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(RESEARCH ARTICLE)

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Design of electric powered hand tractor as a cheaper and cleaner alternative to diesel-powered tractor and of using carabao

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Abstract

With the increasing fuel prices across the globe, Filipino farmers, who are depending on diesel-powered tractors for land plowing, suffer. Moreover, diesel-powered tractors contribute to global warming. On the other hand, carabaos, which are considered farmers' companions in the Philippines, have some disadvantages including the high initial cost of owning as well as the struggles the farmers experience when their carabaos are not in good condition, especially in harsh environments caused by global warming. This study aimed to design a small-scale hand-tractor that can serve as a cheaper and cleaner alternative to diesel-powered tractors and of using carabaos. A 1.2kW Brushless DC motor was utilized in the tractor design which can be charged by residential electricity as well as a renewable system through solar power energy. The design was modeled and simulated through SolidWorks. Stress simulation results showed that the major mechanical components of the design, with its corresponding materials, withstand the external loads that it encounters. The results showed that the design slightly outperformed a carabao in terms of both the time required to plow one hectare of land which is 14.7% faster and overall cost after 10-hectare plowing operations which is 17.8% cheaper. Results also showed that a 20hp diesel-powered commercial tractor is 3.31 times faster than the electric tractor in terms of plowing rate but 121.4% more expensive in terms of operation cost per hectare. Moreover, the optional solar panel in the design extends the operation time by a maximum of 8.75% or 2.94 minutes per battery cycle. Fabrication and actual performance tests of the design were recommended by the authors to further supplement the results of this study.

Keywords: Electric tractor; Drawbar power; Chain drive; Solar panel; Von Mises stress simulation.

1. Introduction

The Philippines is mostly a farming country. Most inhabitants still live and work in rural areas, and agriculture is their main source of income. Rice, corn, coconut, and sugarcane are the main agricultural crops in the country[6]. Despite these resources and land, Filipino farmers are unable to meet our needs. Mechanization is necessary for maximizing long-term food production, and market stability can secure economic prosperity. Mechanization, according to agriculturalists, is also critical for reducing poverty and boosting livelihoods and food security in developing countries like the Philippines[1].

Traditional tractors, while still proving to be a heavy-duty equipment in farms and farmers' livelihoods, have several issues as time passes, ranging from factory defects in machine parts to failure in maintenance, which can lead to breakdown and costly repairs[2]. Carabaos have been a staple draft animal in farming since ancient times. These animals have their own struggles and complications that need to be addressed for them to be operational[4]. Based on the Carabao Situation Report (2020) from PSA or Philippine Statistics Authority, the total supply of live carabao was

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estimated at 3.35 million heads, wherein it declined -0.2% from a 2019 report. This is due to a decrease in beginning inventory by -0.3%, from 2.874 million heads on January 1, 2019, to January 1, 2020.

Many farmers still do not use tractors for their farming equipment because tractor use is easily influenced by rising fuel and oil prices, which has resulted in higher custom rates, making farmers hesitant to purchase tractors for their farming needs and instead rely on traditional methods such as carabaos.

This research aims to design a small-scale electric hand tractor that is driven by a Brushless DC motor and can be charged through domestic electricity and solar energy[6]. This study will be able to help small time farmers to have an additional option in choosing land ploughing equipment according to their needs.

1.1. Statement of the problem

Owning a carabao is pricey based on current costs in the Philippines at the time of writing. A carabao, like humans, has its own set of limits as a living entity. The use of the carabao might impair farming effectiveness depending on the weather, as the carabao requires a lot of rest and would be fatal if forced to labor and lead to tiredness. Carabaos can also become sick if mishandled and not taken correctly, despite their great immunity[4].

Conventional tractors, on the other hand, are the opposite of carabaos, but they, too, have drawbacks. They may be heavy-duty, but their operating expenses are high, because global fuel prices have risen, especially following the Ukraine-Russia crisis. Furthermore, because most traditional tractors are fueled by diesel engines, which emit greenhouse gases, these agricultural machineries would also contribute to global warming, intensifying climate change.

The authors desire to address these problems by designing a cheaper and cleaner alternative machine to plow the fields. This design does not only assist farmers financially, but it also addresses the issue of global warming and climate change.

1.2. Objective of the study

This research aims to design an innovative electric-powered hand tractor as a cheaper and cleaner alternative for carabaos and diesel-powered tractors in small scale plow up or tilling farmlands. This study will be able to help small time farmers financially and help in addressing the issue of global warming and climate change. The specific objectives of this study are:

- To design an electric powered tractor and do a stress simulation of the major mechanical parts of the design.
- To evaluate the theoretical performance of the design and compare it to the performance of a carabao and diesel-powered commercial tractor.
- To compare the estimated financial costs of the design to carabao and diesel-powered commercial tractors.

1.3. Conceptual framework

From Figure 1 the inputs are the specifications of the motor used in the design, gear or sprocket ratio of the chain drive, tractor's wheel diameter and drawbar power of the tractor. Through these inputs, the design will undergo stress analysis simulation in SolidWorks, power calculations, and canvassing of materials used in the design. Lastly the results are the tractor design performance, energy consumption, and costs.

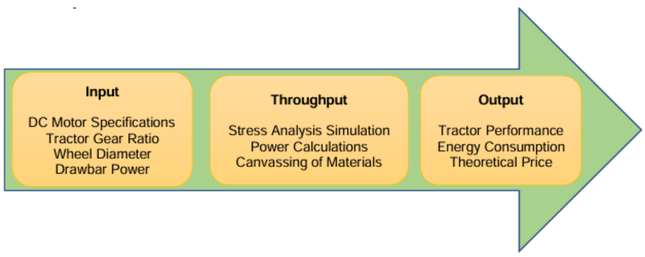


Figure 1 Conceptual framework

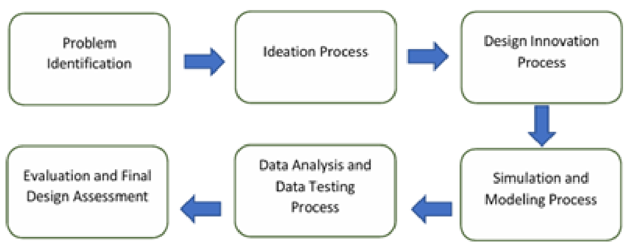


Figure 2 Method flow diagram

1.4. Significance of the study

The significance of designing a cheaper and cleaner alternative plowing machine will address the issues of expensive carabaos, dirty diesel-powered tractors, and non-stop global warming all at once[9]. The results of this study would give small time farmers the choice and benefits of having a cost-efficient and reliable plowing machine, aside from carabao and conventional tractors. The findings would also be significant to the future researchers who pursue the development of agricultural machineries and innovation in terms of mechanization efficiency in farming to elevate the economy, further sustain the needs of the nation, and most importantly, mitigate the effects of climate change.

1.5. Scope and limitations

The electric tractor was designed only for small-scale plowing purposes only. Performance of the design was only based on its calculated theoretical drawbar power estimation. Results of this study were only based on existing data and theoretical calculations. Data used was taken from previous studies related to this topic. The maintenance cost of a carabao was not included in financial cost comparisons. Price data such as electricity rate, diesel fuel price, and prices of the design components were based on current online prices as of the date of writing.

2. Material and methods

In this section, the methods and principles used in this study are being presented. Summary of research processes is represented by the flow chart below. To gather relevant information, the researchers will search, look and study available facts, studies, research materials on the internet such as journals, books, and articles. The researchers also optimize and adjust their ideology based on prior research and studies. Internet journals and previous studies on the topic are sufficient to complete the research with additional knowledge.

2.1. Research flow

Figure 2 shows the flow of the overall processes in conducting this study. The first process is problem identification where the authors choose the need of a problem to solve through this study. Next, is the ideation process followed by design innovation process, then simulation and modelling the design through SolidWorks. After that, data analysis and testing were conducted. Finally, the researchers did the final assessment and evaluation of the design.

2.2. Data gathering

Data gathered and used in this research were taken from previous studies related to this topic. Price data such as electricity rate, diesel fuel price, and prices of the design's components were based on current online prices as of the date of writing. Performance of the design was only based on its theoretical drawbar power.

2.3. Design of the electric-powered hand tractor

The authors designed the electric-powered hand tractor using computer-aided drawing software program, specifically SolidWorks. Design considerations were established such as adjusting parameters of the structure according to different ratio in chain drive and the power supply to meet the desired efficiency of the motor which will be optimal for usage in plowing operations[8]. The main aim is to design a cheaper electric-powered tractor that can have a plowing performance similar to or greater than the plowing performance of a carabao.

2.4. Simulation process

The 3D modelling and simulation of the design was done in SolidWorks. Von Misses Stress model was used in the simulation of stresses of the major parts of the tractor. This model is based on the von Mises-Hencky theory, also known as the Shear-energy or Maximum distortion energy theory.

The Von Mises Stress model in SolidWorks calculates the maximum and minimum allowable stress or pressure a model can handle depending on its material and external loads.

2.5. Data Testing

This section discusses how data testing was done in this study. This includes the principles and equations used in the theoretical calculations in this research[7].

2.5.1. Tractor Linear Speed

Based on the study of Danesh et. al (2011), the average human walking speeds from different ages ranges from 0.94 m/s to 1.36 m/s. This study aims to achieve a tractor linear speed within or close to that range. Although DC Motors are very flexible in adjusting its RPM at a given load, running close to the rated RPM and rated torque gives the highest efficiency for the motor[13]. To achieve a slow tractor linear speed while running close to its rated motor RPM and torque, a chain drive system was used[10].

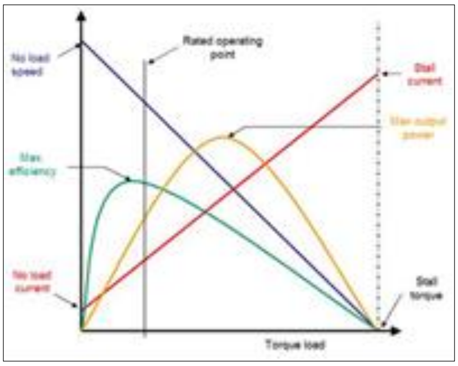


Figure 3 DC Motor Rated RPM & Torque vs Eff.

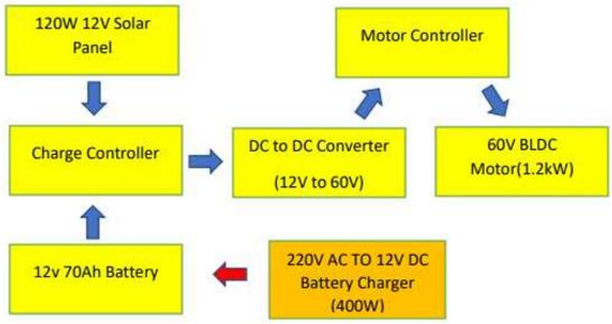


Figure 4 Electrical connection

2.5.2. Chain drive and chain drive ratio

A chain drive is a mechanical energy and power transmission system. According to E. Oberg, F.D. Jones, H.L. Horton, H.H. Ryffel, R.E. Green, C.J. McCauley (1996), a roller chain, also known as a drive chain or transmission chain, transmits power by passing over a sprocket gear and meshing the teeth of the gear with the holes in the chain's links. The chain is pushed back when the gear is turned, creating mechanical force in the system.

Additionally, according to a chain manufacturer, Diamond by Timken, the number of teeth on the large sprocket is divided by the number of teeth on the smaller sprocket to get a driving ratio. For a single reduction, the maximum recommended ratio is 7:1. The size of both the large and small sprockets, as well as the need for sufficient wrap on the small sprocket, determine the single reduction limit in practice. For ratios greater than 7:1, a double reduction is recommended.

To limit the tractor's linear speed, two parameters can be adjusted, the sprocket ratio of the tractor's chain drive and the wheel diameter of the tractor. Equations below were used:

$$\text{Tractor Linear Speed(m/s)} = \pi)\text{(Wheel Diam)(Big Sprocket rpm)/60} \quad \text{Eq.1}$$

$$\text{(Teeth Big Sprocket) / (Teeth Small Sprocket)} = \text{Small Sprocket rpm / Big Sprocket rpm} \quad \text{Eq.2}$$

where Small Sprocket RPM = Motor Rated RPM

2.5.3. Drawbar power

Drawbar Power is a measurement of how much load a tractor can pull over time[3]. This is a very important indicator that determines the tractor's plowing capability. This is measured at the point implements are attached to the tractor. A study by Sumner and E. Jay Williams from University of Georgia College of Engineering (2007) developed an equation that could estimate the drawbar power base from various soil conditions. Base from their study,

$$\text{Drawbar Power} = \text{Power Take Off / Soil Factor} \quad \text{Eq.3}$$

Table 3 from the research works of Summer et al, 2007 is used to calculate Drawbar Power[14].

Power Take Off (PTO) is the final power transferred from the motor to the wheels. In this study, the,

$$\text{PTO} = \text{Motor Rated Power) (Transmission Efficiency)} \quad \text{Eq.4}$$

Equation 4 is based on the research works of Belonio, 2006 and is used to calculate the Power Take Off of the electric tractor.

2.5.4. Efficiency of the roller chain transmission system

The transmission efficiency used was based on the study of Sheng-Peng Zhang and Tae-Oh Tak, titled "Efficiency Estimation of Roller Chain Power Transmission System". Their study shows that theoretical value of chain transmission efficiency was calculated with a range of 86.3–93.1%. According to Sheng-Peng Zhang & Tae-Oh Tak (2020), the theoretical efficiency of a roller chain energy transmission system as a function of rotational speed and offset angle; and the damping coefficient, with an efficiency range of 86.3–93.1 percent depending on driving conditions. For a given lateral offset angle, efficiency falls as the rotational speed and damping coefficient increase. Chain efficiency falls as the damping coefficient and lateral offset angle rise at a given speed. The transmission loss in each parameter was investigated using the chain drive system's varied working conditions, which included rotational speed, torque, lateral offset angle, and damping coefficient[15].

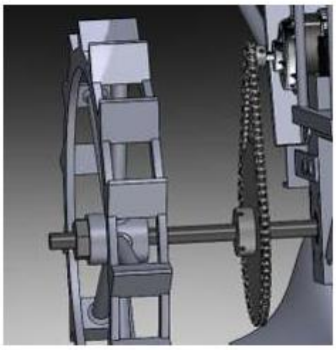


Figure 5 Roller Chain Transmission

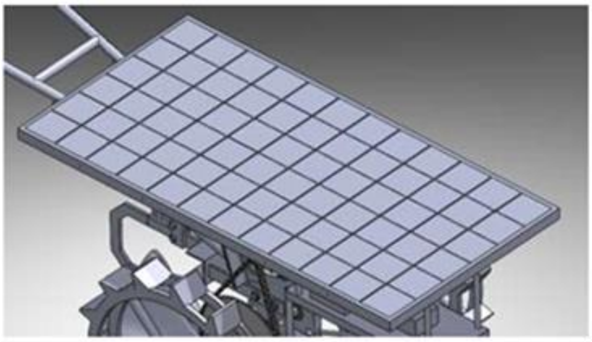


Figure 6 Installation of Solar Panel

The modeled design is using a roller chain drive system as shown at Figure 5. Since the design uses a low RPM and high torque motor, a chain drive was utilized. It is because chain drives are more practical than belt drives for low-speed drives[11].

2.5.5. Renewable Energy Systems – Photovoltaic Energy

According to Kashyap, Mohan & Chanana, Saurabh & Arya, Jai & Associate, Professor & Head, (2013), Photovoltaic energy provides numerous advantages over its fossil-fuel-dependent rivals in terms of energy output. It has no negative influence on the environment, is dependable and efficient, and has a wide range of applications. Because it is modular and adaptable, it may be utilized in a variety of inexpensive sizes, making it efficient and versatile. PVSCs (photovoltaic solar cells) have arisen as an alternative measure of renewable green energy, energy conservation, and demand-side management. Solar energy can be a substantial source of power in arid and poor nations where sunshine is abundant. It has the potential to generate 178 billion MW, which is over 20,000 times the world's consumption. PV energy has significant initial costs, despite its benefits and advantages. Making it a more expensive option for the local power company.

An optional solar panel was included in the design as shown in Figure 6. The primary purpose of this panel is to extend the operation time of the tractor and to harness clean energy from the sun. The optional solar panel can be easily removed by removing the four nuts of the threaded rods connected in the tractor's body.

3. Results and discussion

The simulation results based on the different specific objectives are presented below:

3.1. Specific objective 1

The first specific objective is to design an electric powered Tractor and do a stress analysis of the major mechanical parts.

Figure 7 shows the final overview of the design. This design was modeled using SolidWorks, AutoCAD and simulation software published by Dassault Systèmes.

Figure 8 represents the motion simulation of the modeled design in SolidWorks. Motion simulation input parameter was based on the design of the RPM of the driving motor.

Electrical connections diagram of the design is shown in Figure 4. As shown, the tractor's battery is designed to be charged from residential electricity and solar power through a battery charger and solar panel respectively. A charge controller and DC-DC converter are used to comply with the input electrical requirements of the motor.

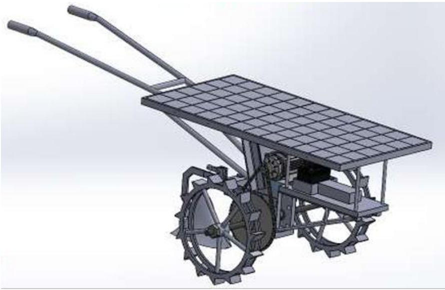


Figure 7 Tractor design model

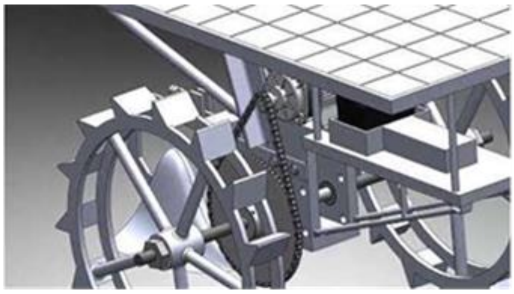


Figure 8 Motion simulation

Table 1 Specification of the motor drive

Model	BM1412HQF-14
Type	Brushless DC Geared Motor
Rated Power	1.2 kW or 1.6 HP
Rated Voltage, Current	60 V, 25.2 A
Rated high RPM, Torque	3000 RPM, 3.69 N-m
Motor Efficiency	≥ 80 %
Gear Ratio	1 : 12.2
Rated low RPM, Torque	245.9 RPM, 45.02 N-m
Rated Torque	45.02 N-m

Table 2 Average Human Walking Speed

Age	Meter/Second	Miles/Hour
20 to 29	1.34 to 1.36	3.00 to 3.04
30 to 39	1.34 to 1.43	3.00 to 3.20
40 to 49	1.39 to 1.43	3.11 to 3.20
50 to 59	1.31 to 1.43	2.93 to 3.20
60 to 69	1.24 to 1.34	2.77 to 3.00
70 to 79	1.13 to 1.26	2.53 to 2.82
80 to 89	0.94 to 0.97	2.10 to 2.17

3.1.1. Desired tractor speed

Our design aims to achieve a maximum tractor linear speed close to human's average walking speed as shown in Table 2. Based on the study of Danesh et. al (2011), the average human walking speeds from different ages ranges from 0.94 m/s to 1.36 m/s. Although DC Motors are very flexible in adjusting its RPM at a given load, running at rated RPM and rated torque gives the highest efficiency for the motor. To achieve a slow tractor linear speed while running close to its rated motor RPM and torque, a chain drive system was used[12].

3.1.2. Chain drive sprocket ratio (Gear Ratio) and wheel diameter

To limit the tractor's linear maximum speed, two parameters can be adjusted, the sprocket ratio of the tractor's chain drive and the wheel diameter of the tractor. The maximum recommended ratio for a single reduction is 7:1 or 1:7, hence the sprocket ratio will be limited to a maximum of 1:7 since single reduction will be used in our design.

After several calculation trials and considering the general recommendations of chain drive design, the closest linear speed to the average human walking is 1.22 m/s. That linear speed had a combination with the smaller sprocket having 17 teeth, the larger sprocket having 72 teeth, and a wheel diameter of 0.4 meters. This sprocket combination gave a Sprocket ratio of 1:4.235.

Table 3 Soil Condition and Soil Factor

Soil Condition	Soil Factor (SF)
Firm, Untilled Soil	1.50
Previously Tilled Soil	1.80
Soft or Sandy Soil	2.10

Table 4 Linear speed of wheel using chain drive sprocket

	Sprocket	Wheel Diameter, meters		
	Teeth Ratio	0.60	0.50	0.40
Tractor linear speed, m/s	1:2.000 (36:72)	3.86	3.22	2.57
	1:3.000 (24:72)	2.58	1.88	1.71
	1:3.429 (21:72)	2.25	2.13	1.50
	1:3.789 (19:72)	2.04	1.70	1.35
	1:4.235 (17:72)	1.82	1.52	1.22

3.1.3. Stress analysis simulation using SolidWorks

This stress simulation uses the Von Mises Stress model, where it automatically calculates the maximum and minimum allowable stress or pressure a model can handle depending on its material. The colors blue up to yellow indicate a tolerable load, red is still tolerable but indicates a load near the yield point, and lastly the black, which indicates a material will experience permanent deformation and could possibly result to a material fracture.

3.1.4. Wheel Stress Analysis

Figure 9 shows the material used in the simulation of the wheel stress analysis. Also, relevant parameters can also be found in this figure such as yield strength, tensile strength, mass density, and Poisson’s ratio. Plain carbon steel was selected because of its availability, durability, and affordability.

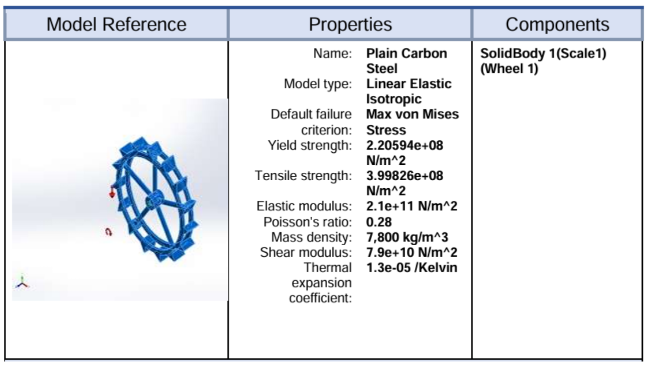


Figure 9 Material properties of wheel

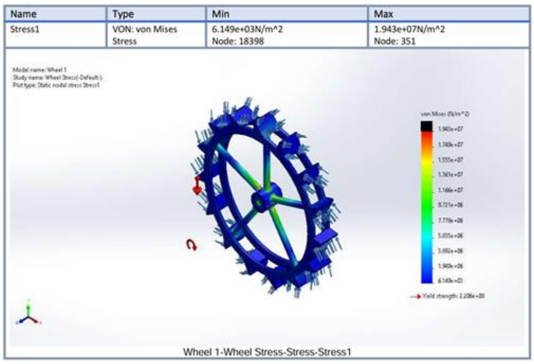


Figure 10 Wheel stress simulation result

Figure 10 depicts that the carbon alloy steel material can handle the external forces encountered by the wheel such as the tractor’s weight, gravity, centrifugal force, and torque. As can be observed, more stresses are encountered on the wheel rods at the middle part of the wheel. The stress could be reduced by adding more rods to the wheel or increasing the rods' diameter to spread the load but at the expense of higher cost.

Figure 11 reveals the different forces encountered by the wheel during the stress simulation in SolidWorks. These forces were the result of the motor power, gravity, and weight of the model. Included forces in the wheel are the centrifugal force due to the rotating motion of the wheel, the torque transferred from the shaft, and the weight of the tractor's body supported by the wheel.

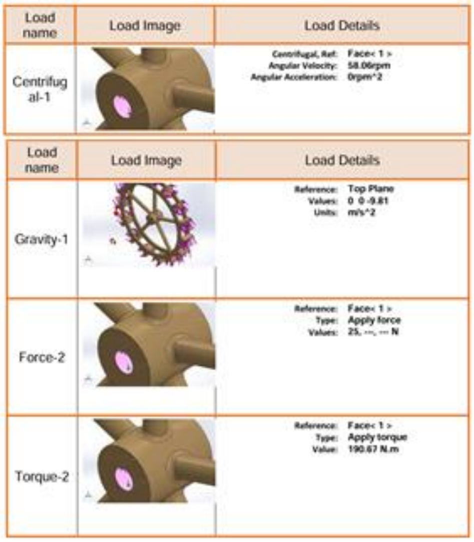


Figure 11 External forces on the wheel

Figure 12 External forces on the shaft

3.1.5. Shaft stress analysis

Figure 12 shows the different forces encountered by the shaft during the stress simulation in SolidWorks. These forces were the result of the motor power, gravity, and weight of the model. Included forces in the wheel are the centrifugal force due to the rotating motion of the shaft, the torque transferred from the chain drive, and the weight of the tractor's body supported by the shaft.

Figure 13 presents the material used in the simulation of the shaft stress analysis. Since the shaft is one of the most critical parts of the design, a stronger material is used. Cast alloy steel was selected because of its higher yield strength compared to the popular carbon steel. Other parameters can also be found in this figure such as tensile strength, mass density, and Poisson's ratio.

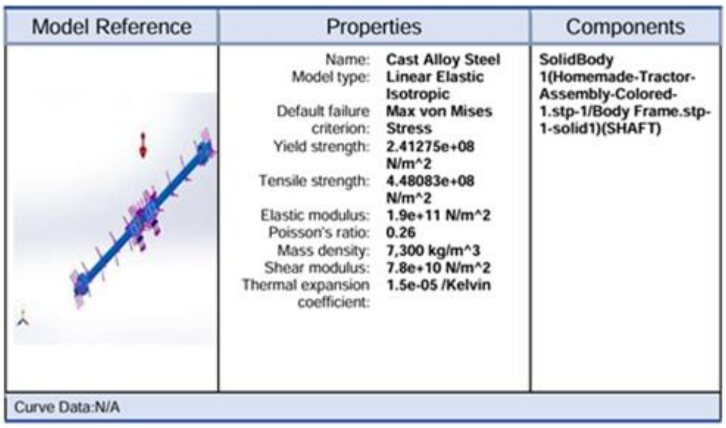


Figure 13 Material properties of shaft

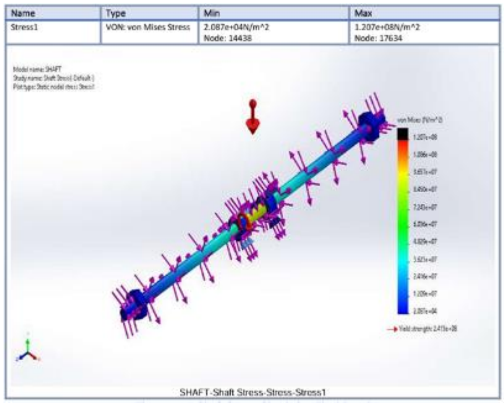


Figure 14 Shaft stress simulation result

Figure 14 indicates that high stress can be observed at the middle portion of the shaft. That's because the tractor's weight was transferred through the two bearings which are connected at the middle part of the shaft. The stress encountered by the shaft could be minimized by increasing the shaft's diameter or using a much stronger material.

3.1.6. Big sprocket (ANSI 40, 1/2 pitch, 72 Teeth) stress analysis

Figure 15 shows the material used in the simulation of the larger sprocket stress analysis. This larger sprocket has 72 teeth and has a ½ inch per pitch. Alloy steel was used in the design because of its high durability and sprockets with this type of material are readily available in the market such as McMaster-Carr, making this design easily accessible for the fabricators.

Model Reference	Properties	Components
	Name: **Alloy Steel** Model type: **Linear Elastic Isotropic** Default failure criterion: **Max von Mises Stress** Yield strength: **6.20422e+08 N/m^2** Tensile strength: **7.23826e+08 N/m^2** Elastic modulus: **2.1e+11 N/m^2** Poisson's ratio: **0.28** Mass density: **7,700 kg/m^3** Shear modulus: **7.9e+10 N/m^2** Thermal expansion coefficient: **1.3e-05 /Kelvin**	**SolidBody 1(Cut-Extrude8)(Sprocket Big ANSI 40 1inch pitch), SolidBody 2(Cut-Extrude7)(Sprocket Big ANSI 40 1inch pitch), SolidBody 3(CirPattern3)(Sprocket Big ANSI 40 1inch pitch)**

Figure 15 Material properties of big sprocket

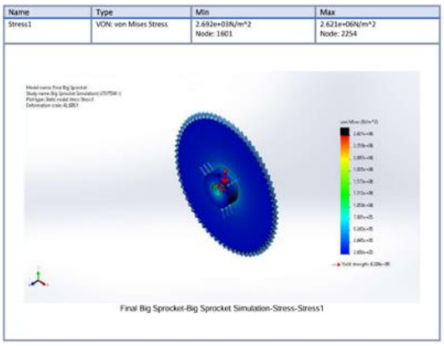


Figure 16 Big sprocket stress simulation

As shown in Figure 16, the big sprocket, which has 72 teeth and ½ inch pitch, handled the load easily. Some minor stresses could be noticed at the shaft hole and the teeth area. It's important to take note that the material used in this simulation is an alloy steel. Sprocket's material properties are shown in Figure 15.

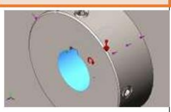
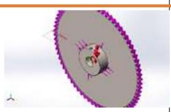
Load name	Load Image	Load Details
Torque-1		Entities: **1 face(s)** Type: **Apply torque** Value: **190.67 N.m**
Gravity-1		Reference: **Top Plane** Values: **0 0 -9.81** Units: **m/s^2**

Figure 17 External forces on big sprocket

Load name	Load Image	Load Details
Gravity-1		Reference: **Top Plane** Values: **0 0 -9.81** Units: **m/s^2**
Centrifugal-1		Centrifugal, Ref: **Face< 1 >** Angular Velocity: **245.9rpm** Angular Acceleration: **0rpm^2**
Torque-1		Reference: **Face< 1 >** Type: **Apply torque** Value: **45.02 N.m**

Figure 18 External forces on small sprocket

Figure 17 depicts the different forces encountered by the larger sprocket during the stress simulation in SolidWorks. These forces were the result of the input parameters such as motor power and gravity. Included forces in the wheel are the centrifugal force due to the spinning motion of the larger sprocket and the torque transferred from the electric motor.

3.1.7. Small wear resistant sprocket (ANSI 40, 1/2 pitch, 17 Teeth) stress analysis

Figure 18 reveals the different forces encountered by the smaller sprocket during the stress simulation in SolidWorks. These forces were the result of the input parameters of the motor. Included forces in the wheel are the centrifugal force due to the spinning motion of the smaller sprocket and the force the teeth encountered while transferring the power of the motor to the chains.

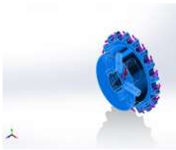
Model Reference	Properties	Components
	Name: Alloy Steel Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 6.20422e+08 N/m^2 Tensile strength: 7.23826e+08 N/m^2 Elastic modulus: 2.1e+11 N/m^2 Poisson's ratio: 0.28 Mass density: 7,700 kg/m^3 Shear modulus: 7.9e+10 N/m^2 Thermal expansion coefficient: 1.3e-05 /Kelvin	SolidBody 1(CirPattern2)(2500T492_Wear-Resistant Sprocket (1)), SolidBody 2(Cut-Extrude7)(2500T492_Wear-Resistant Sprocket (1)), SolidBody 3(CirPattern3)(2500T492_Wear-Resistant Sprocket (1))

Figure 19 Material properties of small sprocket

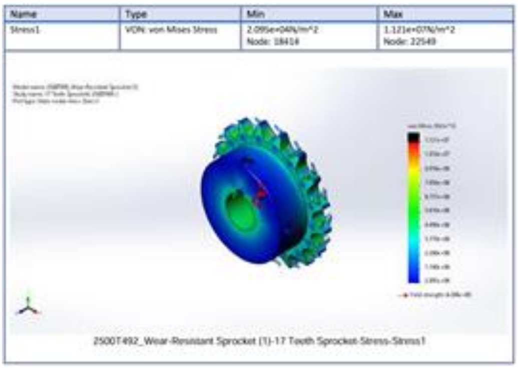


Figure 20 Small sprocket stress simulation result

Figure 19 presents the material, and its properties used in the simulation of the smaller sprocket stress analysis. This smaller sprocket has 17 teeth, complying with the general recommendations of designing a roller chain drive system. Alloy steel was also used in the design because of its high durability and availability in the market. The researchers specifically selected the number of teeth such that the ratio of the larger and smaller sprocket results in the target linear speed of the tractor.

Figure 20 shows that the ANSI 40 17 teeth sprocket encountered a lot of stress at the teeth area. This was expected since only 17 tooth handles the 1.6 hp worth of load as compared to the bigger sprocket which spreads the load onto its 72 teeth. This stress can be minimized by choosing a sprocket with more teeth. Since sprocket sizes are only limited and our design aims to achieve a specific tractor linear speed, we must stick with this sprocket and choose a better material or increase its pitch size instead to improve its durability against external forces.

3.2. Specific objective 2.

The second specific objective is to evaluate the performance of the electric-powered tractor design. Power Take Off (PTO) is the final power transferred from the motor to the wheels. For our design, the PTO is,

PTO = Motor Rated Power) (Transmission Efficiency) Eq.4

PTO = 1.2 kW x 86.3% (Sprocket Chain Transmission Efficiency = 1.036 kW = 1.389 hp

The transmission efficiency is based on the study of Sheng-Peng Zhang and Tae Oh Tak, titled "Efficiency Estimation of Roller Chain Power Transmission System". Their study shows that theoretical value of chain transmission efficiency was calculated with a range of 86.3–93.1%.

On the other hand, Drawbar Power, is a measurement of how much load a tractor can pull over time. This is a very important indicator that determines the tractor's plowing capability. This is measured at the point implements are attached to the tractor. In general, the available drawbar power of a tractor is equal to Power Take Off minus the Traction power. Traction power is the power required to move the tractor.

3.2.1. Drawbar power

Theoretically solving for traction power can be arduous since it involves a lot of variables and actual testing is needed to accurately measure the required traction power. Fortunately, a study by Sumner and E. Jay Williams from University of Georgia College of Engineering (2007) developed an equation that could estimate the drawbar power base from various soil conditions. Base from their study and from Equation 3,

Drawbar Power = Power Take Off / Soil Factor Eq.3

Using that equation, we can get the estimate of our tractor's drawbar power from Table 1.

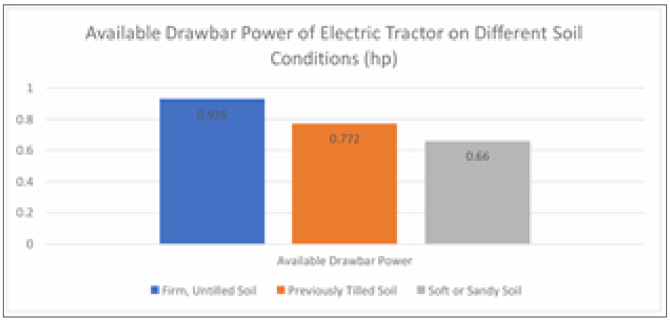


Figure 21 Drawbar power of electric tractor

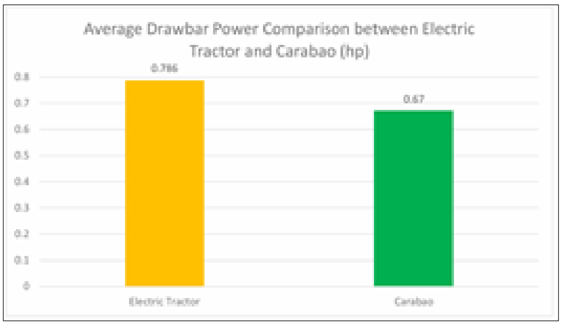


Figure 22 Electric tractor and carabao drawbar power

Figure 21 shows that the available drawbar power is at maximum at firm and untilled soil condition with a 0.926 hp, followed by previously Tilled Soil at 0.772 hp. The minimum available drawbar power is at Soft or sandy soil with only 0.66 hp available drawbar power. Hence, when getting the mean of the three drawbar powers, the average drawbar power of our design is 0.786 HP. Meanwhile, the average drawbar horsepower of a carabao is 0.67 HP. This data was taken from the National Carabao Research Center, Institute of Animal Sciences, UPLB (1990) which was the average power generated of the carabaos at loads of 75 kg and speed of about 4 kph.

As shown in Figure 22, when compared using a carabao, the electric tractor has 17.31% more available drawbar power. From the laws of physics, Power is inversely proportional to time. The relationship between these drawbar powers will be utilized to calculate the estimated plowing rate of the Electric Tractor assuming same plow implements were utilized.

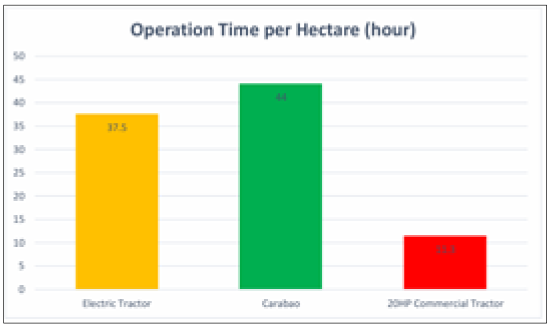


Figure 23 Operation time per hectare

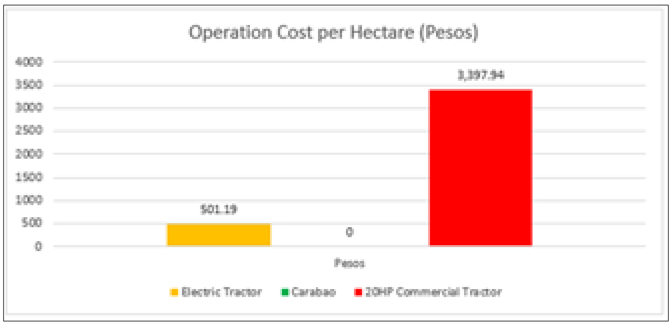


Figure 24 Operation cost per hectare

Figure 23 shows the average time required to plow one hectare of land. Taken from the study of Maranan(1983), a 20HP diesel-powered commercial tractor can plow one hectare of land in an average of 11.3 hours and 44 hours for a carabao[5] . The graph shows an 8.8-hour difference between the Electric Tractor and the Carabao. The electric tractor time requirement was theoretically estimated using the drawbar power relationship between the electric tractor and carabao, meaning the same plowing implement was assumed[17].

(44.0 hours/ hectare) (0.67 hp) = Electrical Tractor Theoretical Time Requirement (0.786 hp)

Electrical Tractor Theoretical Time Requirement = 37.50 hours per hectare

3.2.2. Operation Time Per One Battery Cycle

Input Power = Output Power / Motor Efficiency Eq.5

Input Power = 1.2 kW / 0.80 = 1.5 kW

Operation time(for one battery cycle) without solar panel is,

Battery Power Capacity = 12V x 70 amp-h

=840 Watt-hr =0.84 kWh

One Battery Cycle Operation Time = Battery Power Capacity/Input Power Eq.6

= 0.84 kWh / 1.5 kW = 0.56 hours

Theoretical additional operation time with solar panel is,

$$OT + X = [\,BC + SPR(OT + X) / (IP)] \quad \text{Eq.7}$$

where,

OT = Initial Operation Time, hrs

X = Additional Operation Time by Solar Panel,hrs

BC = Battery Power Capacity, kWh

SPR = Solar Panel Rating

IP = Motor Input Power

0.56 hrs + X = [0.84 kWh + 0.12W(0.56 hrs + X) / 1.50 kW

X = 0.049 hours

As shown in Equation 6, when operating without a solar panel, one battery cycle operation is 0.56 hours or 33.6 minutes. With solar panel, up to 8.75% or 2.94 minutes is added to the one battery cycle operation time. The solar panel in the design is optional, which means the user has the freedom to use the solar panel attached to the tractor while plowing or use the solar panel separately, for example, charging an extra battery away from the tractor through solar panel while plowing.

3.3. Specific objective 3.

The third specific objective is to present an economic analysis of the design and compare it using a carabao and using commercial tractors.

Table 5 Plowing operation cost per hectare

Description	Electric Tractor	Carabao	20HP Commercial Tractor (Diesel Powered)
Fuel Consumption	0	0	48.232 L
Power Consumption	56.25 kWh	0	0
Cost per kWh of residential electricity	₱ 8.91/kWh	N/A	0
Cost per Liter of Diesel Fuel	0	N/A	₱ 70.45/L
Cost per hectare operation	₱ 501.19	0	₱ 3,397.94

Table 6 Total cost for plowing 10-hectare farmland

Description	Electric Tractor	Carabao	20HP Commercial Tractor (Diesel Powered)
Initial Cost	₱ 29,500	₱ 42,000	₱ 42,440
Operation Cost per hectare	₱ 501.19	0	₱ 3,397.94
Operation Cost per ten hectares	₱ 5011.9	0	₱ 33,979.40
Total Cost	₱ 34,511.90	₱ 42,000	₱ 76,419.40

Electric consumption of the electric tractor was calculated by multiplying its input power to its operation time(hrs.) per hectare. The fuel consumption data of the 20HP Diesel-Powered Commercial Tractor was taken from the results of past studies[16]. Fuel and Electricity rates were based on the current price rates as of the date of writing.

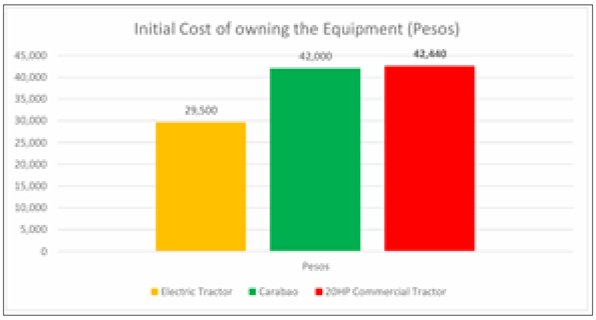


Figure 25 Initial cost of owning the equipment, Pesos

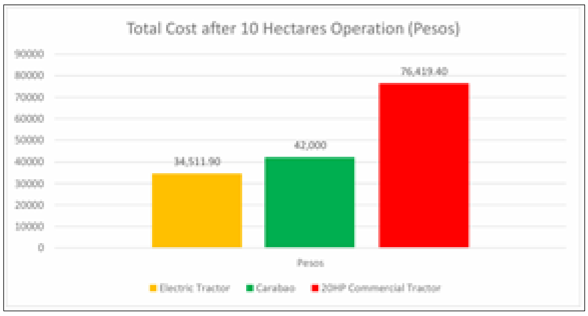


Figure 26 Total cost for 10 hectares

As shown in Figure 25, the one hectare plowing operational cost of the Electric Tractor is ₱501.19. Meanwhile, the 20 HP Diesel-Powered Commercial Tractor's operational cost is 6.78 times or 570% more than the electric tractor's, which is ₱3,397.94. As expected, Carabao has zero operation consumption since it does not rely on fuel or electricity. It's important to take note that maintenance cost of a carabao was not included in the calculations in this study.

Shown in Table 6 is the estimation of Electric Tractor's cost. Estimation was done through the current pricing of each product listed on its corresponding manufacturer's website. It is also important to take note that the Electric Tractor pricing was purely based on the estimate of its raw materials.

Shown in Figure 25 is the estimated initial cost of the electric tractor, carabao, and a 20HP Diesel Powered Commercial Tractor. It can be shown that owning an Electric Tractor is 29.76% cheaper than a Carabao and 30.49% cheaper than buying a 20HP Commercial Tractor.

As shown in Table 6 and Figure 26, in terms of the overall cost after 10 hectare plowing operations, when compared to the Electric Tractor, using a carabao is 21.7% more expensive. On the other hand, a 20HP Diesel-Powered Commercial is 121.4% more expensive than the Electric Tractor.

4. Conclusion

The general objective of this study is to design an Electric Powered Tractor that can serve as a cheaper and cleaner alternative to a Carabao and 20hp Diesel Powered Commercial Tractor. In terms of the tractor design, the Electric Tractor handled the major external forces and stresses through Stress Simulation Analysis in SolidWorks. Based on the theoretical results, the Electric Tractor slightly outperformed a carabao in terms of both the time required to plow one hectare and overall cost after 10-hectare operations.

On the other hand, a 20hp Diesel Powered Commercial Tractor is 3.31 times faster than the Electric Tractor but 121.4% more expensive in terms of operation cost per hectare. In terms of performance and financial cost, an Electric Tractor is a good alternative to a carabao. Although an electric tractor is much slower compared to a 20 HP Diesel Powered commercial tractor, in terms of financial cost and energy efficiency, the Electric Tractor outperforms the 20 HP Diesel Powered commercial tractor.

The researchers' recommendation includes the fabrication of this design and conduct actual experiments to further supplement the results of this study. Another recommendation is to include the carabao's maintenance or operational cost in financial comparisons. Lastly, minimize the stress of the design by tweaking some of its parts such as using more teeth in the smaller sprocket, using higher roller chain pitch, increasing the bore or shaft diameter, or using stronger materials.

Compliance with ethical standards

Acknowledgment

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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