Faculty of Engineering & Applied Science

MECE 3030U Computer-Aided-Design

Design project

Group 4

Design and Analysis of a Driverless Delivery Vehicle (DDV)

CRN: 43451

GROUP: 4

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Table of Content

Table of Contents

1.0 Introduction

This design project aims to create a driverless delivery vehicle (DDV) for an online business. In summary, ABC is a supermarket that wants to hire engineers to develop a DDV to face competition from online retailers and provide online service. But since online services are expensive due to high delivery costs, ABC has decided to create the DDV to reduce the cost of delivery while catering to online customers' needs. The ABC supermarket will see the order of the groceries and stock it in the DDV that will travel a distance of a maximum of $25km^2$ and has a weight limit of 250kg. Our group is in charge of the mechanical portion of the design of the DDV. Research and analysis will be made to create the DDV to meet the ABC supermarket.

2.0 Logbook

Date	Event
Nov 17th 2021	-Start of meeting 8pm on discord, -discussion on market options of DDV and design possibilities
Nov 18th 2021	-Meeting on discord 8pm -Concept drawing display preparation -discuss brainstorming on refining the final design concept -concept ideas based on our drawings and coming up with our final design with additive features.
Nov 19th 2021	-Container volume specs, motor specs, were adjusted by Rudra and Aidan

	-presentation preparation started with Danish, Andy and Enrique. Andy working on the report that is relevant to the presentation.
Nov 20th 2021	-Material selection work safety factor, Factor of safety calculation
Nov 21th 2021	-Readjustment to the size and amount of containers and changes in material selection because of experience with packaging that customers don't like.
Nov 22th 2021	-Meeting on discord 8pm -discuss and review what we brainstormed. -Discussion on the electric DDV and concerns about the battery life and recharge time for the vehicle. - Discuss the worst-case scenario of what kind of conditions the vehicles will undergo. The interval of loading the groceries. - Discuss how the AI will calculate the distance and weight limit on the vehicle and will not function if it exceeds the limit. - -Discuss the material inside the container to help insulate and safely package the groceries. Created the frame of the DDV design.
Nov 23rd, 2021	CAD works on the "bridge" of the vehicle.To try to match the appropriate size and length to allow the containers to fit inside while

	allowing it to rotate as well.
Nov 24th, 2021	Continuation of the bridge of the vehicle and the steering system. -Chassis of the car for support and analysis to see if it meets the required safety factor to be allowed to drive.
Nov 25th, 2021	-Finalization of the CAD design, and preparation on the PowerPoint and the presentation script. -Meeting on discord 8pm to work on finalizing our presentation and script. -Danish and Enrique fixed the PowerPoint presentation to make it look presentable. -Andy and Aidan worked on trying to simulate the container to rotate on an axis to the mechanism of how the project DDV will work. -Assigned themselves to sections of the script and wrote a script for the presentation.

Dec 3rd, 2021	-Meeting on discord 8pm - Finalize the report and assign different parts of the report to respective people. Andy- 1,2,4 Enrique- 3.5.7 Danish, 6,9,10 Aidan- 8 Rudra- 8

3.0 Existing driverless delivery car survey

Gatik- This company was founded in 2017 having offices in Toronto and Palo Alto [1]. The main focus of the company is to deliver good business to business for the retail industry, optimizing the chain supply of their customer [1]. Gatik has recently partnered with Walmart and received approval from Arkansas Highway Commissioner's office to operate with a human driver behind the wheel [2]. These vehicles are capable of delivering grocery orders from Walmart. The company started a partnership with top universities and the Ontario government [3] and is collaborating with Isuzu on the development of level 4 medium-duty trucks [4]. On the image below it can be seen one of their delivery trucks.

Figure 1. Driverless Delivery Vehicle from Gatik

Udelv: This company is operating in San Francisco Bay Area, Phoenix and Houston, with a driver as a safety measure [5]. The driverless vehicle from this company is currently at level 4 of autonomy, being able to drive by itself on operating design domains [5]. Udelv counts with a mobile application for Android and iPhone platform [6] and has partnered with mobileye, Walmart, Microsoft and other companies [7].

Fig**ure 2: Udelv Driverless Delivery Van**

Figure 3. Driverless Delivery Mobileye Model

Nuro: This is a company founded in 2016 with the help of leaders from robotics and artificial intelligence [8], being the first company to operate an autonomous commercial delivery service headquartered in Mountain View, San Jose, California [9]. The company has produced two models of their autonomous delivery vehicle called R1 and R2, respectively [8]. From these models, only the R2 is fully autonomous. This model is designed to do short neighbourhood trips and it exclusively transports and delivers groceries [8]. In order to do this, Nuro has partnered with three companies: Dominos, Kroger and Walmart [8] from which customers can start ordering and enjoying the service. The R2 model can deliver groceries, prescription drugs and pizza [8]. When it comes to safety, Nuro R2 has sensors such as 360 degrees overlapping cameras, thermal cameras, lidar, short and long-range radar, ultrasonic sensors and many others [8]. All these features can be seen in the picture below.

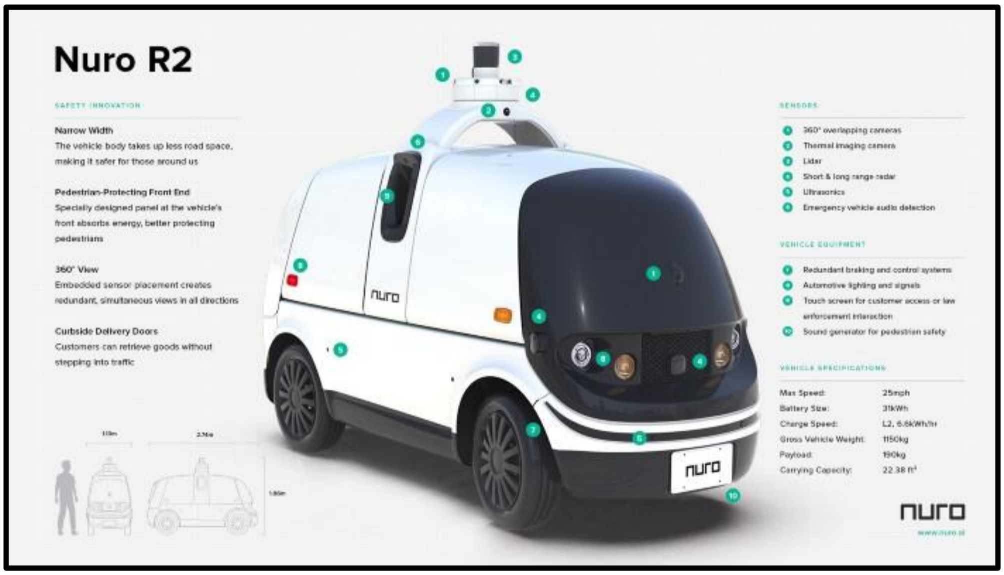


Figure 4. Nuro R2 Sensors and Safety Information

<u>Advantages & Disadvantages of DDV</u>

Advantages - Contactless Delivery is great during Covid times, since these vehicles can transport water, food and medical supplies, reducing the spread of the disease [8]. It is a mostly safe and reliable option on the road as they can navigate their surroundings without getting distracted, which can avoid human errors and therefore save lives [10]. It creates more job opportunities for people in different fields from marketing to engineering and many other fields [11], as well as creating new opportunities for people to work remotely. It is more reliable when it comes to delivering many orders at once, as it can guarantee that each customer will receive their right order. One important advantage about driverless delivery vehicles is that as they can communicate with each other and are being driven by themselves, they are efficiently optimized to operate in heavy and light traffic conditions. Another advantage is the factor that these DDV's are electric cars, a reason that makes them more environmentally friendly.

Disadvantages - One of the main disadvantages about DDV is that at the same time it creates new job opportunities, it will replace other jobs like delivery drivers [10]. It will only help in the long run since the initial price to get a DDV is expensive, but prices will go down when these technologies mature. Also as technology advances more there may be a possibility that the vehicle can be hacked and tampered with, which could create problems from delivering goods to accidents in busy roads [10]. The influence of weather may hinder the system of the AI that is controlling the DDV, which can cause accidents. Constant maintenance is required to see if it's properly functioning at all times since there are no humans to inspect it immediately when it is running.

4.0 Brainstorming

The self-driving delivery truck includes a container that will be separated into subsections which will include 8 small containers and 1 big container. The idea of separating the grocery between chemicals and food is the number of containers has been increased to 7 small containers and 2 big containers for better satisfaction due to experience working in a grocery store. Some customers did not like the idea of putting food and chemicals in the same section. We wanted to implement a system where it allowed the container to rotate to the side where the customer's groceries would be relocated to the side where the customer approaches the delivery vehicle. It was decided to add a touchpad on the side of the car for allowing one to input a code given to them through their phone to the DDV to allow a reliable and secure way to prevent theft. We also decided to create the dimension of the big and small container; the two big containers each will have dimensions of 28” (L) x 15” x 20 (W); the seven small container dimensions each will have 14” (L) x 15” x 20 (W). Since it will only travel within 25km^2, we will want to make the DDV electrical to reduce the cost and provide an economical and eco-friendly option. Also, the charging station of the DDV will have solar panels to efficiently store energy in the car. The material of the container that was chosen to contain the groceries was stainless steel, this is because initially thought of using aluminum but aluminum was researched to leak the chemicals into the food so to prevent them it was changed to stainless steel. Inside the container will contain an insulator to maintain the temperature and cushion the material to prevent the product from breaking. We also want to implement a Lidar, which is a light detector and ranging sensor which allows it to sense its surroundings and act accordingly. We discussed the limitations of the DDV by setting an AI to calculate the weight and distance limitation also calculates the battery life to set a limit on how far the DDV can travel to a destination and won’t allow the vehicle to function if it exceeds any of those limits, for example, the weight limit of 250kg and the vehicle can not exceed that limit. Also, we want to implement a system where no random civilian can jump on the vehicle while it’s on delivery as it will activate voice activation to request civilians to get off of the vehicles. The container will have an LED screen to advertise the company to promote the company’s online service with the DDV. Also, an AI can automatically close the door of the container if it does not detect any object inside the container after a certain amount of time because customers may not close the door after getting the grocery. Add a gas kit on the DDV to prevent water from trickling in the DDV. The DDV will have front and taillight to allow the car to be able to be seen during the night by other vehicles.

5.0 Concept generation and freehand sketch

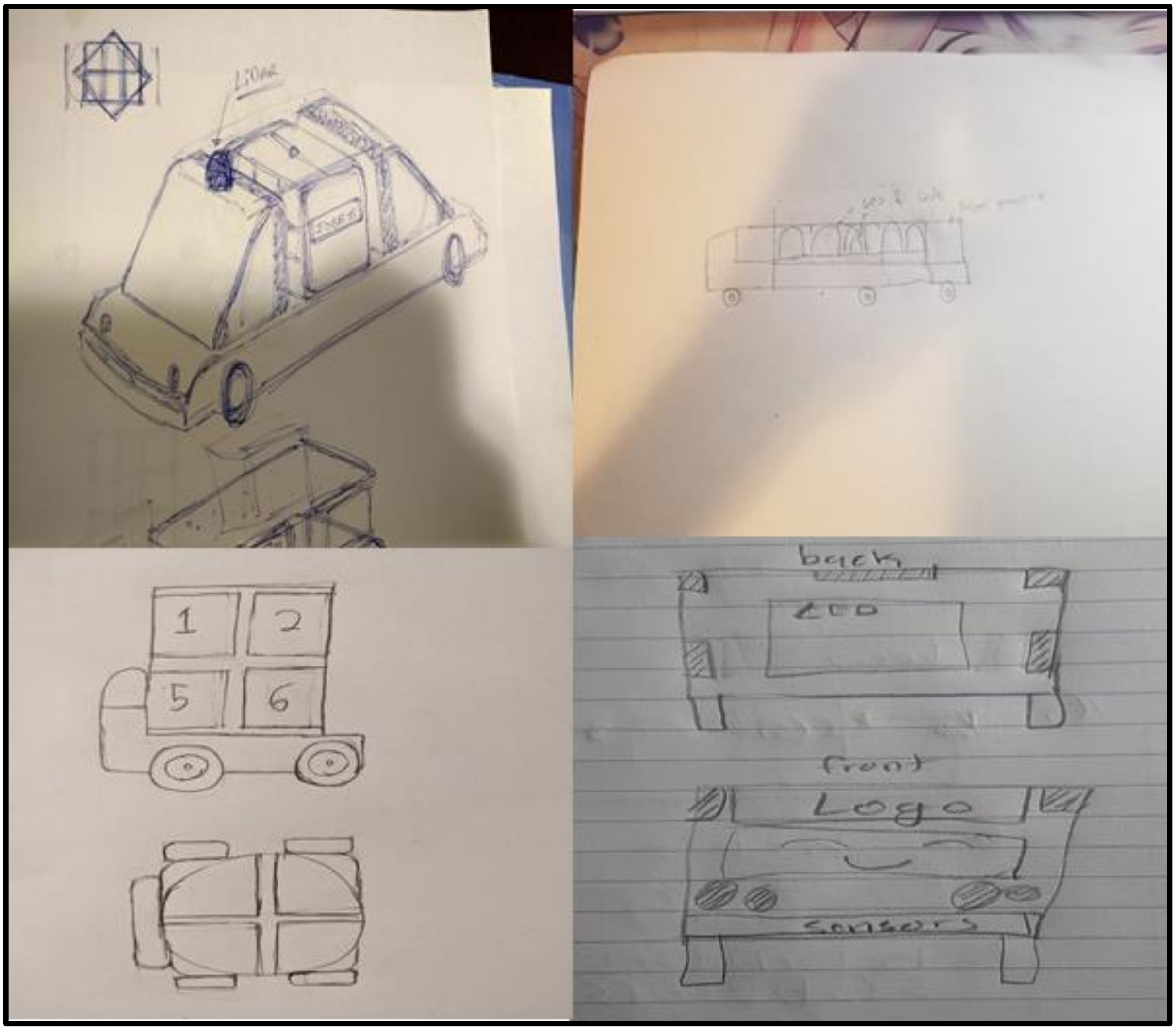


Figure 5. First Concept Generation Sketches

In the picture shown above, it can be observed the first concept design our team suggested for creating a driverless delivery vehicle. These designs were discussed and the team decided that the design presented on the left corner of figure 5, was the best suitable option for our needs. Further modifications to this design were made and many ideas from other designs were incorporated until the next concept design was created.

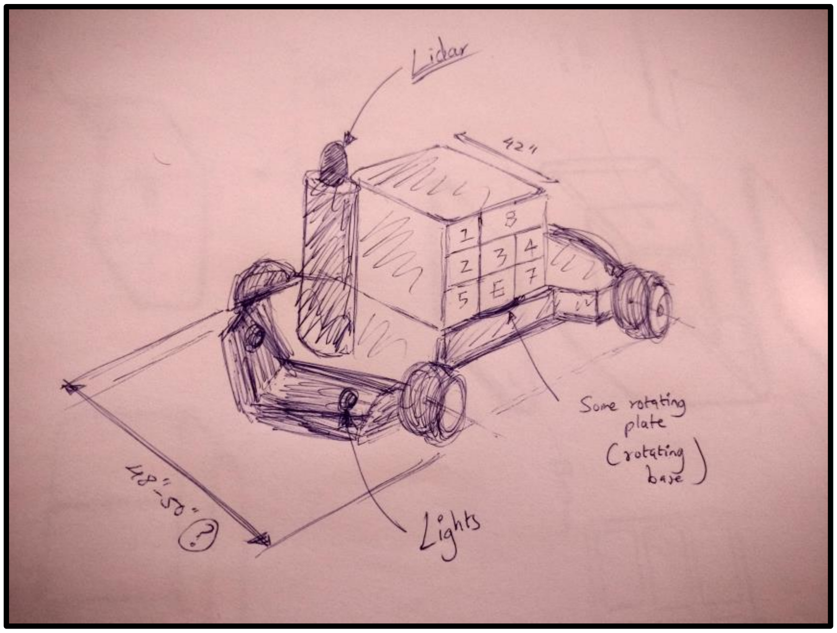


Figure 6. Second Concept Iteration

As can be seen, this design incorporated all the elements from the main design and many other features, however, it did not have a roof. This was fixed on the next concept iteration; a roof was added as a layer of protection against the rain and sunlight. This can be seen in the picture below.

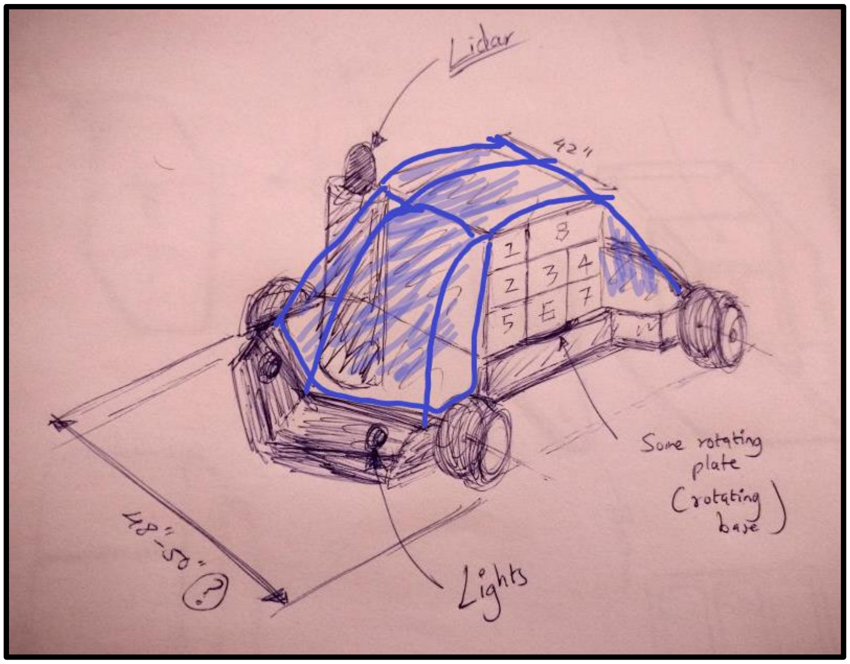


Figure 7. Third Concept Iteration

Once agreed with the design, our team proceeded to 3D model this concept using CAD software called *Siemens NX*.

For the container, the first design was conceived to have 6 equally spaced small containers. As can be seen in the picture below, the groceries would have been placed in the same container as food products.

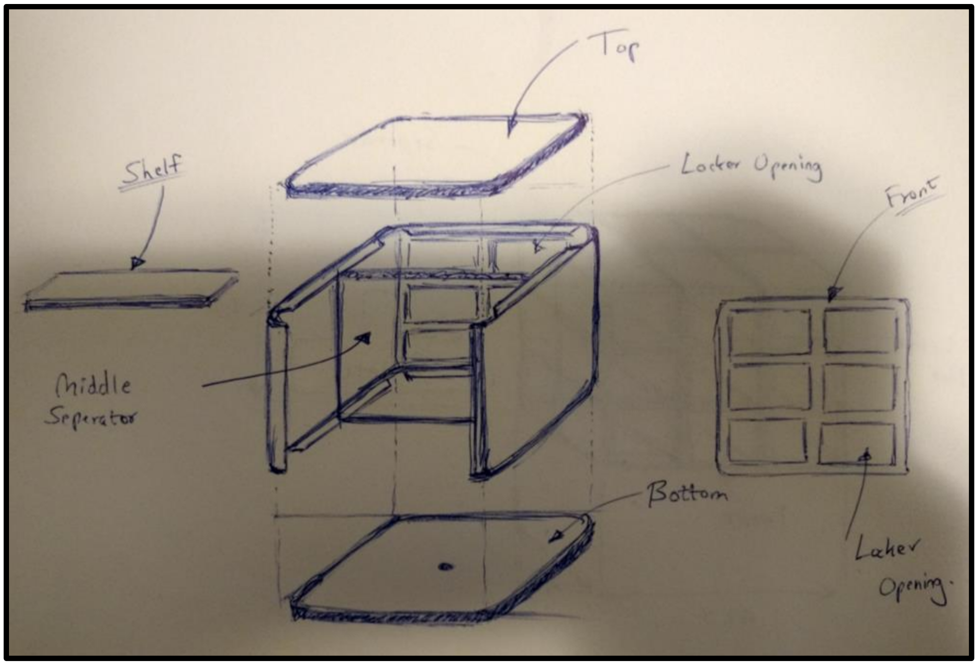


Figure 8. Freehand sketch of the container.

Even though this design meets the purpose of carrying products, our team decided to expand the number of containers from six to nine. However, for the practical purpose of storing cleaning products, two containers were merged into one larger container.

6.0 Final Design Concept

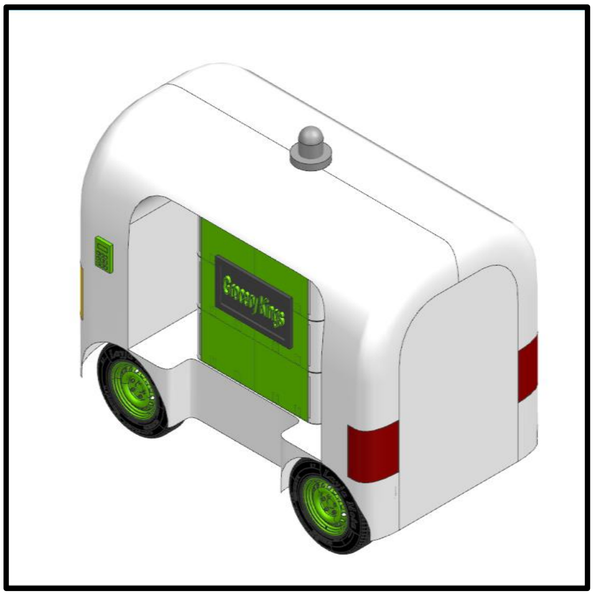


Figure 12. Isometric View of the Final CAD Design

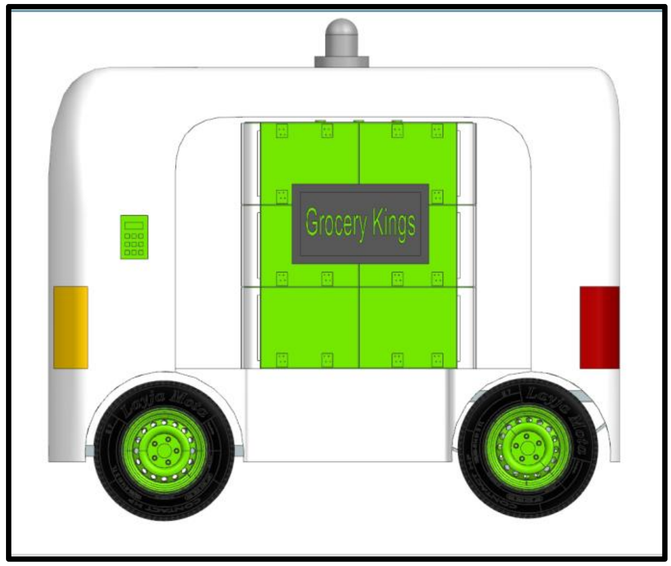


Figure 13. Front View of the Final CAD Design

Figure 14. Trimetric view of the Final CAD Design

As seen in the images above, the driverless delivery vehicle final design underwent some final modifications from the sketches discussed on the concept design, to improve its reliability and performance. The dimensions of the DDV are 2.65 meters long by 1.52 meters wide by 2.29 meters in height. When it comes to the container, its dimensions are 1.06 meters long by 1.06 meters wide by 1.14 meters in height.

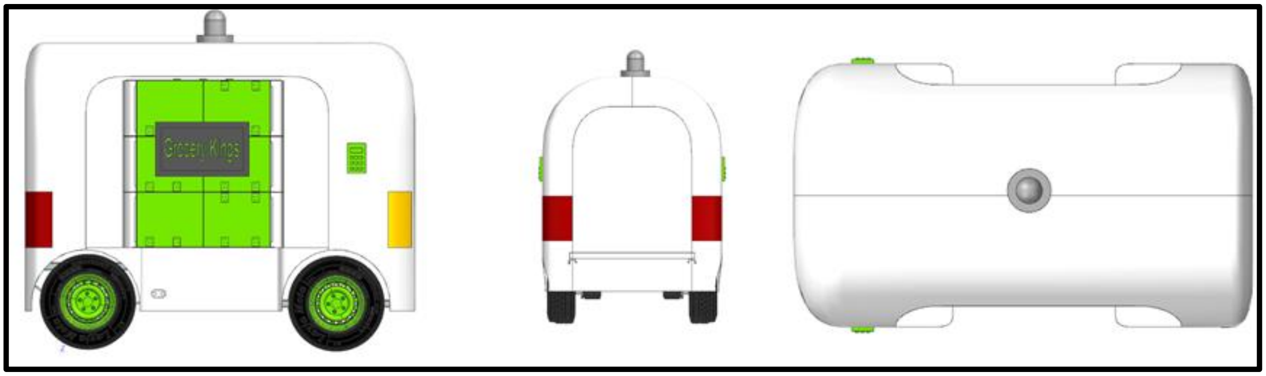


Figure 15. Front, Right and Top View of the Final CAD Design

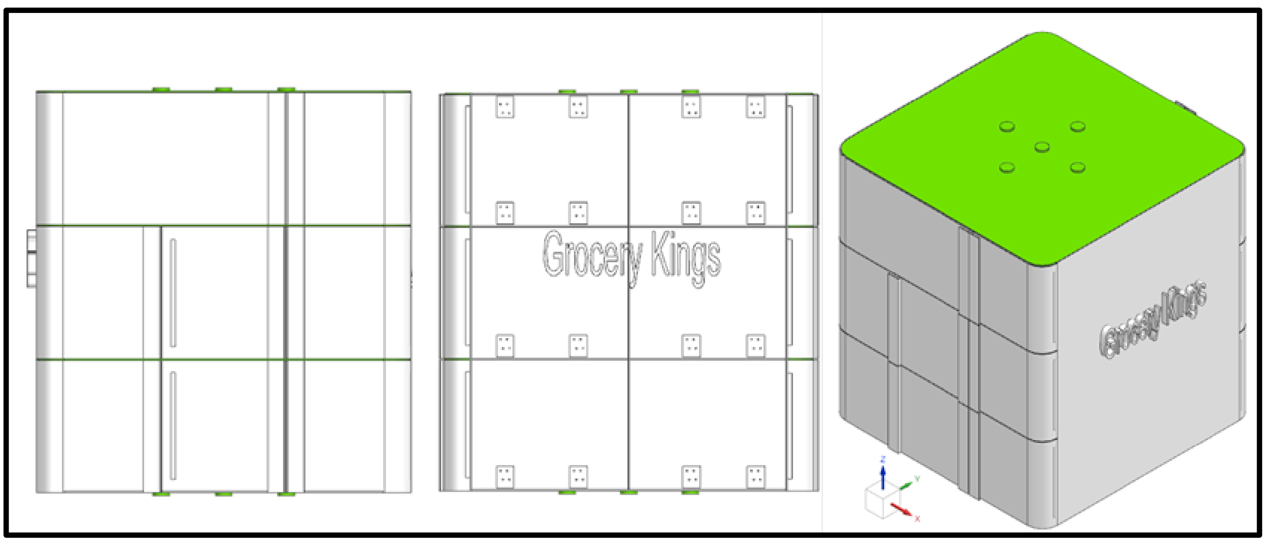


Figure 16. Front, Right and Isometric view of the container

The Lidar sensor is placed in the middle at the top to cover the vehicle more evenly. Cameras are placed to identify objects on the road, accelerometers will track the speed of the vehicle and the gyroscope will keep the orientation of the vehicle when turning on curves. Headlights and taillights were incorporated into the final design to help drivers and pedestrians to see the vehicle and the actions that will be performed to avoid collisions and accidents. The groceries are placed in the storage units located in the middle of the driverless delivery vehicle. This storage unit can rotate 360 degrees automatically. To further understand the concept, the steps below indicate the Design Process for the automated systems.

Step 1	Order is placed via cell phone or computer. Customer provides pick up location at this point
Step 2	Customer receives details for their DDV which includes DDV number, container code and number
Step 3	The DDV is loaded with commodities as per the order
Step 4	The DDV leaves the SuperMarket towards the customers pickup location
Step 5	The DDV sends notification when its five minutes away from the pick up location
Step 6	Customer Receives the notification from the DDV on their cell phone or computer, and prepares to receive the ordered items
Step 7	The DDV parks along the curb or a suitable location as per the areas urban location
Step 8	The customer is greeted with friendly hello and instructions to type in the provided code into one of the interfaces on the desired side (left or right) of the DDV.
Step 9	The customer enters the code to one of the side interfaces on the DDV (right or left), and the main container then automatically rotates towards that side of the DDV and opens the locked doors for the customers designated container.
Step 10	The customer picks up the items from their designated container and closes the container door. If the container door is not closed, then the spring solenoid hinges at the container door automatically closes the container door.
Step 11	The main container rotates back to its home position and leaves the premises when it is safe to do so.

The design includes a helpline system at the interface in case of any issues and also Anti-Theft/Tampering Alarms which notifies the SuperMarket and the customer as well.

Warning System for Equipment Safety

The DDV is programmed to only carry a specific amount of weight. Any weight beyond the threshold would show up a warning notification informing the SuperMarket employee about it and the DDV would not leave the facility. This is a feature added in order to protect the DDV from being overloaded.

The DDV is programmed to accept distances it can cover with respect to the battery's charge amount. If a DDV is prepared to make a delivery which spans a distance more than its battery capacity, then the DDV would display a warning, informing the SuperMarket employee about it and would not leave the facility.

Furthermore, warning notifications for any electrical, or component failures are also programmed for added safety.

These warnings would prevent the DDV from operating in a failed system state. This is to prevent any sort of accidents.

Some of these warnings can be overridden to operate the DDV by an access code which only a manager level official would possess.

7.0 Design Feasibility Analysis

7.1 Chassis

The chassis will be manufactured at existing motor companies such as GM in this case, as it cuts cost of manufacturing as they have the resources to mass produce the chassis to our specifications. It also is in a close Proximity making it cost effective by cutting costs on transport. The Chassis would be made up of Carbon Steel which is commonly used for most cars. This makes it possible to procure recycled frames for the vehicle and also cut the cost. A leaf spring suspension system will be incorporated in order to withstand impacts. This was chosen as it is easy to manufacture, maintain and reduce the costs involved.

7.2 Electrical

The Battery would be outsourced from various Battery manufacturers. These batteries are 14 kWh Lithium-Ion batteries typically used in electric vehicles as research showed that it is the best source of power for Electrical Motors when considering the fast charging and operating temperature ranges. The vehicle would be driven by standard electrical motors of 10 kW which would be outsourced from various vendors. Two of these motors will be utilized in a Rear Wheel Drive configuration in order to compensate for space in the front for the steering mechanism . A 500 W universal motor at the center would drive a Gear Box in order to rotate a circular plate on which the main Container sits.

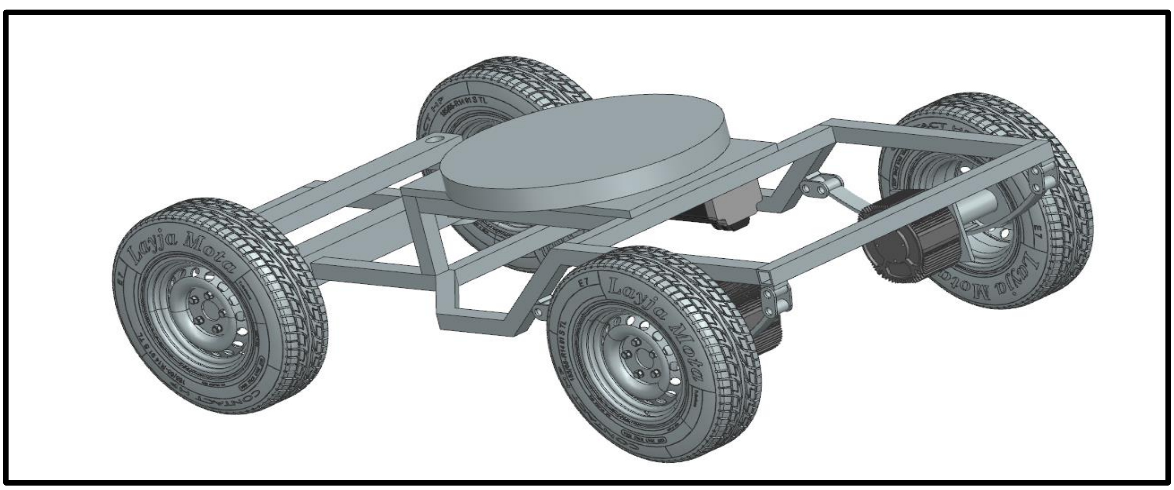
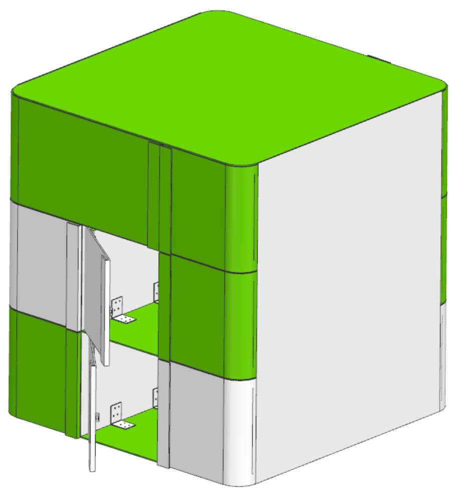


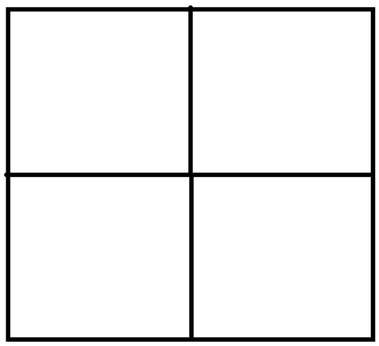
Figure above demonstrates the chassis which would include all the Electrical components as described earlier. It would also include additional digital control systems and electronics for various sensors on the vehicle. The enclosure of the chassis would be done by 300 series stainless steel sheet metal as it is durable to weather, attractive and easy to weld and machine. The thickness of this sheet metal would be 4.5 mm as it is one of the standard thickness available for SS300 series.

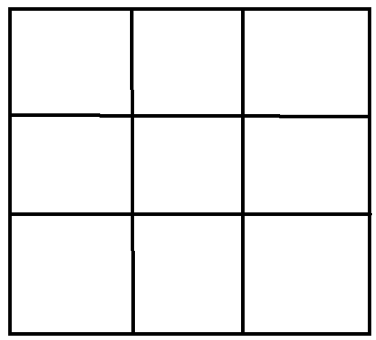
6.3 Container

The container will be made out of 300 series Stainless Steel of thickness 4.5 mm. This is a standard thickness of sheet metal available readily in the market. Various methods of welding and nuts and bolts will be used to create the Main container as shown below. Ideally the doors will be mounted with Spring Solenoid hinges for automatic opening and closing, with electronic locking mechanism. The design of



The container itself can have various configurations in order to fit the items as required by the ABC SuperMarket. There can be four large containers on both sides of the cube, or nine smaller containers on both sides of the cube. The figures below show the configurations for visualization.

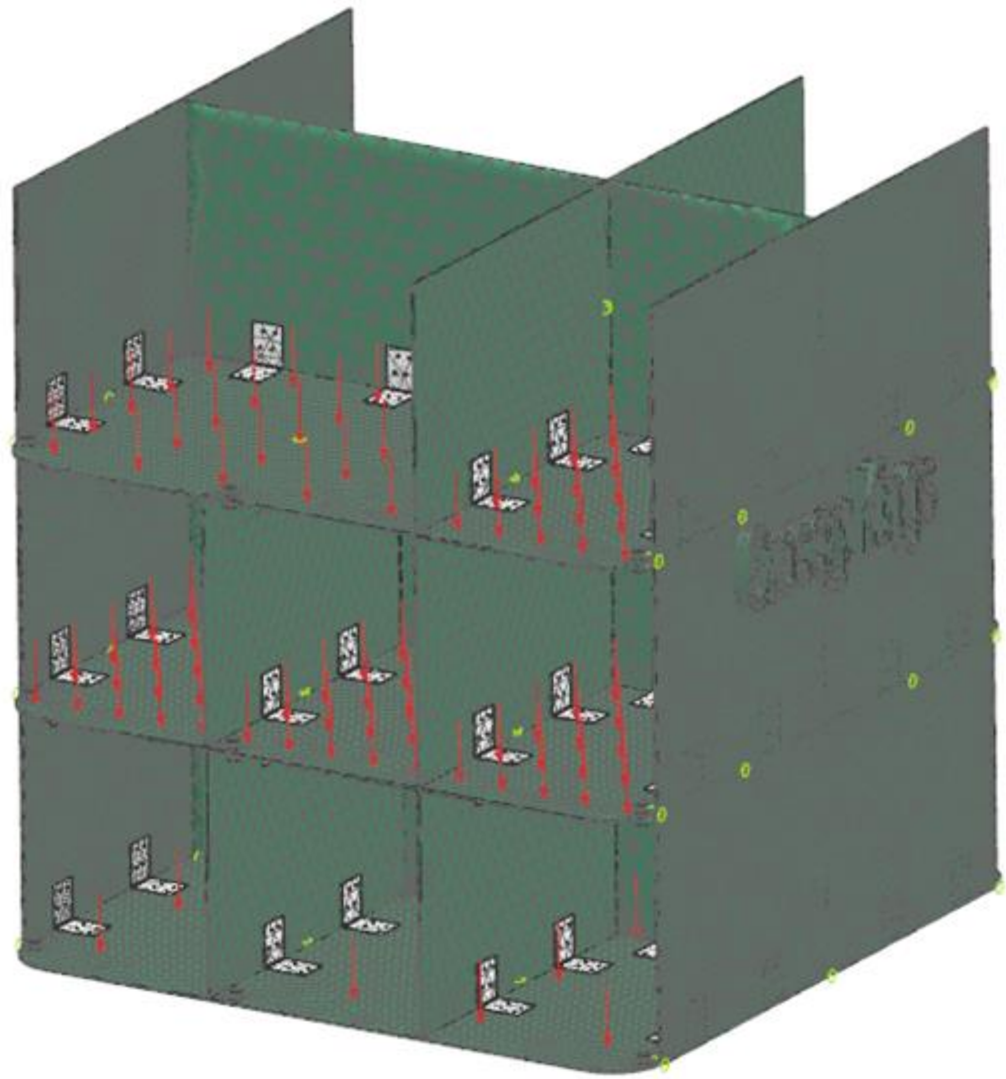




8.0 Analysis

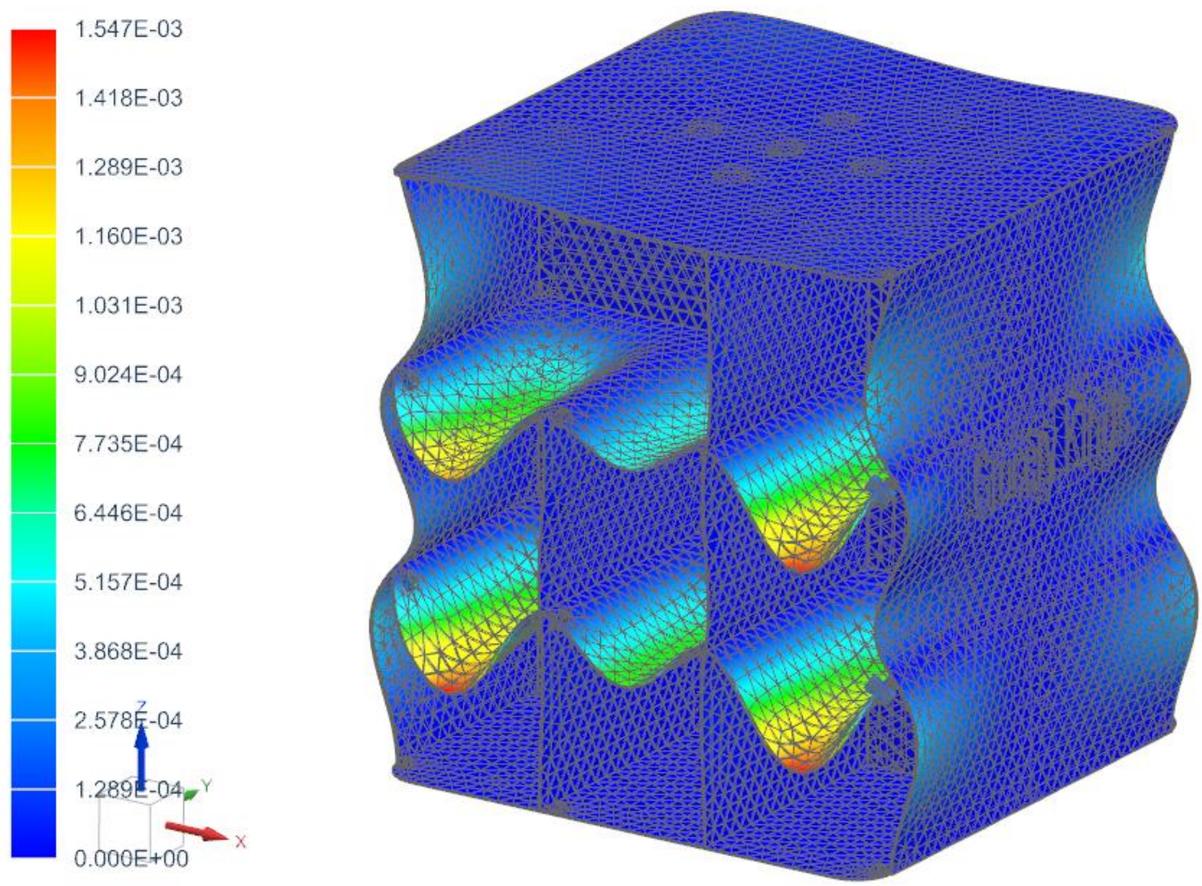
8.1 Container Analysis

A force of 250 Kg.f was applied to the Container on the CAD model in order to perform the FEA



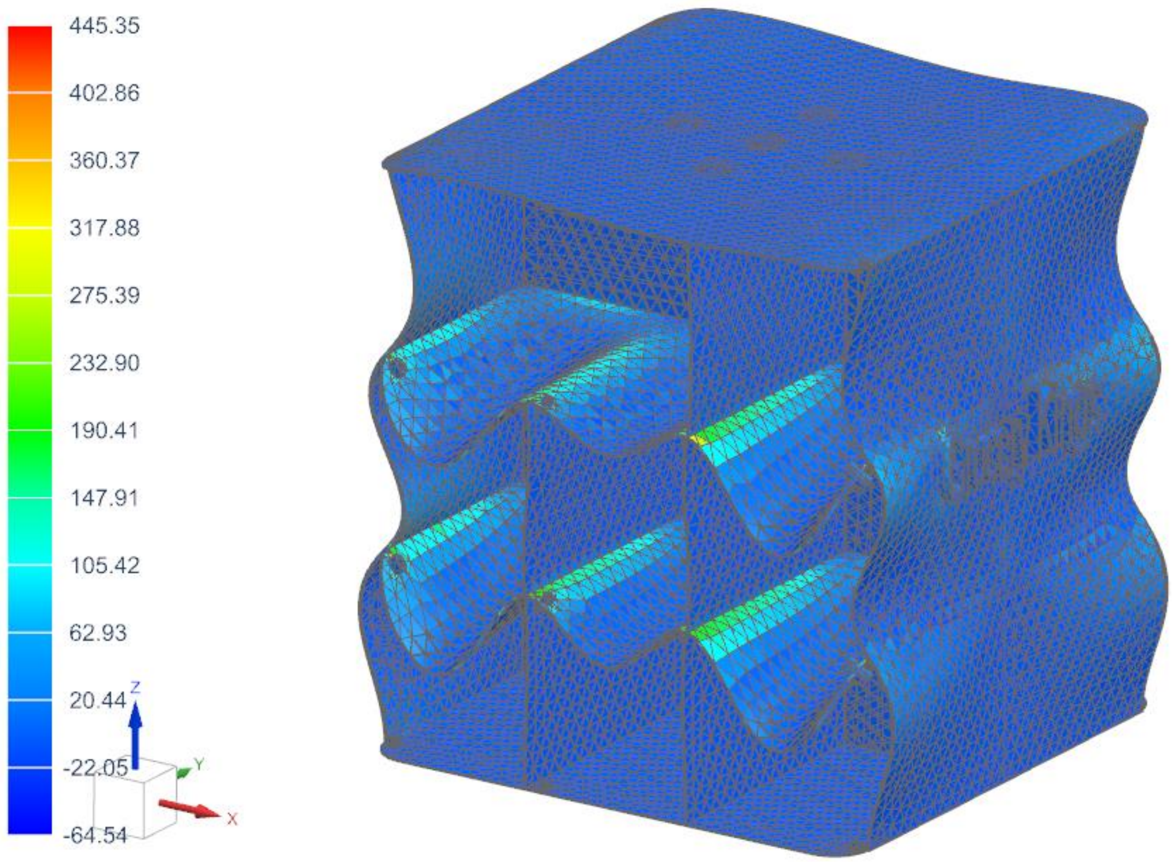
The Vectors in Red show the Force Application.

8.1.1 Displacement Analysis



The FEA Displacement Analysis of the container above shows that maximum displacement for overall Mass Force of 250 Kgf is maximum at areas marked Red in color. The scale on the left shows maximum displacement to be approximately 1.547 x 10^-3 inches in the negative Z direction. This is for Stainless Steel 310 of thickness approximately 4.2 mm which is available standard in the market. This is an acceptable range as there are no added supports to the container. Additional L-Bracket supports would be added to the structure in order to reduce any type of displacement.

8.1.2 Stress Analysis - Safety Factor



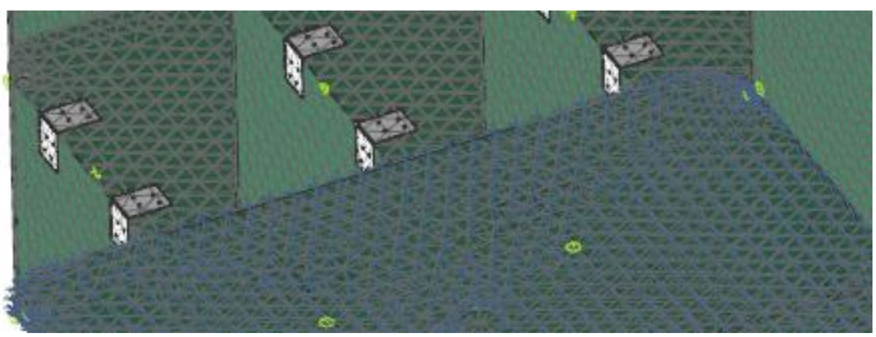
The Stress analysis helps identify the maximum Stress the container will undergo. The Applied Stress of the system can be derived using the FEA in the NX model. The model above shows max Stress at regions colored Yellow, and the scale on the left shows Yellow range of stress to be approximately 317.88 lbf/in^2. This converted to MPa is approximately 2.2 MPa. The Yield Strength of SS310 is 245 MPa [12].

Therefore, Stress (acceptable) = 245 / 2.5 (Safety Factor) = 98 MPa

Applied Stress = Maximum Stress on Container = 2.2 MPa

Since 2.2 MPa < 98 MPa, we can conclude that SS310 is acceptable material to withstand a total weight of 250 Kg and higher.

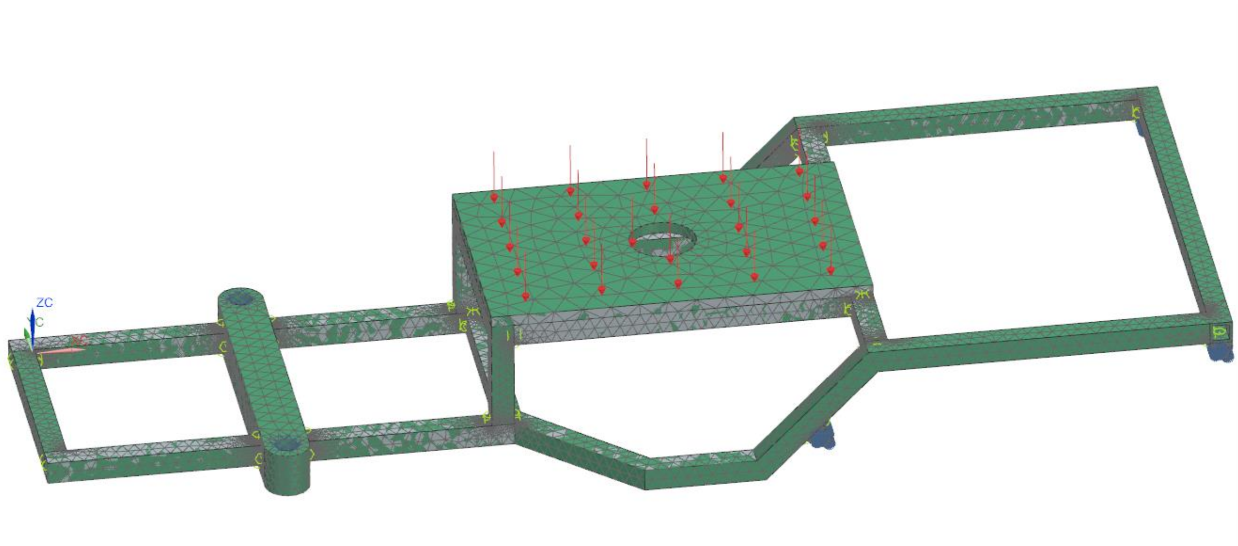
8.1.3 Added Support



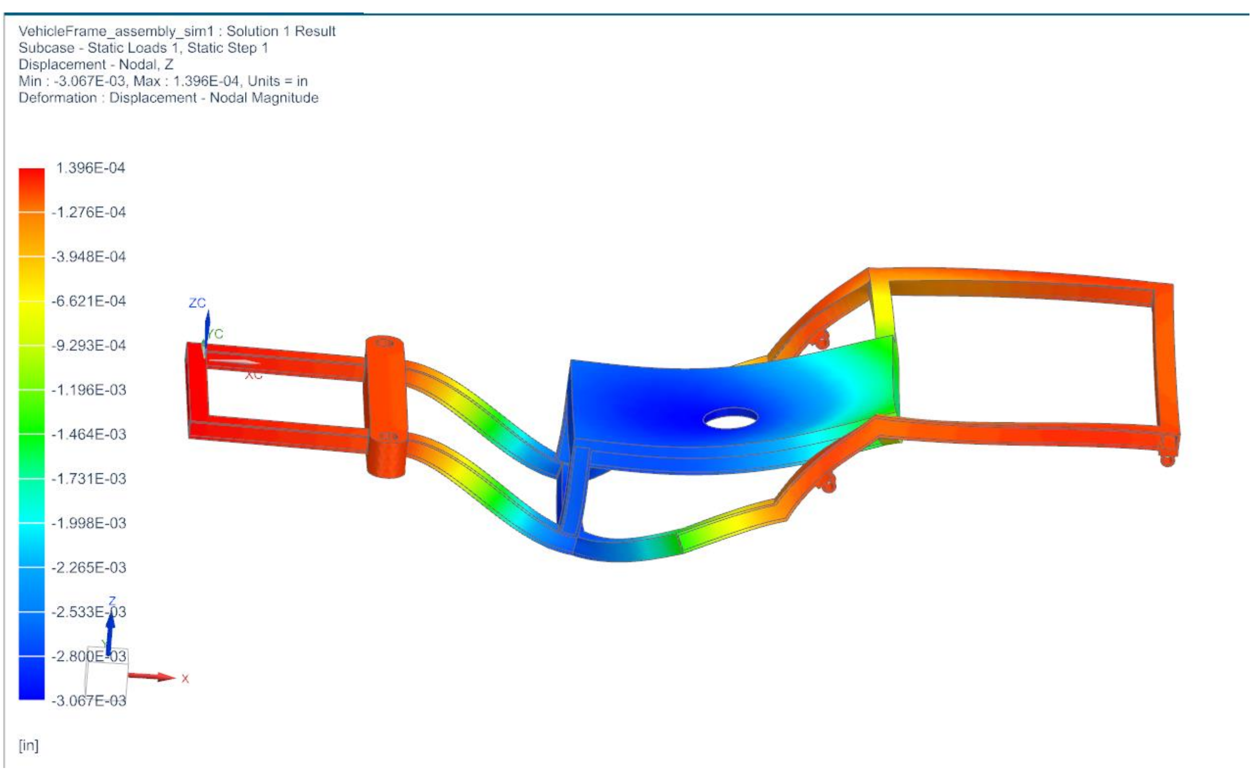
To reduce any further Sagging and to add rigidity in the Container. L-Bracket supports are added at various joints. These Supports are made of Galvanized Steel [13]. It is one of the Standard Parts derived from McMaster Carr.

8.2 Frame Analysis

A force of 250 Kg.f was applied to the Frame on the CAD model in order to perform the FEA

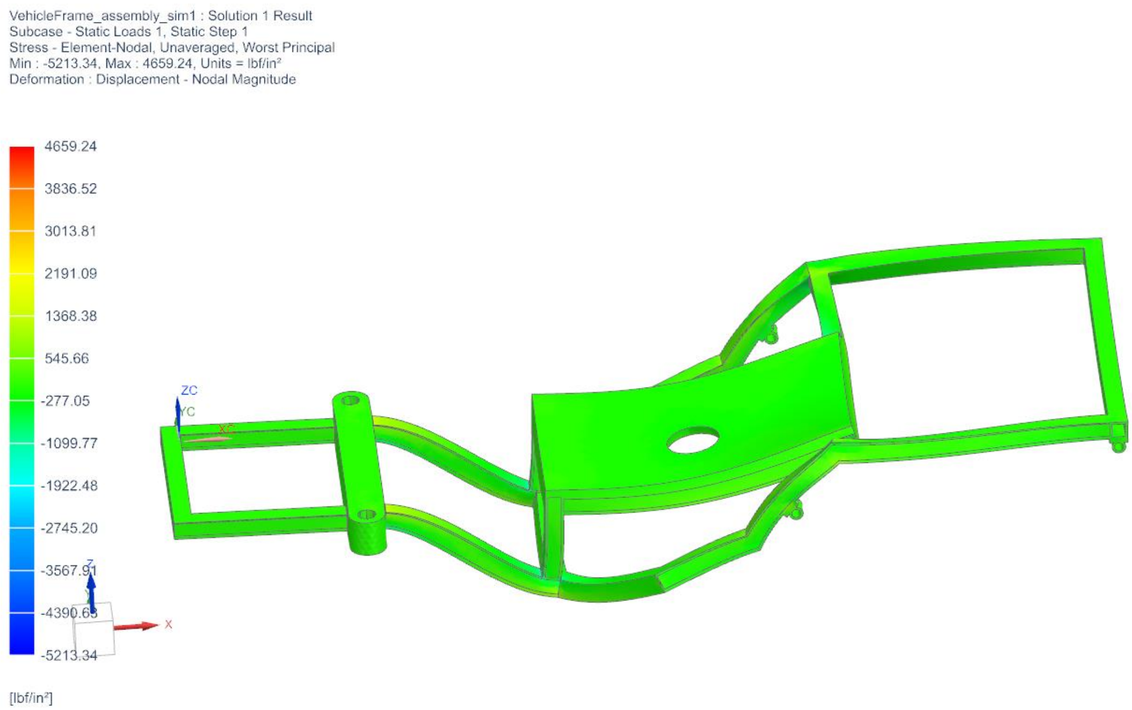


8.2.1 Displacement Analysis



The FEA Displacement Analysis of the frame above shows that maximum displacement for overall Mass Force of 250 Kgf is 1.396E-4 inches. This displacement is very minimal.

8.2.2 Stress Analysis - Safety Factor



The FEA Stress Factor Analysis of the frame above shows that maximum stress for overall Mass Force of 250 Kgf is 4659.24 pound force per square inch. This value was used to calculate the safety factor as seen in the calculations below.

Load From FEA

$\sigma_{Max} = 4659.24\ lbf/in^2$

$= 32.124\ MPa$

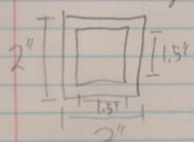
Max yield strength of AISI Steel 4340

1.178 GPa

$\sigma_{Allowed} = \frac{1.178\ GPa}{2.5} = 471.2\ MPa$

$\therefore 32.124\ MPa < 471.2\ MPa$

$\therefore$ currently the are is

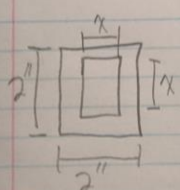


$A = 1.75\ in^2 = 1.129 \times 10^{-3}\ m^2$

$\therefore$ Max Force $= 32.124\ MPa \times 1.129 \times 10^{-3}\ m^2$
$= 36.27\ N$

$\therefore A_{should\ be} \rightarrow 471.2\ MPa = \frac{36.27\ N}{A}$

$\rightarrow A = 7.697 \times 10^{-5}\ m^2$



$4\ in^2 = 2.58 \times 10^{-3}\ m^2$

$7.697 \times 10^{-5}\ m^2 = 2.58 \times 10^{-3}\ m^2 - x^2$

$x = 0.05\ m = 1.97\ in$

9.0 Maintenance

The DDV (driverless delivery vehicle) we have designed has included the ability for easy maintenance for the vehicle. When the DDV requires maintenance it will come into a certified mechanic shop that has the tools and equipment to work on the DDV. The frame is held by bolts placed by the base and internal support pillars. The mechanic will have to use a power wrench to unscrew the bolts to loosen the frame, once that is complete, the frame can be disassembled by pieces, as a modular entity. Once the frame is removed the mechanic will have access to the electronics. We decided to go with this method because we wanted the mechanic to be able to safely and comfortably be able to access the electrical components without needing to unplug or move the electronics in order to do their task. It also prevents further complications in maintenance as the DDV will have a substantial amount of wiring and electronics compared to a normal vehicle, and a preventable accident could stop the DDV’s ability to function.

For the electronics the software will have a self diagnosing software that will be able to test whether a component is not working as supposed to. This will assist in identifying the source of the problem, where then the technician will be able to test the electronic part given the maintenance manual. A survey will be collected from the technicians where the data can be collected on the performance of the part for future installments of the DDV.

The status of the battery will be tracked by the software as it is a vital part, maintenance for the part will be on site. The technician shop will have a spare battery stored for the store that has their DDV come to the shop for insurance for when the DDV’s main battery comes faulty and will be used temporarily so the store using it would still be able to use it in operation, during the repair or replacement of the main battery.

For the electronics we plan on prioritizing the placement of each of the electronics so it is as organized as possible and allows the maintenance of the electronics to be as simple as possible. If a certain part were in need to be replaced the technician would not need to remove as little to no other components to access the part they need.

10.0 Business Model

With the grocery delivery market growing in the recent years and growing rapidly in recent times of Covid the market has proven itself to be invested. The company will order the DDV for specific locations and will require meetings to identify the needs of said company. Research will be done to look into the store's environment and look into what will be needed in
accommodation. It would mean that if the environment has snow in the winter, the order will include a supply of winter tires for the DDV, or if the temperature changes rapidly it would reduce the lifespan of the battery and an extra battery or an insulator for the battery will be included in the order. The average cost of modifying the store to integrate the DDV will cost $30,000 which will include one DDV, and an additional DDV will cost on average $10,000.

When the store approves, our company will work on building the custom DDV, starting with the chassis, which will be ordered from a motor company which we are able to order from. This is because motor companies already have the resources and manufacturing plants to build the required chassis to a large scale for this business to operate. The battery will be ordered by a battery manufacturing company as for the same reasons stated for the chassis, they will also be able to produce safe and reliable batteries as the order states. The electrical components that the DDV will use in all orders, they will be easy to acquire and replace, and as operation continues the data that will be collected by the mechanics will dictate the future of the use of the sensors.

When the order is made the store can customize the paint job of the DDV to suit the store's aesthetic, as well as the user interface their customers will see. The DDV will have three outdoor led screens which the store can use to advertise their promotions, with no additive cost. This will allow stores to reduce their advertisement costs and will be guaranteed to be seen by their audience as the DDV will drive into communities that fit into their demographic.

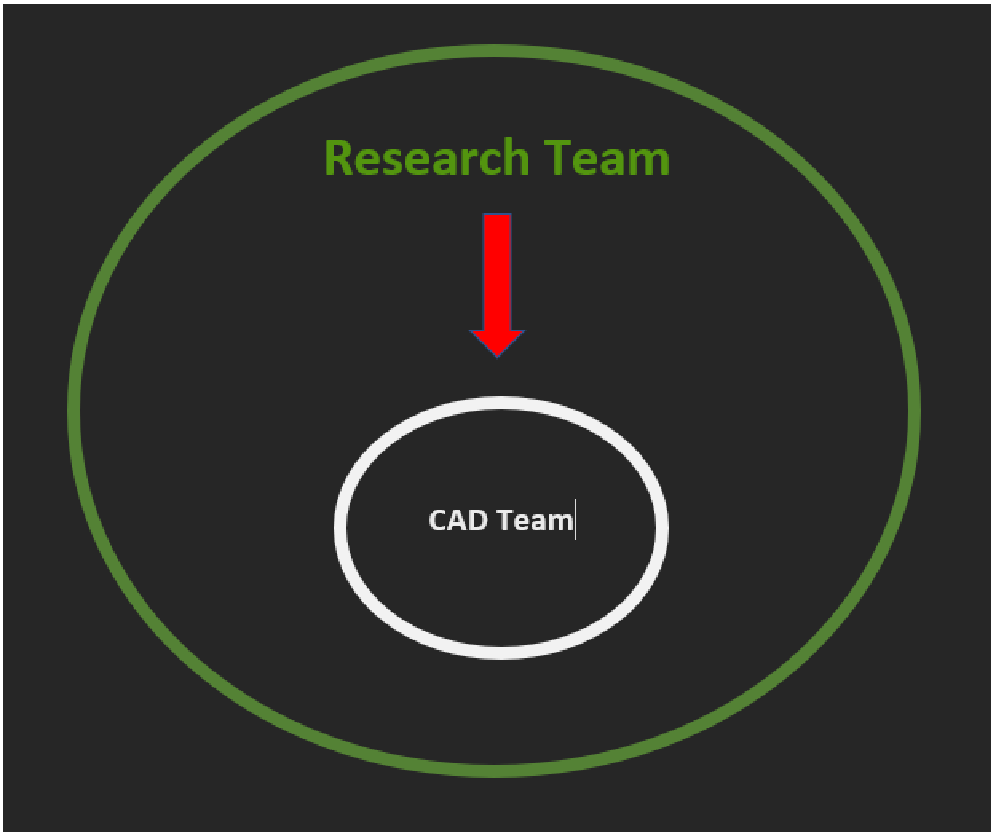
For the navigation software the DDV will use, the store company can customize where the DDV delivers their product, for example the store can avoid certain routes that are prone to accidents, or where their product is not allowed to be distributed, or go on routes to get the most attention for their advertisements. This is an additional $5000 fee to the total price, or a later addition where a survey will be conducted in the area to integrate those routes.

The maintenance will be conducted with an average of $3000 in maintenance fees per vehicle per year. They will be offered by certified mechanic shops where the equipment, and supply of parts are certified by an assessment that meets to our standards. Technicians that are qualified to operate maintenance on the vehicle will conduct the maintenance. Maintenance will vary per store due to their routes and environment. Software will be provided to the technicians and store that will keep track of the condition of the parts of the DDV and will calculate an estimated time of when maintenance is in need so the store can accommodate for the DDV's maintenance without impeding on their operation.

For the store to get an assessment a $1000 fee will be required as surveys will be required to calculate a quote. The survey include and are not limited to: The environment, the effects to the components due to the average temperatures for the four season, the supply chain for the electrical and mechanical components for the area, the assessments of the routes the DDV is expected to drive, the modifications to the driving and operating software of the DDV needed to function in the area, laws and bylaws for the region, and the cost of customization for the store's DDV.

With the growing market it should be seem as a long term investment for the stores as they re getting into a growing and profitable market, and is expected to breakeven costs of initial startup and maintenance of the DDV.

11.0 Project Management



The Team has five members, who at the beginning brainstormed various ideas to generate concepts. These concepts were then sketched out to have visual representations. Two teams were made out to further carry the Project in detail. The Figure above demonstrates the fundamental flow of team work. The Research Team supplied the necessary information and specifications to the CAD Team in order to produce the targeted DDV CAD prototype. The table below shows the team collaborations.

	Member	Collaboration
Research Team	Andy	• Super-Market Research and Requirements • Record Keeping • Co-ordinating • Business Modelling • Concept Brainstorming
	Danish	• Electrical Motor Research • Controls Systems • Sensors • Manufacturing and Feasibility • Concept Brainstorming
	Enrique	• DDV Design Research • DDV Market Research • Battery Research and Requirements • Patent Survey and Research • Concept Brainstorming
CAD Team	Aidan	• Vehicle Design • Vehicle FEA • Motion Simulation • DDV Assembly • Concept Brainstorming
	Rudra	• Container Design • Container FEA • Container Material Selection • Vehicle Material Selection • Concept Brainstorming

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