

Remote Control Drywall Cart

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I. INTRODUCTION

In order to facilitate the transport of marble pieces during the manufacturing process as well as assist in the transport of finished components at the installation site, the goal of this paper is to modify the Drywall transport carts that currently exist in the company's workshop. so that these can be operated remotely [Fig 1].



Fig. 1. Standard Drywall Cart.

For this, the requirements of the car will be evaluated through the implementation of different analytical techniques such as a static, dynamic, structural analysis, analysis of the system's powers, additionally a characterization of the components will be carried out. These analyzes will allow us to acquire a greater knowledge about the behavior of the system and the maximum load that it is capable of supporting, guaranteeing stability to overturning, as well as allowing us to understand the stresses on the car chassis and its components. From this, a design that can be manufactured in its entirety with tools available in the workshop will be selected, simultaneously trying to use components that allow to reduce the total cost of the vehicle and finally through a 3D modeling the new design will be validated through the use of a commercial Finite Elements package.

II. DESIGN REQUIREMENTS

Drywall carts are used in the industry to transport materials such as Drywall, Glass, Marble slabs, Durock among others, the platform where the pieces are located has an angle that inclines the pieces making them rest against the structure of the cart [Fig. 1], allowing the pieces to be stable during the movement of the vehicle, these vehicles are used for the

transport of material inside the manufacturing workshop as well as in the place of installation, this being commonly houses or apartments.

When the vehicle is used at the installation site, it must first be transported to the work area, normally this activity is carried out in a truck or van, due to this it is important that the vehicle is relatively light [Table 1], allowing it to be It can be loaded and unloaded by two workers. Once the vehicle is unloaded and the marble pieces are assembled, it commonly enters the house or apartment together with the workers and given this, it is important that the tires are made of a soft material so that it does not scratch the tiles of the car. However, simultaneously many of the installations are carried out in houses or apartments that are still under construction, which is why it is necessary for the vehicle to have enough traction to be used on wet or muddy floors. Additionally, each tire has the ability to rotate 360 degrees, thus having a 0 degree turning radius allowing the vehicle to be maneuvered in closed spaces such as an apartment or a furnished house.

Requirement	Variable	Value
Support up to 500 pounds	Mass	500 lbs
Should work in wet environments	Dimensionless	-
Be light weight	Pounds	180
Be operated by one person	Operators	1
Require few hours of training	Training Time	3 hr
Use current carts	Dimensionless	-
Manufactured with tools in the shop	Dimensionless	-
Should not be too expensive	Cost	1000 usd
Move at least at walking speed	Speed	3-4 mph
Use inside and outside the shop	Dimensionless	-
Control the car remotely	Distance	30 m

TABLE I
DESIGN REQUIREMENTS.

In contrast to the operation of the vehicle at the installation site, the manufacturing workshop is a relatively predictable environment, with a uniform, flat and mainly dry floor, however the function of these cars is crucially different, since even though they are used extensively. For the transport of parts between the different stages of the manufacturing process, they are also used for the storage of parts, to the point that the carts are loaded up to the maximum capacity of parts that the platform space allows, that is where the carts experience the greatest efforts and simultaneously where a critical failure of the machine could imply great costs for the company since the total value of the parts that the car is supporting can be 20 times higher than the value of the vehicle, for this among other reasons the cars of Drywalls that are currently on the market have a capacity to withstand greater stresses than those experienced commonly with a maximum capacity of 3000

lbs.

Based on this characterization of the use of the vehicle in combination with requirements of both company managers and members of the manufacturing workshop, a list of requirements was drawn for new vehicle modifications that would allow, encourage and facilitate both its use in the installation and manufacturing process, as well as its economic viability as a tool that seeks to reduce the time and number of operators required to carry out an installation as well as facilitate the movement and transport of parts in the manufacturing process. These requirements can be seen as a list in [Table 1], additionally it has been determined in the cases where the variables and the value of each of these requirements are possible.

III. MATERIALES Y MÉTODOS

The first analysis carried out is a static analysis, this is relatively the most important since it is done with the objective of determining the forces caused by the pieces of marble or stone that the vehicle may experience, it should be noted that during the rest of this document they are pieces of marble, quartz, granite among others will be referred to as "pieces of stone". Simultaneously, it seeks to simplify the system by analyzing only the geometry and fundamental loads, reducing components that in real life that have greater complexity, this complexity makes static calculations that include the entire geometry impractical, so certain simplifications are made that distance the analytical model from the real one, increasing the error in the results but allowing its analysis, one of these assumptions is the simplification of the three-dimensional model to a two-dimensional model, this does not take into account torsional loads that may be the result of distributions of Non-symmetrical loads on the truck bed with implications that can range from mild to critical for the vehicle as well as the chassis. In the same way, homogeneity in the material will be assumed, where there are no cavities or non-uniform distributions of materials with a higher density, thus assuming that the center of mass coincides with the centroid of the geometry, in which the entire load is concentrated.

A. Análisis Estático

The model that was used to study the distribution of the loads caused by the stone pieces is a two-dimensional static analysis which seeks to determine the relationship of the geometry with the contact area between the piece and the carriage platform, in [Fig. 2] the first figure represents the most common geometry used in the manufacturing workshop, the distribution of the force of a piece with this geometry is determined in relation to the dimensions of the piece and the contact area.

$$P = \frac{F_g}{L_x} \quad (1)$$

In the second geometry of [Fig. 2] it can be seen that the increase in the complexity of the geometry makes it difficult to locate the center of mass of the part, this however in rigid materials does not affect the load distribution.

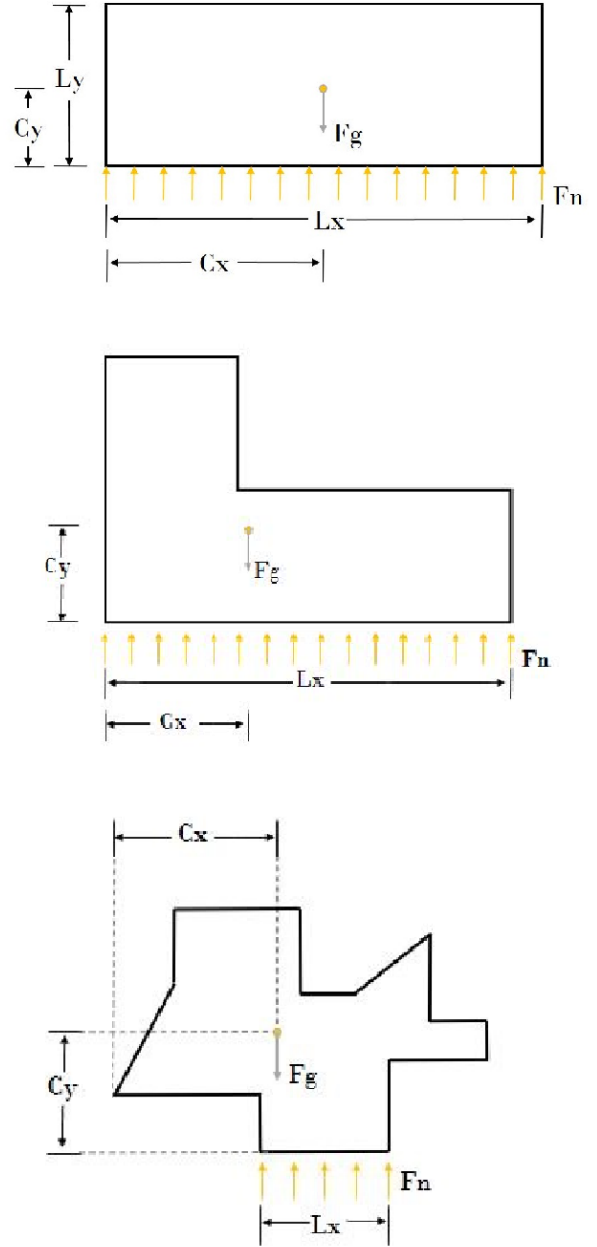


Fig. 2. Weight Distribution of different Stone Pieces.

thus allowing the pressure generated by the second geometry in two [Fig. 2] can be calculated again with equation 1 as the relationship between the weight and the contact area between the part and the carriage platform.

$$P = \frac{m * g}{L_x} \quad (2)$$

In this way it can be concluded that for any figure with an arbitrary complexity as in the third figure of [Fig. 2] can be represented by the relationship between the mass and the contact area that the part supports.

In [Fig. 3] the forces caused by the inclination of the part as a consequence of the angle of the platform where the parts are located are studied, making them rest against the structure of the car, this allowing the parts to be stable during the movement

of the vehicle. However, this angle at the same time creates new forces that can overturn the vehicle once the weight of the part causes the center of mass of the car in combination with the part to leave the contact area created by the four tires with the ground.

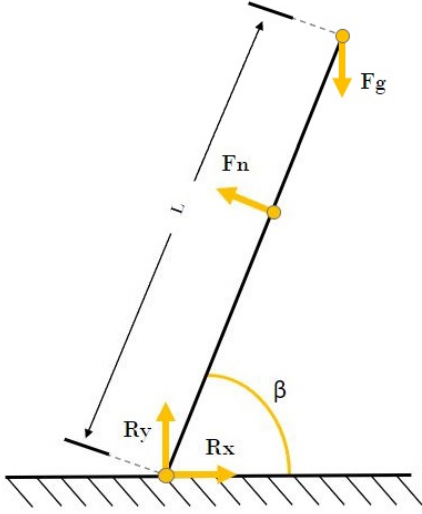


Fig. 3. Static Analysis of the forces created by the inclination of a piece of stone.

It can be seen in [Fig. 3] a static analysis of the piece of stone when it is supported on the cart where F_g is the force generated by the mass of the piece, F_n is the resultant force between the contact between the piece of stone and the frame of the car, α is the angle measured between the part and a line parallel to the ground. Finally R_x and R_y are the forces resulting from the contact of the part at the fulcrum with the vehicle.

Based on this, a summation of forces and moments is carried out to determine the resulting forces in R_i and R_j .

$$\eta = 90 - \beta \quad (3)$$

$$\sum F_i = -R_i + F_n \cos(\eta) = 0 \quad (4)$$

$$\sum F_j = -R_j + F_n \sin(\eta) - F_g = 0 \quad (5)$$

$$\sum M = 86F_n - F_g \sin(\beta)L = 0 \quad (6)$$

Based on the above equations we can solve equations for R_i , R_j and F_g .

$$R_i = F_n \cos(\eta) \quad (7)$$

$$R_j = F_n \sin(\eta) - F_g \quad (8)$$

$$F_n = \frac{F_g \sin(\beta)L}{86} \quad (9)$$

With these equations and assuming a value for F_g of 500 pounds which represents the weight of two marble slabs

mounted on the car simultaneously and a value for L of 32 inches for L , we obtain that the resulting values for R_i , R_j and F_g are:

$$F_n = -2082N \quad (10)$$

$$R_i = 1747N \quad (11)$$

$$R_j = -1091N \quad (12)$$

Based on these values we can know the forces that the elements of the trolley structure will be supporting and design or size the components based on these estimates, however it is still necessary to take a safety factor in order to guarantee that the simplifications that are have done in the analytical calculation do not result in the critical failure of the machine, for this a safety factor has been taken for the static analysis, based on the safety of the operators who are involved in the assembly and disassembly process of the parts since a critical failure could involve the fall of a slab or several slabs on an operator resulting in possibly fatal injuries due to the great weight of the slabs taking this into account and following the guidelines (LRFD) for safety factors with loads involving people, an over-resistance of 1.6 is applied, therefore it is estimated that the forces that the car must resist are:

$$F_{load} = MaxF_{load} * 1.6 \quad (13)$$

$$F_n = -2082N * 1.6 = 3331N \quad (14)$$

$$R_i = 1747N * 1.6 = 2795N \quad (15)$$

$$R_j = -1091N * 1.6 = 1528N \quad (16)$$

B. Capacidad de potencia

Based on the requirements of [Table 1] it is determined that the maximum weight to be moved with the new modifications to the vehicle is 500 pounds, additionally it was recommended that it be possible to move at a speed of between 3 and 4 miles per hour From these data it is possible to perform power calculations to determine the energy that is required to carry out this work at that speed, however the ground conditions are unknown so for greater precision it would be necessary to carry out experimental tests to determine friction. of the different terrain where the vehicle is going to be moving in relation to the tire material, in the same way the tire material has a significant impact on the traction of the tires, so it is important to find an adequate balance between friction tires and their traction, in such a way that the vehicle does not lose traction without having friction coefficients that decrease nuyas the efficiency of the movement of the same. Based on the uncertainty of these factors, a safety factor will be applied to the maximum weight of the vehicle so that the components selected to carry out this work will be able to overcome friction forces despite not knowing their value, allowing the vehicle to

comply with The desired characteristics, this implies that the vehicle is capable of exceeding the maximum weight in ideal conditions of low friction, however it is not recommended to exceed the maximum weight with which the vehicle is designed since this may imply structural failures in other components.

$$Work = Force * Distance \quad (17)$$

$$Power = \frac{Work}{Time} \quad (18)$$

Assuming a factor of safety of 1.3 for the necessary force as well as a distance of 4 miles made in 60 min, we obtain:

$$Work = (2224.11N * 1.3) * 6437m \quad (19)$$

$$Work = 18610654N * m \quad (20)$$

$$Power = \frac{18610654N * m}{3600s} = 6355Watts \quad (21)$$

Based on this, it can be stated that the vehicle's power system must have the capacity to exert 6355 Watts to be able to transport 500 pounds at a speed of up to 4 miles per hour, this power value as well as those obtained in section 3. A will be used to size and characterize the new vehicle components.

C. Selección de Componentes

From the requirements given in [Table 1] as well as the results obtained in sections 3.A and 3.B it is possible to affirm that the vehicle must be capable of withstanding 3331 N of force and have the capacity to generate 6355 Watts of power, it must be remotely operated by a single operator, have soft tires that prevent it from scratching the floor in the houses or apartments where it is used, its manufacture should not be very complicated so that it does not require tools that are not available in the workshop and simultaneously to have a low cost so that it is economically viable for the company.

The need to control the vehicle implies that the turning direction of the vehicle must be controlled, the vehicle moves on the XY plane, the movement in this space requires three types, translation in X, translation in Y and rotation in Z, this movement is achieved in the conventional vehicle given that each of the tires can rotate, this implies that the vehicle has the ability to reach a turning radius of zero, this means that it is capable of rotating on its own axis, without moving in X or And, however, this is achieved mainly thanks to the actions of the vehicle operators, where it is possible to exert pairs of forces that move the vehicle in pure rotation or pairs of parallel forces that move the vehicle in pure translation as well as combinations of these allowing a combined movement.

To achieve this type of remote control it would be necessary to control at least 3 degrees of freedom to achieve pure rotation in Z, pure translation in X and Y, this however, although feasible, would imply the acquisition of 3 motors, increasing the total cost of the vehicle having taking into account that engines are the most expensive components of the vehicle, additionally this increase in the number of engines implies

greater energy consumption, based on these characteristics and what this implies, a system of two degrees of freedom is chosen, this allows the pure translation but not pure rotation implying that the radius of gyration of the vehicle would be greater than zero.

There are different mechanisms with two degrees of freedom that meet this objective, one of the most conventional are automobiles, these achieve movement in the XY plane by means of the control of two rear wheels and the control of the angle in a limited range of the wheels. front tires.

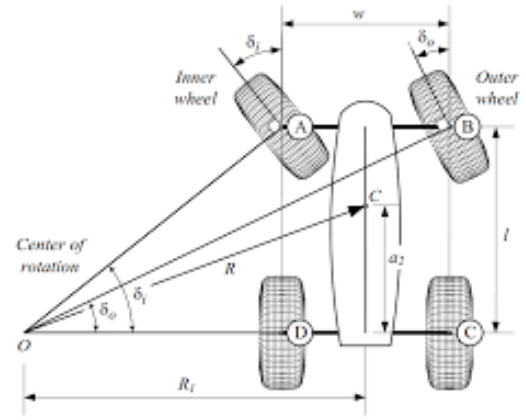


Fig. 4. Motion of 2 degrees of freedom mechanism.

This mechanism, however, presents other challenges, mainly the manufacture of a differential system for the rear tires so that there can be different angular speeds in each of the tires in maneuvers with a low turning radius, in addition to the tire orientation system. Forces commonly involves more complex manufacturing processes such as parts in revolution, welded parts, machining, these processes are not currently available in the workshop, which is why, although it is a conventionally used solution, with a short learning curve for the operators, is a mechanism that would significantly increase costs by requiring processes carried out outside the workshop.

Based on the aforementioned, a two-degree-of-freedom mechanism is sought that does not increase manufacturing costs and does not imply the acquisition of new components. The most promising mechanism for this type of requirement is based on the operation of aircraft, one of the systems that aircraft use to move on the ground is known as differential braking, through which the aircraft decreases the angular velocity of one of the two rear wheels generating a moment in Z that tries to turn the aircraft, this in combination with the front tire that has the ability to rotate freely allows this moment to turn the aircraft.

Based on this mechanism, it is determined that the two front tires of the vehicle can continue to be the original tires of the drywall car and control will be given by means of motors connected to each of the rear tires, so that speed can be controlled. of the rear tires and the front tires allow the Z-moment to turn the vehicle.

With these criteria for the mechanism and the required power, the engine is selected, taking into account that it is required that the vehicle be operated remotely as well as that it be used outside the company's facilities, it is necessary that

it has the Ability to store energy so that it can perform work, with this information the need to use a battery and motors becomes evident, given the ease of storing direct current and the inherent difficulty in transforming from DC to AC, it is then determined The advantageous use of a DC motor in addition to the use of DC motors is that these deliver instantaneous die at 0 RPM as can be seen in [Fig. 4] this allows the movement of the slabs at low speeds where the machine mainly operates to be with the entire engine die, unlike its counterpart combustion engines.

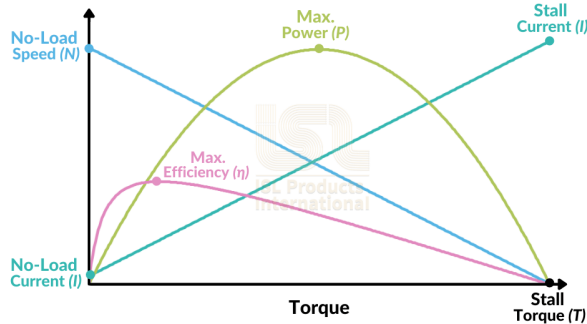


Fig. 5. Graph torque vs speed of a DC motor.

Taking this information into account, 6 main categories of components are created that are crucial for new vehicle modifications, these are:

- **CPU or Controller:** The need for this componenet derivate from the requieremnt to remotely control the individual velocity of each power wheel.
- **Motor:** The need to do work as well as the advantages of DC motors at low speeds, the fast responses and the ability to revert direction of speen makes this component a great and convinient adition.
- **Battery:** With the use of a DC Motor as well as the need to be controlled remotely this component is necessary.
- **Wheels:** The variability of the enviroment as the redesign of the source of power created the need to convey the energy from the motor into the ground and the wheel is a fundamental and inexpensive solution.
- **Remote Controller:** The requierement to be controlled remotely makes this part necessary.
- **Transmission:** A necessary way to convey the energy from the motor to the wheel as well as allowing to increase the torque of the motors while reducing the speed for this low speed aplication.

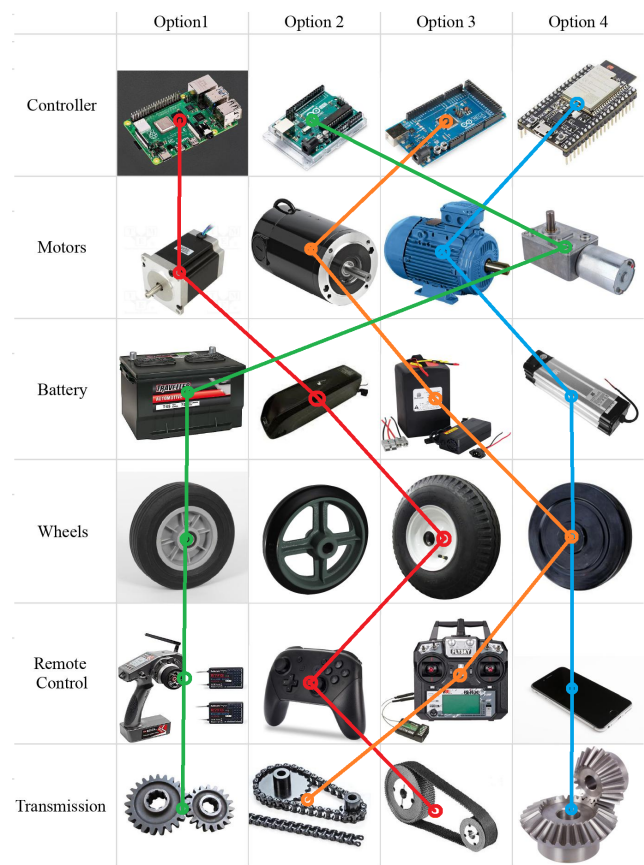


Fig. 6. Components Selection Process.

Based in the previous components different solutions are evaluated to determin the most convinient solution, for this a grid of 6 by 4 is created where four different options are selected, each one represented by a color and a line uniting the different selections of each component.

Type	Option 1	Option 2	Option 3	Option 4
Processor	Raspberry	Arduino Uno	Arduino Mega	ESP32
Motor	Stepper	Redu DC	Brushed DC	Brussless DC
Battery	Unit Pack	Car Battery	Cell Pack	X-go Battery
Wheels	Plastic	Steel	Solid Rubber	Solid Rubber
Controller	Bluetooth	RC4GS	fs-i6x	Phone
Transm	Belts	Gears	Chain	Bevel Gear

TABLE II
COMPONENT OPTIONS LIST.

With the above information we can separate each of the options and the corresponding components, the result of these selections can be seen in [Table 2] based on engineering criteria as well as in consultation with the managers in charge of supervising the project, which one was determined. of the options mentioned in [Table 2] and illustrated in [Fig. 6] is the most convenient for the company based on the characteristics of charging and discharging of the batteries, speed of the motors, complexity of programming and maintenance of the CPU as well as maintenance or repair cost of the transition and remote controls, this added to the experience of the operators in the field and the recommendations or difficulties that they may see in the design.

Based on the information previously mentioned and with the approval of the members of the company in charge of moni-

toring the project, it was determined that the most convenient solution in relation to all the requirements is option 3.

D. 3D Modelling

With the information obtained in the previous analyzes and having determined option 3 of [Table 2] as the selected combination of components, it is possible to proceed with the finite element modeling with the use of a CAD tool.

Initially, it is necessary to obtain the dimensions of the existing trolleys in the workshop, for this it was necessary to temporarily take one of the trolleys out of service to take measurements. Once this information is obtained, it is possible to reconstruct the main structure of the vehicle, the result of this modeling can be observed in [Fig. 7].

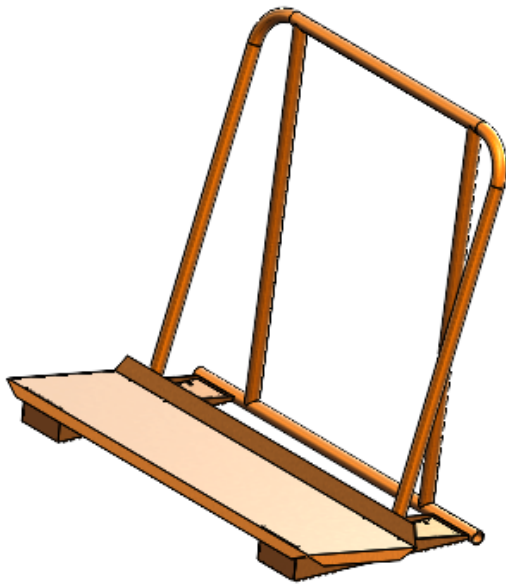


Fig. 7. 3D Modelling of the structural frame of the Drywall cart.

With the modeling of the main structure of the car, which contains the actual dimensions existing in the workshop, it is possible to begin to build or adapt around it the necessary components for the construction of this new improvement.

Next, it is possible to model the components selected in [Table 2], the modeling of each of these components implies replicating products that are on the market to measure, however, in the search for dimensions, the availability of the pieces is not determined. Therefore, it is possible that the modeling requires eventual modifications to adapt to market availability, the search for dimensions may result in errors or partial or incomplete representations of the same.

These models contain the main dimensions of each of these elements and allow us to understand to a great extent the type of joints, the distribution of components, the orientation and the spaces necessary for the construction and assembly of the components, facilitating the manufacturing process when creating an initial guide to the ideal positions, however the manufacturing process is unable to faithfully replicate tolerances, distances and joints so this modeling is unable to fully represent the final result of the manufacturing process, with

this in mind it is possible understand the function of these components and the objective of 3D modeling. In [Fig. 8] the 3D modeling of the selected components can be seen in section 3.B.

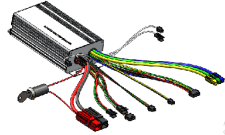


Fig. 8. 3D Modelling of Cart Components.

Additionally, in the modeling and assembly process of these components, the need to add components that fulfill functions such as fastening, transmission, protection or that are necessary additions to the main components becomes evident, the modeling of these components is necessary to understand the location, distribution of components and simultaneously these increase the total cost of the project since these additional components require their purchase or manufacture, although in this document we refer to them as additional, they are not components whose structural limitations or costs should be underestimated since it is through the component weaker than the machine may have a critical failure, or whose operation implies a significant increase in maintenance costs.



AAA Battery Holder



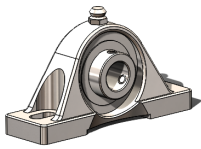
YK31C



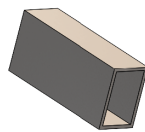
IP 68 Water
Resistance Box



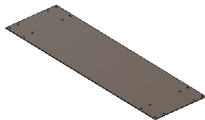
Front Wheels



UCP204-12



Metallic Rectangular
crosssection Beam



1/8 Inch Thick Plate



3/4 Inch Axis

Fig. 9. 3D Modelling of Additional Cart Components.

With the components illustrated in [Fig. 8] and [Fig. 9] it is possible to build the entire remote controlled drywall cart vehicle, it should be noted that the 3D modeling does not contain fastening components such as screws, bolts, washers and cables.



Fig. 10. Final 3D Model of the Drywall Cart controlled remotely.

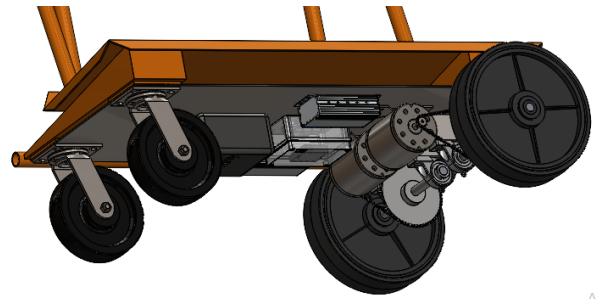


Fig. 11. Bottom view of the final 3D Model of the Drywall Cart controlled remotely.

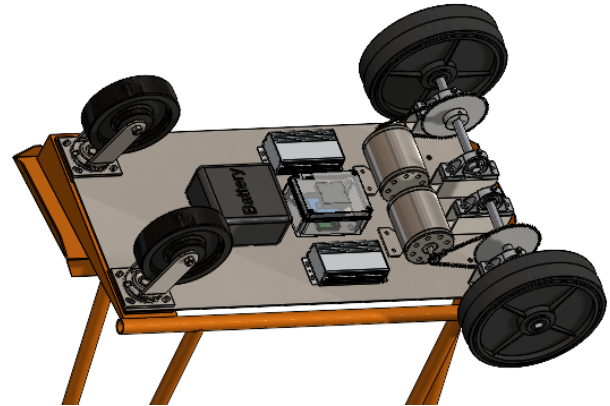


Fig. 12. Distribution of componentes in the final 3D model.

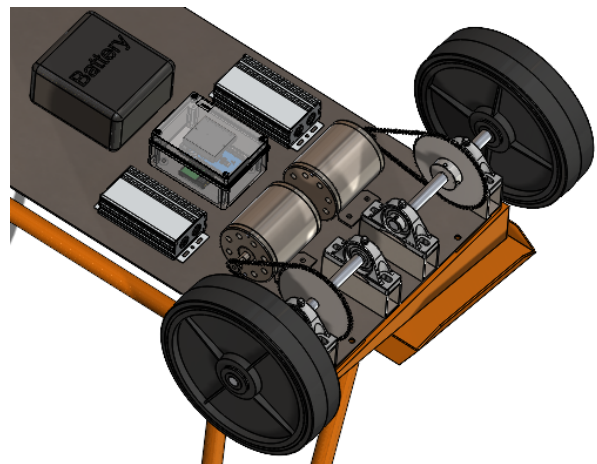


Fig. 13. Bottom view of power mechanism.

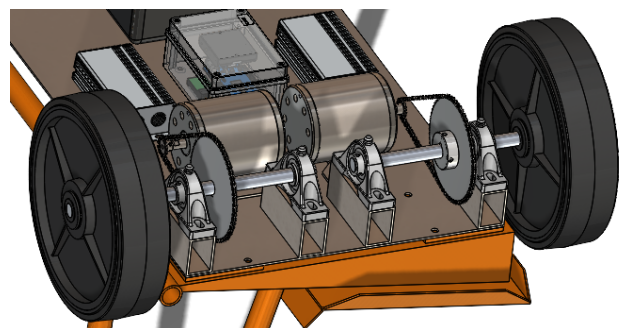


Fig. 14. Wheel motor transmiccion system.

The final assembly presents the final position of each of the parts as well as the relationship between each of the

components, additional holes are required in the IP68 Water resistance box to allow the entry and exit of cables.

The selected motors have a power of 1600 Watts and the ratio between the transmission system creates a mechanical advantage of 1: 5 increasing the torque of the motor 5 times, resulting in a power of 8000 Watts, this validated with the information obtained in section 2.B confirms that the mechanism exceeds the 500 pound carrying capacity established by design requirements.

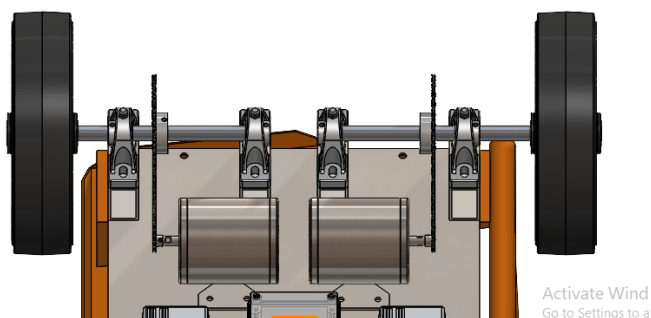


Fig. 15. Position and relation between components.

In [Fig. 10] the final assembly of the remotely controlled drywall cart vehicle modeling is presented.

In the following figures [Fig. 11] to [Fig. 15] seeks to provide the reader with a better understanding of the positioning of each of the parts and the distribution of components, as well as the relationship between them, you can see the difference between the type of front and rear wheels responsible for generating power necessary to move the vehicle. In [Fig. 12] you can see the distribution of components as well as the system used to connect the motors with the axles and tires. Additionally, you can see the controllers of each motor and the IP60 box where the CPU or microcontroller is located together with the AAA battery pack and the FS I6X remote control receiver.

E. Cost Estimation

Based on the list of parts it is now possible to provide an estimation of the possible cost of the new modifications to the drywall cart, it is yet not possible to determine the cost of labor required into assembling this design nonetheless it is possible to reduce cost as worker acquires more experience with the processes involved.

F. Electric Connections

Once all the components of the system have been determined, it is possible to make a diagram of the system connections, it is intended to create a diagram that allows the workshop workers to easily understand the electrical operation of the system, additionally it is important to specify that the battery illustrated in [Fig. 8] delivers direct current at 48 V and the motors used in the system use a direct current at 36 V for this reason it is necessary to make a voltage divider [Fig. 16] calibrated to that current that allows the voltage to be lowered to 36 V.

Component	Manufactured	Cost(USD)
Arduino Mega	NO	17.5
Jcmoto 36V 800W	NO	120
Ebike Battery 48V	NO	200
Solid Rubber Wheel	NO	35
Fs I6X	NO	61
11 Tooth Gear	NO	20
50 Tooth Gear	NO	45
Chain	NO	35
AAA Battery Holder	NO	8
Yk31C	NO	Included
IP68 Box	NO	11
UCP204-12	NO	26.5
Metallic Beam	YES	10
18 Inch Thick Plate	YES	35
3/4 Inch Axis	YES	15
Total Cost	-	640

TABLE III
COMPONENTS COST.

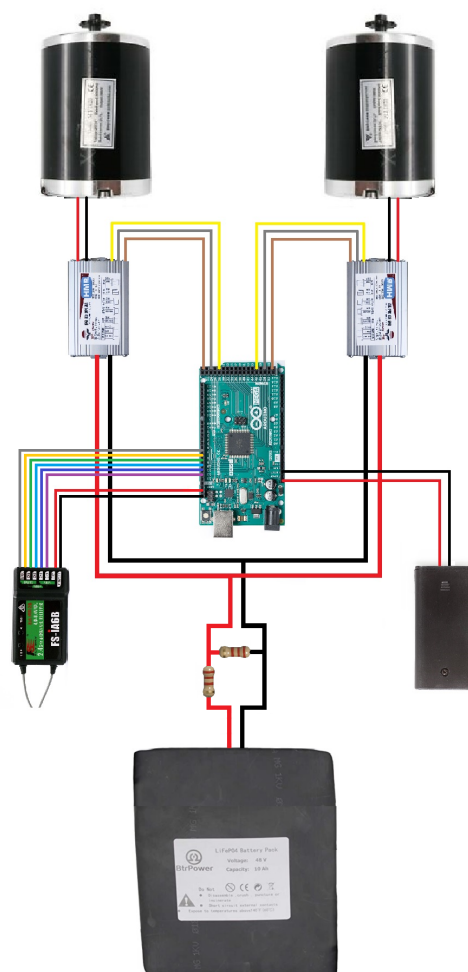


Fig. 16. Electric Connections Diagram.

Taking this information into account, it is possible to make the connection diagram, it has been chosen to use a graphic representation of each of the components [Fig. 17] preserving the real position distribution of the systems in the vehicle, this with the aim of facilitating interventions in the system and

helping the process of recognizing the different cables and their connections.

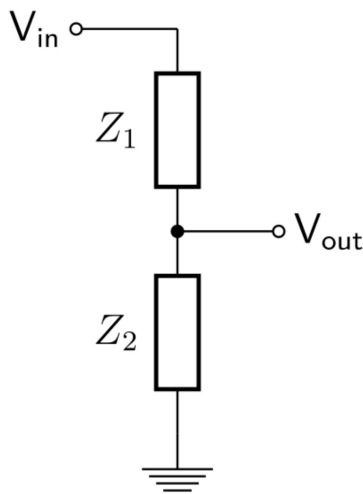


Fig. 17. Voltage Divider.

G. Programming

The FS I6X remote control works by means of radio control, it comes with a receiver which has some before they capture the signal generated by the control, this control has a range of 500 meters and has the ability to transmit 5 channels, each of these channels represents one of the control switches or potentiometers, as can be seen in [Fig. 18] additionally it has a display which is capable of illustrating information on the position sensor, speed, temperature, among others. This control has the ability to be controlled by a bus signal where all the information travels through a single cable, however this implies small delays in the signal and an increase in the complexity of the control programming, simultaneously it can be controlled by 6 different channels where each one would correspond to an input of the Arduino Mega that will be used as an interface between the speed controllers of the Yk31C motors and the signal receiver of the FS I6X control.



Fig. 18. RC Controller FS I6X.

To develop the programming, a finite state diagram was built by means of the MATLAB StateFlow tool, with this it is possible to visualize the different states in which the program is and the necessary transitions to go from one to another.

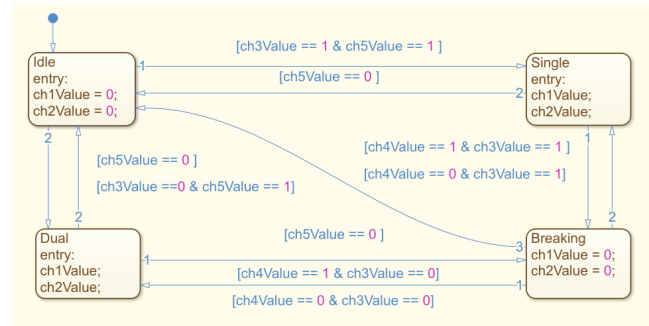


Fig. 19. Finite State Machine using StateFlow.

It is possible to observe that there are four main states, IDLE, SINGLE, DUAL and BREAKING, each of these states and their transitions are expanded in greater detail below:

- **IDLE:** It is the initial state where the machine is, there is no current flowing through the motors so they can rotate freely, additionally the ignition switch is off and it is indifferent to the position of the other potentiometers.
- **SINGLE:** This mode is reached when both the ignition switch is activated and the single switch, this allows both engines to behave as one allowing the vehicle to be controlled more easily, this function is especially useful when looking to perform simple movements how to move the machine forward or backward.
- **DUAL:** This mode is reached when the ignition switch is activated but the single switch is off, this mode activates the ability to control the speed of each of the tires individually, this allows the vehicle to turn, this mode is controlled For both potentiometers and its operation requires a higher level of concentration compared to the single mode that can be operated very easily with one hand, in contrast, the dual mode requires both hands to be operated.

Below is the Arduino code used to control the Drywall cart by means of an Arduino Mega controller and an FS I6X.

```

#define CH1 3
#define CH2 5
#define CH3 10
#define CH4 11

// Integers to represent values from
// sticks and pots

int ch1Value;
int ch2Value;

// Boolean to represent switch value

bool ch3Value;
bool ch4Value;

```

```

int Motor1 = A2;
int Motor2 = A3;
int Break = 1;

int breaking = 0;
int Speed1 = 0;
int Speed2 = 0;

int readChannel(int chInput, int minLimit,
int maxLimit, int defValue){
    int ch = pulseIn(chInput, HIGH, 30000);
    if (ch < 100) return defValue;
    return map(ch, 1000, 2000, minLimit,
maxLimit);
}

```

```

bool readSwitch(byte chInput, bool
defValue){
    int intDefValue = (defValue)? 100: 0;
    int ch = readChannel(chInput, 0, 100,
intDefValue);
    return (ch > 50);
}

```

```

void setup(){
    Serial.begin(115200);

    pinMode(Break, OUTPUT);
    pinMode(Motor1, OUTPUT);
    pinMode(Motor2, OUTPUT);

    pinMode(CH1, INPUT);
    pinMode(CH2, INPUT);

    pinMode(CH3, INPUT);
    pinMode(CH4, INPUT);
}

```

```

void loop() {

// Get values for each channel

    ch1Value = readChannel(CH1, 0, 100, 0);
    ch2Value = readChannel(CH2, 0, 100, 0);

    ch3Value = readSwitch(CH3, false);
    ch4Value = readSwitch(CH4, false);

// If Dual Control is deactivated

    if (ch3Value == true){
        ch1Value = ch2Value;
    }
// If Breaks are activated

```

```

    if (ch4Value == true){
        ch1Value = 0;
        ch2Value = 0;
        breaking = 1;
    }
    else {
        breaking = 0;
    }
    Speed1 = map(ch1Value, 0, 100, 0, 255);
    Speed2 = map(ch2Value, 0, 100, 0, 255);

    digitalWrite(Break, breaking);

    analogWrite(Motor1, Speed1);
    analogWrite(Motor2, Speed2);
}

```

H. Finite Element Analysis

From the 3D modeling illustrated in section 3.D it is possible to perform a finite element analysis, with this analysis it is sought to understand the distribution of efforts along the different elements of the system, mainly the chassis of the structure which It is in charge of supporting the efforts generated by the pieces of stones and directing them towards the ground. Likewise, the forces generated in the transmission mechanism can lead to a critical failure generated by the new components of the system, mainly the chain and gears, since the bearings and shafts are oversized for the loads handled in the system. Using the values obtained in section 3.A where it was determined that the maximum effort corresponds to 3331 N, with this information the structure of the car is evaluated.

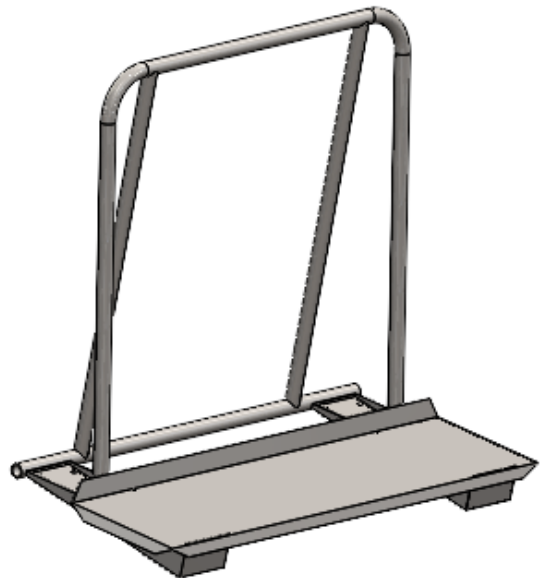


Fig. 20. Frame of the car with applied material.

Initially, it starts with the chassis of the car which was created from the real dimensions of the cars found in the workshop, these cars are made of alloy steel, therefore this

material is applied to the structure of the car in the modeling. 3D, the result of this process can be observed in [Fig. 19].

A fixed fastening is applied to the vehicle in the rectangles where each of the wheels are fastened [Fig. 21], this allows limiting the movement of the vehicle in all degrees of freedom and simulates the opposition to the movement made naturally by the ground assuming that the tires do not have a point of failure lower than the car chassis, this is done based on the information of the manufacturer, where it is established that the wheels are designed to withstand up to 1500 N of force and given that the forces are distributed in four, it is possible to affirm that the maximum vertical force that the wheels are capable of supporting is 6000 N, this value is higher than the stresses evaluated for the 3331 N chassis.



Fig. 21. Force Conditions of Finite Element Analysis.

A force of 3331 N is applied to the vehicle platform based on the data obtained in section 3.D and a force of 1528 N is applied to the section of the chassis that is responsible for supporting or preventing the horizontal movement of the chassis as shown. illustrated in [Fig. 22].

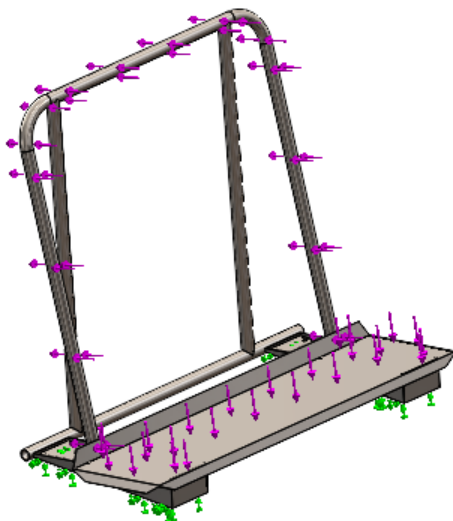


Fig. 22. Force distribution in finite element analysis.

Once the load conditions for the chassis have been determined, we proceed to mesh the structure [Fig. 23] and [Fig. 24], for this a fine mesh combined with a minimum size of 0.01 mm is applied, this allows to improve the precision of the data obtained and at the same time reduce the computational load in the sections with a simpler geometry.

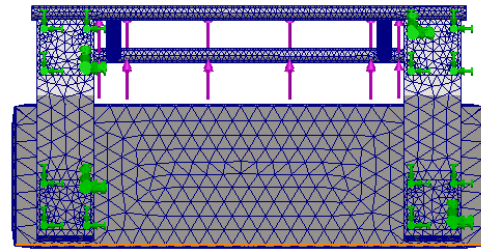


Fig. 23. Combined Mesh Construction.

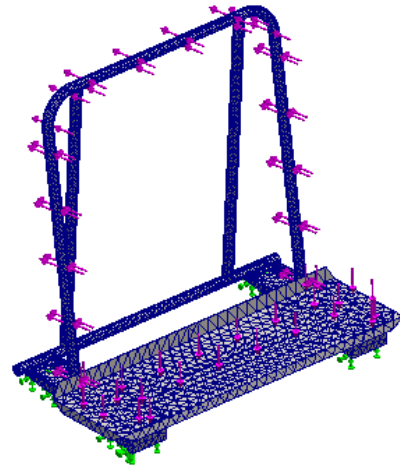


Fig. 24. Mesh and Forces for FEM analysis.

With the characteristics illustrated in [Fig. 23] and [Fig. 24] it is possible to carry out a finite element simulation, where the maximum stresses and critical points where there is a greater concentration of stresses are determined, as well as to determine if the part reaches the critical stresses leading to permanent deformation or a critical failure.

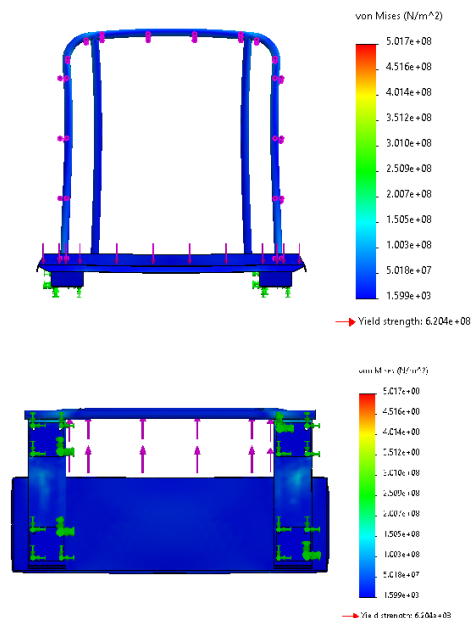


Fig. 25. Stress Results of FEM Analysis.

with the study illustrated in [Fig. 25] it is possible to determine that the greatest effort achieved in the piece is $5,017 \times 10^8 Pa$ taking into account that the structure of the car is built in a steel alloy with a force of $6,204 \times 10^8 Pa$ it can be affirm that the part does not reach the necessary forces to deform or to fail, thus we can determine that it is capable of supporting the weight of 500 lb.

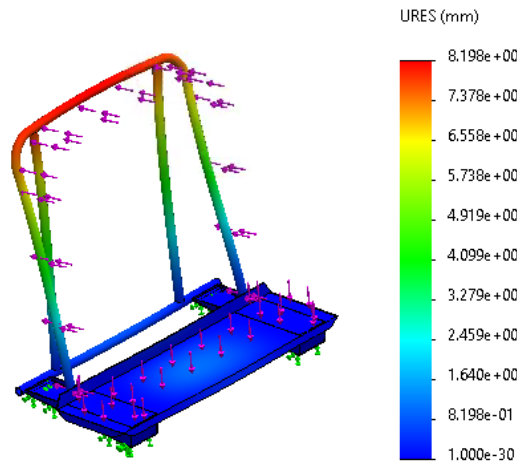


Fig. 26. 3D View of Deformations.

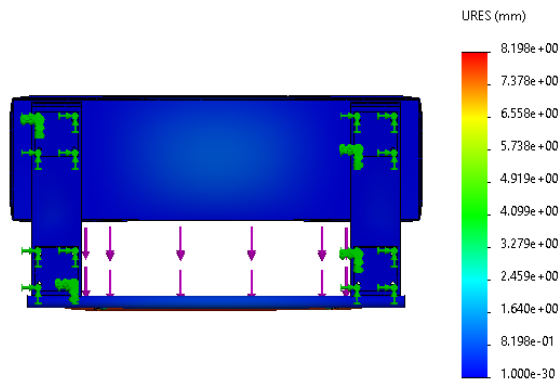


Fig. 27. Deformations results out of a FEM Analysis.

Additionally, the effort of $5,017 \times 10^8 Pa$ is a specific effort that can be caused by data collection near stress concentrators, due to this it can be stated that an effort with greater precision although relatively less conservative is $3,512 \times 10^8 Pa$ with this the value of 500 lb is far from the maximum capacity that the car can support, however, in order to reduce the uncertainty of the calculations, it is decided to limit the maximum load to 500lb.

With the results obtained in the figures [Fig. 26] and [Fig. 27] we can affirm that the greatest displacement in the vehicle is observed in the upper part of the chassis where it reached a deformation of 3,198 mm, this has mainly minor consequences, although it can result in extreme cases in the movement of the center of mass of the part-car structure leading to the overturning of the same, it is important then to limit the height and inform the operators that the increase in the weight of the piece limits the maximum height that it can have.

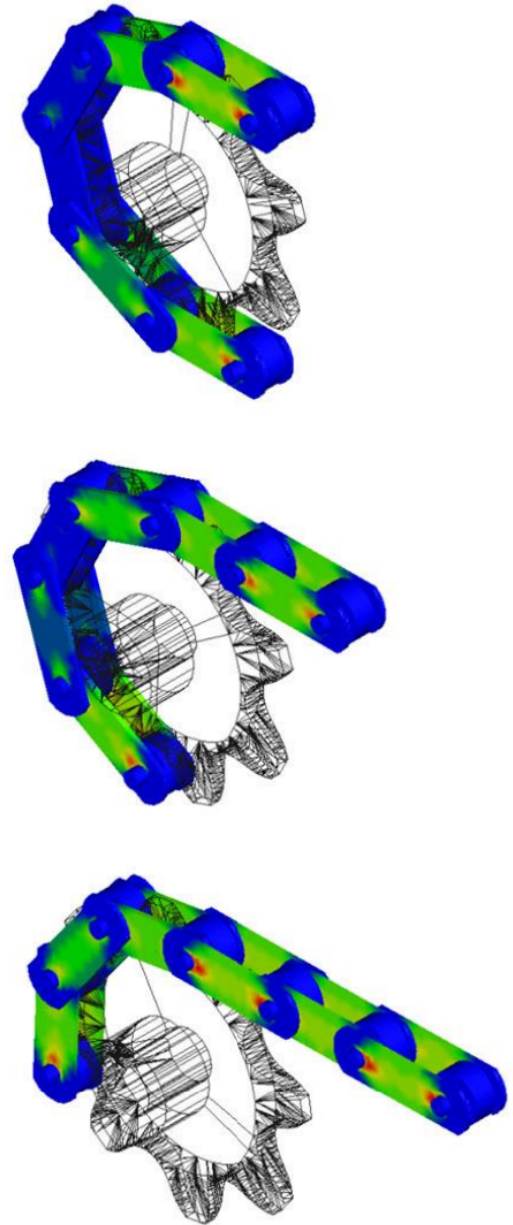


Fig. 28. Results of Stress Analysis in a chain mechanism.

Two of the crucial components in the transmission system are the gears in charge of driving the movement of the motor and the chain that transports these efforts, with the objective of determining the capacity of these components and using the information obtained in section 3.B perform two finite element studies whose results can be observed in [Fig. 28] and [Fig. 29] from these studies it is stated that both components, both the fall and the gear, are not subjected to stresses that exceed their permanent deformation stress, both components are made of a steel alloy whose deformation stress is $6,204 \times 10^8 Pa$, the chain reached an effort of $4,152 \times 10^8 Pa$ and the gear an effort of $3,882 \times 10^8 Pa$, therefore it is stated that both components can withstand the forces present in the transmission system of vehicle.

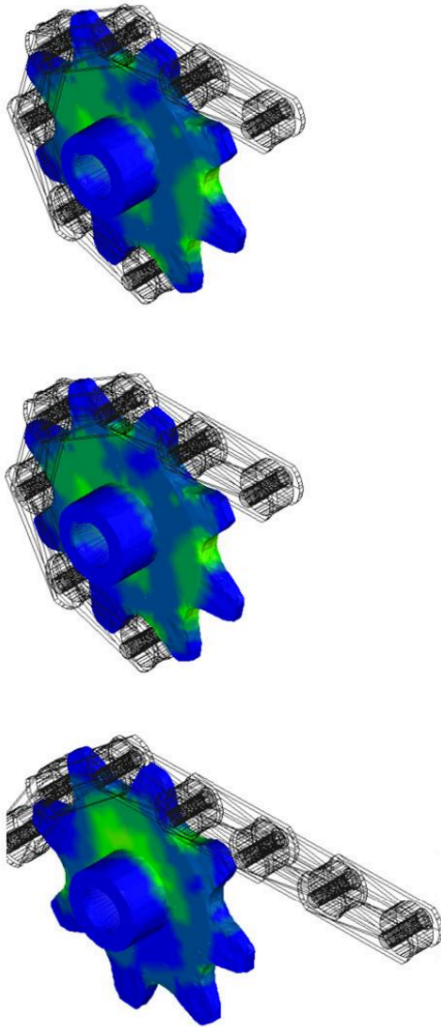


Fig. 29. Stress analysis of the drive gear.

I. Manufacturing

As part of the design requirements, it is necessary that all the components can be manufactured with the tools available in the workshop, taking into account the previous models and the selections of parts, it was determined that it is only necessary to manufacture 3 types of components, these correspond to two Metallic Beams both with a 3/4 inch radius and a length of 13 inches and 14 inches correspondingly these can be seen in [Fig. 30] and [Fig. 31], it is possible to acquire 3/4 inch shafts, however it is necessary to cut them to the established dimensions since this allows a reduction in cost and can be done in the manufacturing workshop.

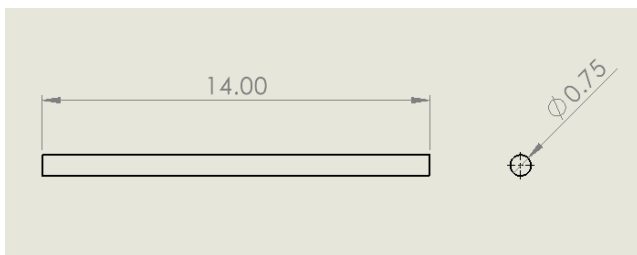


Fig. 30. Axes 2 of 14 inches with radius of 3/4.

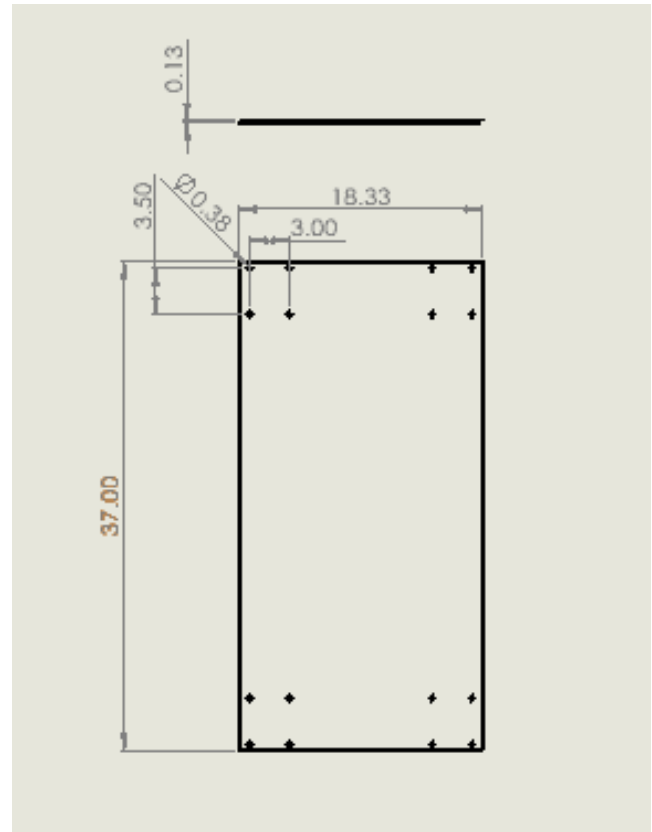


Fig. 31. Size of crystalline silica dust particles.

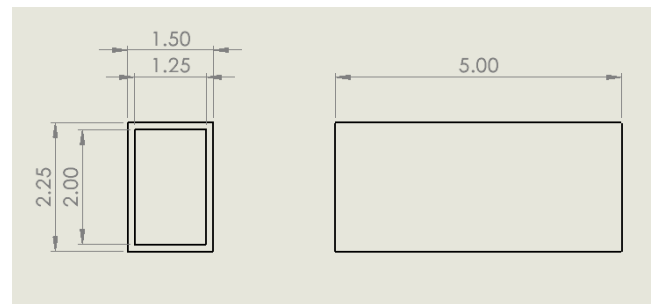


Fig. 32. Size of crystalline silica dust particles.



Fig. 33. Axes 1 of 13 inches with radius of 3/4.

Similarly, it is necessary to manufacture metal beams with the dimensions presented in [Fig. 32] these can be purchased and cut in the workshop to the necessary length or it can be welded using four sheets, it should be clarified that the precision of these is crucial for their proper functioning, however they have a tolerance of 1/8 inches.

It is necessary to manufacture a metal sheet with the dimensions shown in [Fig. 33] this can be purchased in the required size and the corresponding holes can be made by a milling machine in the manufacturing workshop.

J. Maintenance

The environment in which the vehicle operates is an environment with high ion concentrations of silica particles resulting from the marble handling processes, these vary in size as can be seen in [Fig. 3. 4].

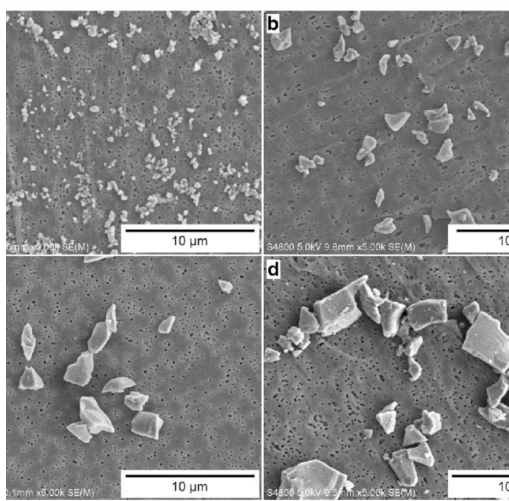


Fig. 34. Size of crystalline silica dust particles.

The implications of these particles represent the greatest challenge for the maintenance of the machine since they affect the main components of the vehicle, such as engines, gears and chains, these being the main components of the vehicle's power mechanism, these are subjected to the greatest amount of stresses and fatigue cycles, in combination with the silica particles, small indentations in the metal [Fig. 35] These indentations will be formed that over time where they will decrease the efficiency of the system as well as the maximum stress that the mechanism supports, since these deformations in the geometry of the material represent stress concentrators that accelerate the wear of the components as well as decrease the maximum effort they are able to withstand.



Fig. 35. Wear due to small particles in bearings.

Bearing this in mind, constant lubrication of the components of the power mechanism and constant supervision of them is recommended in order to monitor the wear of the parts. Given

the low cost of these components, it is recommended to replace them once significant wear has been detected.

Both the motors and the electronic systems must be constantly cleaned with an air compressor to prevent the accumulation of dust that could interfere with the operation of the electrical or mechanical system of the motor, however, given the high cost of the motor, it is not recommended to interfere with the motors. motor bearings since these interventions can be counterproductive by inserting particles or lubricant contaminated with silica particles to the motor gears.

IV. RESULTS AND CONCLUSIONS

Based on the previous information it is stated that the vehicle designed in this document is capable of supporting 500 pounds, it can be remotely controlled at a distance of up to 500 meters by a single operator using only one hand, the vehicle can move at 3 or 4 miles per hour although it is capable of reaching speeds of up to 10 miles per hour. In the same way, it is affirmed based on the finite element studies carried out previously that both the structure and the power mechanism are able to withstand the maximum efforts required for this application and that all the components of the system can be manufactured with the available tools. in the fabrication shop. However, the vehicle has a weight of 183.8 pounds which exceeds the desired value of 180 by 3.8 this however is a relatively small amount that when evaluated with the members of the company was found acceptable. In addition to its programming and the selected control mechanism for the tires, the SINGLE mode of the controller allows any inexperienced operator to perform simple movements with the vehicle.

Finally, most of the requirements, except for the weight of the vehicle, were met with a machine whose manufacturing cost is 640 USD. This price meets expectations and simultaneously the machine meets or exceeds project requirements.