicity	light weight	low cost	minimum vibration	easy for assembly
1	Driving wheel													
2	1gear mechanism powered by engine	+												
3	Material availability													
4	Strength		+	+										
5	Efficiency	+	+		+									
6	Design for manufacturability			+	+	+								
7	Ergonomically designed	+			+	+								
8	Guided by human	+	+		+			+						
9	Design simplicity					+	+	+						
10	Light weight	+							+					
11	Low cost													
12	Minimum vibration		+						+					
13	Easy of assembly						+							

Table 4: Summary of engineering specifications/quality characteristics.

Row Number	Quality Characteristics (a.k.a. "Functional Requirements" or "How's")	Minimize (▼), Maximize (▲), or Target (x)	Target or Limit Value	Max Relationship Value	Requirement Weight	Relative Weight (Relative Importance)
1	driving wheal	x	simple	9	140.38	6.00%
2	1gear box mechanism powered by engine	▲	simple	9	346.15	14.79%
3	material availability	▲	easy	9	190.38	8.13%
4	strength	▲		9	248.08	10.60%
5	efficiency	▲	0.85	9	432.69	18.49%
6	design for manufacturability	▲	excellent	9	86.54	3.70%
7	ergonomically designed	x	excellent	3	57.69	2.47%
8	guided by human	x	1 person	9	121.15	5.18%
9	design simplicity	▲	excellent	9	207.69	8.87%
10	light weight	▼	150kg	9	109.62	4.68%
11	low cost	▼	1000usd	9	86.54	3.70%
12	minimum vibration	▼	0	9	105.77	4.52%
13	easy for assembly	▲	excellent	9	207.69	8.87%

- The conveyer pulley on shaft B transfers its motion to the other conveyer pulleys by the conveyer belt.
- As the conveyer belt rotates through the conveyer pulleys, the lugs fixed on the belt are responsible for rotating the star wheels which in turn are used for the conveying action.

Typical specifications of the reaper machine: Typical specifications of the reaper machine described in Table 6.

Cost estimation: The total cost of the machine is the summation of direct material cost, direct labor cost, manufacturing overhead cost, and general/administrative overhead costs.

TC=DMC+DLC+MFGOH+ADOH

Where: DMC is direct material cost

DLC is direct labor cost

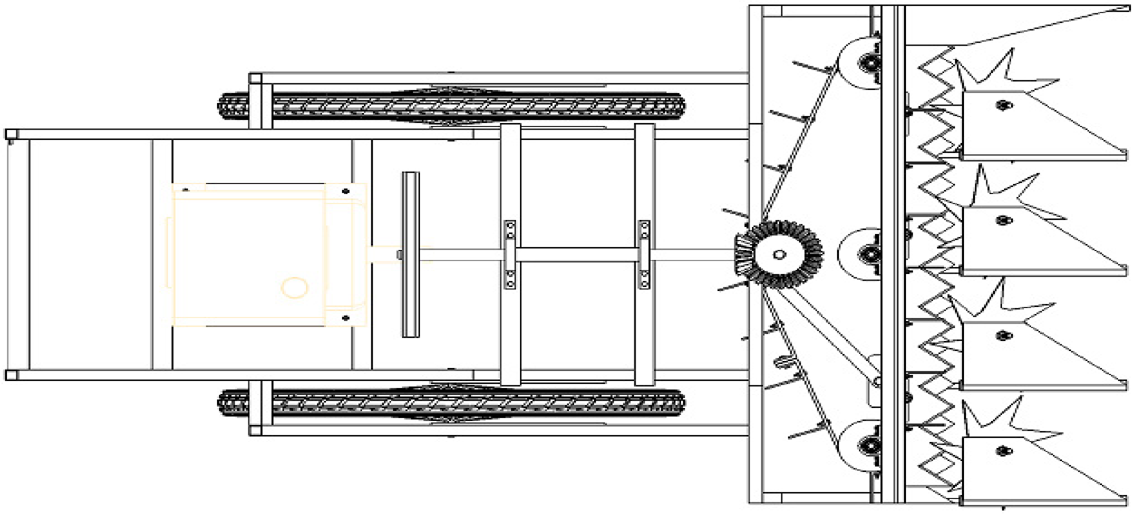

Figure 2: Top view of power operated reaper machine with 1 gear box.

Table 5: Results of detail design for reaper machine components.

No	Part name	Material selection	Dimension	Force & moment
1	Cutter bar	Sheet metal	L=0.95m	F=201.5N P=306.28 W
2	Conveyor	rubber	L=2141mm W=25mm	P=0.01984w
3	Star wheel	Sheet metal	Do=226mm Di=106mm	V=1.24m/s
4	Crop divider	Sheet metal	β=25^0	
5	Diesel engine		2.2 kw	V=3000rpm
6	v-belt	rubber	B-type W=17mm t=11mm	P=2.05kw
7	Engine pulley	Cast iron	Dp=112mm W=25mm	
8	Driven pulley	Cast iron	Dp=315mm W=25mm	
9	Bevel gear	40c8 steel	i=1.77	Ft=547.26N t=6.3mm
10	Shaft A	40c8 steel	D=35mm L=1m	F=250N τ_{max}=23 mpa δ_{all}=123.12mp
11	Shaft B	40c8 steel		τmax = 52.84mpa $\delta_{all=123.12\ mpa}$
12	Key	45c8 steel	4*4*22 mm	F=2626.7 N τ =58.83n/mm^2
13	Shaft B	45c8 steel	D1=4*4*22mm D3=8.75*8.75*40mm	F=4666.7n τ =58.83N/mm^2
14	Bearing		Db=20mm Do=52mm	Dynamic load=11.55kN
15	Cup	Sheet metal	T=4mm	δ =0.000323mm
16	Cutter knife	Sheet metal	L=0.95m	V_k=1.512m/s V_m=1.12 m/s

MFGOH is manufacturing overhead cost

ADOH is general/administrative overhead cost

DMC=23143 ETB (costs of necessary materials to produce components of the machine in Ethiopian birr).

DLC=2500 ETB (mainly costs for operators to machine each parts).

Manufacturing Overhead Cost (MFGOH): Some examples of manufacturing overhead costs include the following:

- Depreciation, rent and property taxes on the manufacturing facilities
- Depreciation on the manufacturing equipment, managers and supervisors in the manufacturing facilities

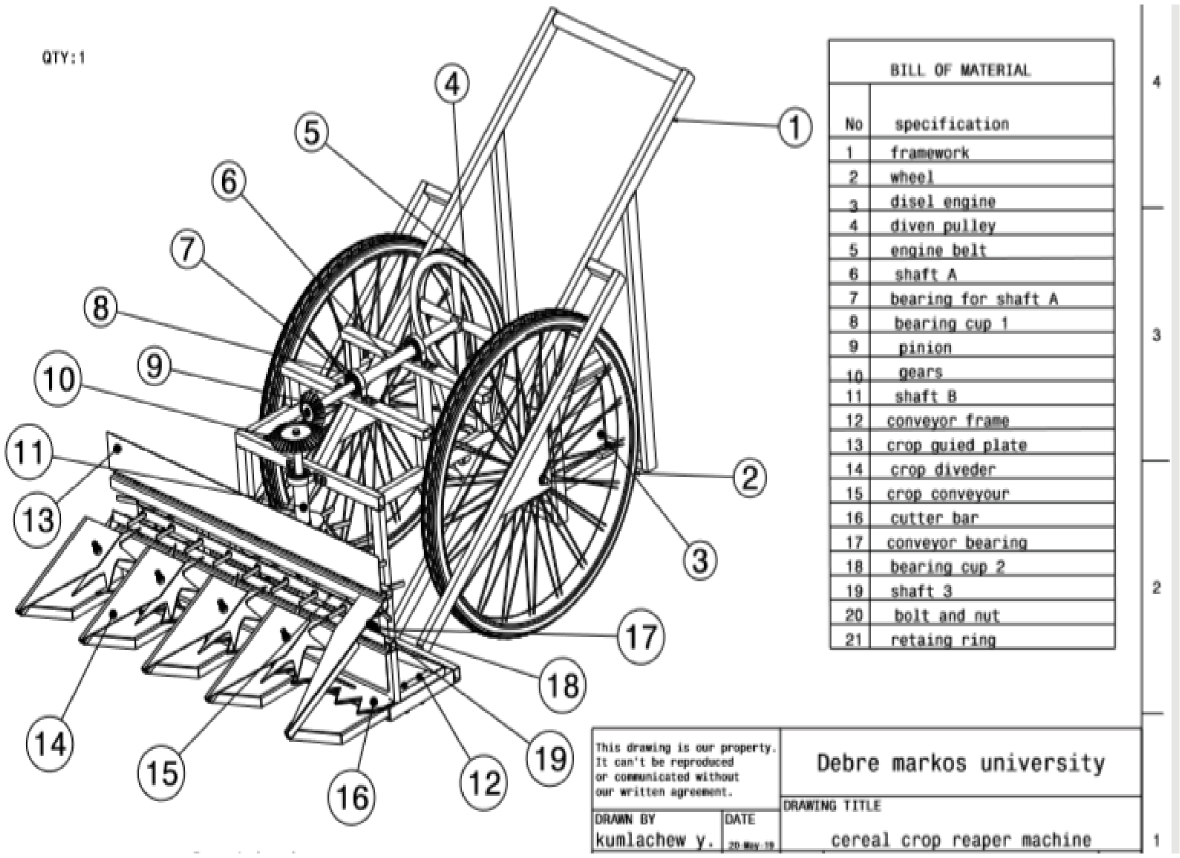

Figure 3: Assembly drawing.

Table 6: Specification of the reaper machine.

No.	Descriptions	Details
1.	Name of the harvesting machine	reaper
2.	Working width	1 m
3.	Cutting bar width	950 mm
5.	Height of the machine	1 m
6.	Length of the machine	2 m
7.	Weight of the machine	50 kg
8.	Source of power	Single cylinder, 4 strokes, air-cooled recoil diesel engine.
9.	engine power	3 hp
11.	Cost of equipment, Birr	23,143 birr
12.	Types of wheel	Two-wheel bicycle type tire
15.	Number of machine Operator	One man
16.	Cutting Speed of operation	1.512 s

- Repairs and maintenance employees in the manufacturing facilities, electricity and gas used in the manufacturing facilities
- Indirect factory supplies, and much more

In general, total manufacturing overhead cost is 150-250 percent of the cost of direct labor cost [3]. For this machine we take 150 percent and the total manufacturing overhead cost (MFGOH) becomes 3306 ETB.

General and Administrative Overhead Cost (ADOH): Typical items listed as general and administrative costs include: Rent, Utilities, Insurance, Executives wages and benefits, deprecation on office fixtures and equipment, Legal counsel and accounting staff salaries and office supplies.

ADOH costs tend to be in the 10–25 percent range of the direct labor cost. We take the ADOH cost to be 20% [4-6]. Therefore, the general and administrative cost (ADOH) will be 440.8 ETB.

Therefore, the cost of the machine will be:

TMC=DMC+DLC+MFGOH+ADOH

=23143+2500+3306+440.8

=29,389.8ETB

CONCLUSIONS

A cereal crop reaper machine is developed from cost effective and readily available materials. In the evaluation of the developed reaper machine the following conclusions are made.

- The materials and the mechanisms we used reduce the cost of the reaper machine
- The developed machine is compact and it reduces other extra mechanisms that have been implemented on other standard reaper machines
- Significant components of reaper are studied and analysis's in terms of material selection, geometric analysis, and force analysis is clearly made.
- One surly can say that the design outputs have generally been illustrated more after having investigation on the different assembly drawings and part drawing of each component and the result reveal that by integrating CAD and solid work will be highly beneficial and the design is safe.
- This design reduces manufacturing cost, labor time and maintenance cost; the machine can easily be available by small scale farmers with reasonable cost (with around 32,000 ETB).

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