3/29/20

MIE 415 Senior Capstone Design: Final Report

Team 27: SolarFi Cart 2

UMass Amherst

College of Engineering

SOLARFI

Donovan Walls: Team Lead
Hunter Hughes: Fabrication Lead
Nathaniel Lobik: Design Lead
Abigail Risse: Evaluation Lead
Yaziel Rivera: Analysis Lead

Executive Summary

The goal of this project was to design the cart of the future. A team of UMass Engineers was contracted to engineer an efficient solar powered cart for the company SolarFi. For this cart to be successful it needed new features for street vendors. With a green power source, this cart has the ability to charge phones, offer cold drinks and shade, and potentially act as a wifi hotspot in the future. Meanwhile, it still needs to be compact, affordable and structurally reliable. This cart offers a better alternative for your average working street seller. Engineering this into reality was a complex but achievable goal.

UMass students have worked to make this cart feasible, calling upon many engineering disciplines and fields. The structure was crafted using a CAD model to simulate real world parts. The solar panel design was chosen with attention paid to cost and power delivery capability. An electrical system has been designed to provide power to all necessary components of the cart. Using Matlab and solar data from the National Solar Radiation Data Base, there are simulations displaying expected solar gains, accounting for varying power usages. All work undertaken has delivered a solar powered street cart necessary to propel street vendors into the future using the most accurate methods and data possible.

The design seen in Figure 1 outlines the expandable and collapsible solar panel array design as well as the compactness of the inside of the cart. The inside of the cart includes the refrigeration system and storage lockers for a variety of different options that all satisfy the criteria of the sponsor. There is the ability for storage of mobile phones via fast charging ports for the phones. There is also potential as well for portable chargers able to be picked up at one cart and returned to another once a potential network is developed. Chargers stored inside of these storage lockers that are to be powered from reserve batteries.

Summary of Impact

Upon consideration of the project's motivations and goals, Team 27 has taken the previous design iterations of the SolarFi cart created by previous senior design teams and added to the entirety of the engineering design process. The contribution of our team includes a partial redesign of the existing SolarFi cart and a performance evaluation of the redesigned cart. The final deliverables of this design project will include a model of the cart, a MATLAB code to predict the performance of the cart in different locations, and a Bill of Materials for the full scale model of this cart to provide our sponsor the ability to assemble our design.

Our design enables vendors and customers to charge multiple phones in a more compact, accessible way and allows for the convenience of ordering beverages from a solar powered refrigerator while underneath shade provided by a five solar panel array that folds out over the top of the cart. While providing the customers of the cart the convenience and shade, this simultaneously will provide the vendors of the cart a mobile and compact cart that has the ability to work in off-grid locations. Electrical considerations of the solar panels and their power generation has been included.

The redesign of the cart more effectively produces shade for the customers and more compactly fits the necessary components of a refrigerator, phone charging storage lockers, and counter space as outlined by our sponsor. The performance of the solar panels is evaluated based on multiple potential locations of the cart and the power generation of the panels based on data from the National Solar Radiation Data Base. Our design also includes batteries that are able to be recharged at night before taking the cart out for the day. Our contribution to the cart specifically differs from previous design iterations in that the solar panels have a different folding array to provide more compact fold-up when not in use and more surface area for shade over the cart during the day when in use by utilizing a cost effective cloth material to connect all of the solar panels' capability for shade. Specifically, this design will provide 53 square feet of shade for customer comfort and has a lower center of gravity than previous design iterations, providing for security and ease of movement during transportation.

Moreover, the in depth electrical circuitry was also planned for application, which comprises the solar panel array, a charge controller, an inverter, a DC combiner box, batteries, and switches. This circuit is meant to be an outline for the full scale model of the cart, and the materials and specifications for each of these components can be found within a completed bill of materials we have made as one of our final deliverables to our sponsor. This electrical circuit will provide the manufacturer the ease of assembly and a comprehensive overview of the electrical units inside of the cart.

The final contribution that Team 27 saw as crucial for a comprehensive project scope includes the evaluation of the performance of the cart in different locations. Our sponsor had mentioned the cart being used in many different locations including, but not limited to regions such as Africa, Miami and Southern California where there is almost constant sun exposure during the day, in addition to Boston, where cloud coverage and sun coverage are variable on any given day. The simulation of the performance of the cart is crucial to understand what seasons and months the cart will have the highest performance. This code outputs a chart showing the wattage required and the wattage produced by the solar panels. This gives the vendors and customers of the cart an idea of where and when the cart will perform it's best.

Introduction and Objectives

The original motive for this project comes from the many reasons that street vendors in off-grid locations have a difficult time transporting and selling goods in places with constant sun exposure and high temperatures. The trouble of bringing goods to and from the market is significant for goods that require refrigeration, and these street vendors rely on selling these goods for their income. For these vendors, spoiled food due to lack of refrigeration is a waste of money and time, both of which usually can not be afforded to go to waste. Without constant refrigeration, street carts are not efficient in keeping food for long periods of time, which can be detrimental for vendors in some countries.

The under-utilization of sun in off-grid/sun-rich locations such as Africa provides a platform for the development of a solar powered, mobile street cart for vendors. SolarFi, the sponsor of this project, and previous design teams at the University of Massachusetts Amherst have developed many iterations of this solar powered street cart to include convenient features such as the mobility of the entire cart and mobile phone charging. Although originally intended for less developed locations, SolarFi is aspiring to make a network of these carts in not only developing nations but also in places with adequate sunlight to run a street cart in marketplaces across the world.

Our project objectives include a partial redesign of the cart, which will comprise of adequate power generation, complete mobility of the cart, more considerable shade, and a more compact design. The second portion of our project deliverables include the estimation of the performance of the street cart in different locations based on data and a MATLAB code to output the performance curve over the course of any given day in certain locations.

Contributions of Each Team Member

Nate Lobik created a 3D CAD model of two designs based on the groups concepts and ideas. Once the final design was chosen he continued to add detail and improve the CAD model of this design. This allowed the team to visualize our ideas, as well as create a Bill of Materials based on the parts used in the CAD. Nate Lobik also wrote the code for the simulation in MATLAB. This consisted of writing code to find all the location names, extract all the data needed from the excel files, and create a GUI so that the specific location, date, and battery size can be chosen to be analyzed. Nate also wrote the analysis code for the year long simulation and the one day simulation, this created the figures seen in the report, as well as the results of where and when the cart will fail.

Donovan Walls directed group communications and helped organize scheduling and responsibilities. This included keeping in contact with not only team members, but also team sponsor Antonio Dixon of SolarFi. With the ongoing Coronavirus Pandemic, this allowed the group to effectively communicate in safety, while progressing seamlessly on completing the project. Donovan has also contributed to editing the Final Report, with writings in the Executive Summary and Structural Decomposition, as well as the accompanying figures.

Abigail Risse contributed to all of the initial design components and organization of the design process while simultaneously facilitating brainstorming sessions for key technical objectives and team structure. This included posing the important questions about the feasibility of our design and driving the necessary timeline concerning the design requirements. Brainstorming design ideas and solutions as well as contributing to the evaluation metric ideas for the project. To better understand how to evaluate the performance of the cart, after meeting with Professor Lacker, Abigail coordinated the research of different solar metrics to use for the MATLAB code for performance simulation.

Yaziel Rivera contributed to the MATLAB code written by Nate, analyzing different sets of data presented by it and generating figures and tables for the report. This includes battery level, charge and failure data. Yaziel also initiated contact with professor Lackner as the group's main advisor. This would allow for the group to have a more focused direction for the solar power analysis which is key to this project. Yaziel also contributed to the brainstorming of initial design ideas that would be generated by other members of the team.

Hunter Hughes managed scheduling for the group and tracked the completion of key technical objectives of the design process through a running schedule on Microsoft Project. In addition he met with Professor Manwell along with Donovan in order to understand how we could translate the hourly global solar radiation data pulled from the National Solar Radiation Database into the energy our panels would produce and which data was valuable from the site to be loaded into the code. He completed the ANSYS structural analysis of the hinges and frame of the cart and produced the videos of the ANSYS load simulations. He also worked with Nate to create a bill of materials using the CAD model for a scaled down model that was going to be produced before the coronavirus shutdown classes and is currently working on creating a projected cost for the full scale model.

Functional Decomposition

The Project's thought process for structural design was heavily influenced by engineering principles. The functional decomposition in Figure 2 displays actual group work results. For example, one of the important facets is adequate power. Engineering principles demanded an investigation as to how the system could be powered. This involved researching solar panel designs which provided high power outtake. This was then compared with expected power usage as extracted from the National Solar Radiation Data Base. Simulations with Matlab showed system interaction and identified any flaws in design, which were then rectified. Inadequate batteries were edited and replaced while the solar design was made to provide the correct amount of power. This process was then repeated for structural design, ensuring the cart had the most practical and efficient design.

Engineering Standards and Patents

The engineering standards used in this project were limited. Most standards related to the electrical circuitry of the cart, and the electrical contributions of Team 27 were simply an overview of the circuitry of the solar panels and not the complete focus of our design project. However, it was important to consider the security of moving parts and the structural soundness of our street cart. The general engineering standards relating to structural integrity (including simply not breaking when fully assembled) were complied with by choosing material and performing simple engineering analysis to verify that the cart would not fail under the load of the solar panels. While there are no dedicated engineering standards related to factors of safety in a cart like this, it is a generally accepted standard in structural and automotive engineering to have a safety factor of 3 or 4. As the maximum principal stress found in the aluminum cart hinges was 5.35 MPa as seen in Figure 9, while the yield strength of aluminum is 276 MPa, there is a factor of safety of 51 in the hinges, far above the accepted safety factor in the hinges. In the eigen buckling analysis it was found that for buckling to occur with the weight of the roof on the columns a load factor of 1397 was calculated in order for buckling to occur, as seen in Figure 10. As this means that a load 1397 times larger than the load the roof exerts on the columns is required to cause the column to buckle so it is effectively a safety factor of 1397 for the frame's structure.

Specifications

Our target specifications are outlined in Table 1. These specification values were determined by the rating of the refrigeration system that we had chosen as well as the battery capacity in conjunction with the solar panel ratings. The refrigeration system that we chose had a rating of 60 Watts, sufficient enough to provide enough cooling for the average beverage street vendor, whereas each solar panel we chose based on cost effectiveness and accessibility had a rating of 157 Watts. With our solar panel array, we arrived at the generation of 783 Watts over five solar panels delivering it to the salt water batteries. These batteries, chosen correctly, will deliver close to the maximum energy generated by the solar panels to the fast charging ports and the refrigeration system.

These total power generation specifications were calculated based on a combination of the energy inputs and outputs, but most heavily relies on the solar panel generation. This energy generation is only suitable when the solar panels deliver their maximum energy to the batteries. With the cart being used in many different locations, the energy generation will be different based on location. This required Team 27 to understand where exactly the cart could be placed while having enough battery power to sustain the cart and it's internal components. A MATLAB code was developed to simulate the battery performance and therefore the cart performance in different cities based on data collected by the National Solar Radiation Data Base.

This dedication to quality is shown in our House of Quality, displayed in Table 2. Our goal was to optimize not only the electrical system, but the overall design function. Emphasis was placed not only on the ability to generate power, but various other features to enhance customer satisfaction. Solar Panels will generate power for phones and cold drinks and provide shade for customers. Shade cast from the panels will allow people to cool off on hot days while they wait for refreshment. The overall cart will also be collapsible and be easily portable, making it more appealing to owners. Solar panels and important features will be protected in compact form. As a team of Engineers, Team 27 took into consideration a variety of features and expertly designed this cart to accomplish multiple functions.

Design Selection and Solution

The design for this product was not solely created by Team 27 since inspiration for the build came from previous teams. Although Team 27 perfected and differentiated the design specifically for the Spring 2020 semester, the basic structure of the cart was shared by both the previous teams and Team 27's contributions and includes a few basic components. The base of the cart includes foldable and expandable counter space, storage capacity for internal necessities such as the refrigerator and batteries, and some sort of base with wheels. Our design process included evaluating the different types of storage capacity routes that are able to be taken given the guidelines of this project. Initial ideas included different ways that the refrigerator could open, whether that be like a typical refrigerator door that opens like a door from a vertical position outwards, or whether it would be like an ice cream truck, in that the refrigerator opens from a horizontal position upwards. It was decided that because of the storage capacity of our design and the goal of making the design compact, the refrigerator opening similarly to a door would provide the cart more storage beneath the counter space. With the goal of compactness in mind, Team 27 concluded that with less space taken up by internal components, the vendors would more easily be able to transport the cart with less weight and volume. The ergonomics of this cart are the most important factor when considering design alternatives, and with the vendors in mind, the feature of having a refrigerator open below the counter for compactness and vendor convenience was much more beneficial.

Another specific consideration was the solar panel array structure. Two options were to have all panels slide in and out from a central stack of solar panels, allowing for the vendor to simply slide out the panels once set up (Figure 3). The other option was foldable panels from a central panel, all connected with hinges to allow for a flat plane of solar panels once fully assembled (Figure 4). This provided the design with a lower center of gravity given that the panels all folded out onto one plane, and also provided the design with the capability to provide more shade by connecting the solar panels on the outer rim of the rectangle with a material such as cloth, keeping the design cost effective and ergonomic for both customers and vendors of the cart. For these reasons, the solar panel array that folded out completely was chosen to be the final option for how the solar panels would be incorporated into this design.

For material choices of different components, Team 27 had a few options in a few different contexts. To portray the final design, our initial goal was to have a scaled down, fully functioning model of the cart to show judges. The goal was to have a fully assembled prototype scaled down to about one-fourth of the actual size of the full scale cart. For our final deliverable, we decided to create the base of the model out wood, for ease of manufacturing and for cost effectiveness. Making it out of aluminium would have been expensive and difficult to assemble. However, for the full scale model of the cart, aluminum would be the best option considering the cost of the material compared to other weather resistant materials and common alternatives such as stainless steel or fiber reinforced plastic. Additionally, another consideration was the supporting structure connecting the solar panel array and the base of the cart. In both the scaled down model and the full scale model, these rods would be made with T-slot aluminum extrusions to allow for ease of manufacturing, since the adjustable capability of T-slots make for strong, corrosion resistant, and flexible manufacturing outcomes.

Models and Methods

To simulate how the solar cart would work in different locations, we wrote a simulation code using MATLAB. Relating the data from the National Solar Radiation Data Base to our cart is where our mathematical model was used. The location radiation data is given in Watt-hours per meter squared. To relate this to our cart we just had to multiply by the area of the solar panels on our cart and multiply by the efficiency of the solar panels. This gives the following model;
$Energy\ Captured\ =\ efficiency\ *\ Area\ *\ radiation\ =\ watts * hour$
Using this formula we are able to calculate the energy our cart will capture each hour of the year for any location that has the radiation data. Next, we needed to calculate the battery level of our cart, to determine if the cart will have power all day or not. This was just a simple sum of energy in and energy out. The model is; $Battery\ Level\ =\ Battery\ Level\ -\ Energy\ Out\ +\ Energy\ In$. In this model the energy captured this hour is added to the battery level of the last hour and the energy out this hour is subtracted, giving the current battery level. The simulation code took into account that there is a max battery level which, it can't go higher then and there is a minimum battery level of zero. Using these two models the simulation was able to calculate when and where the cart would fail, which is shown in Figure 5.

Data

The Data used in the simulation is from the National Solar Radiation Data Base. This Database has hourly measurements of solar radiation for hundreds of locations across the United States. The data was gathered in two different ways, the first being taking measurements of the radiation using sensors on the ground. This is as close to real as it gets, since the clouds affect the value of the measurements as much as they would affect the amount of energy that reaches the solar panels. Not all of the locations had this type of data, so in some locations, the data used was gathered by measuring the solar radiation in the atmosphere with thermal imaging satellites. This data was then put into a mathematical model to make it more accurate measurement for how much radiation would be getting to the ground. This takes into account cloud coverage and errors with cameras. Measurements are in Watt-hours per square meter, which can easily be related to how much energy the solar panels would capture in the same location.

Detailed Design

The sponsor for this project requested an ergonomic and versatile solar powered cart. To design this cart Engineering students researched appropriate construction material that would be included in the final design. The team considered energy demands, structural integrity and design knowledge as discussed previously, when picking materials to work with. These materials formed a planned micro model of the SolarFi cart and a full scale model for industrial creation. The Bill of Materials (see Appendix) lists the most optimal components suggested for constructing the cart.

The cart needs a big enough solar array and battery to last an entire day. Having a bigger solar array makes the design less ergonomic. The solar array clearly needs to collapse or store away in some fashion. We determined the size of our array by simply calculating the power used by the cart and calculating how much area of the solar panel we will need to create more power than needed. We chose five 100-Watt Polycrystalline Solar Panels from Home Depot which fit our size constraint. With these panel types our design theoretically produces twice as much power than needed to make up for the times when it is not operating at full efficiency.

Several concepts for the solar array were envisioned; two main ones can be seen in Figure 3 and 4. Figure 3 shows the sliding design which allows for all of the solar panels to slide in and be protected and stored when the cart is being moved. The design in Figure 4 allows for a collapsible solar panel array. The benefit of this design which led us to use it, is the cart will have a lower center of gravity which will negate tipping in travel. The solar panels are also still protected in this design because the pieces of fabric that are seen in the corners of the array not only provide more shade for the cart but also fold back on top of the panels to protect them in transport. This structure needs to be held together with a sturdy frame.

For the frame of this cart we decided to use t-slotted aluminum framing with wood paneling. Aluminum brackets and T-frames provide a strong and lightweight design and also allow the cart to be versatile. Wood panels are easy to acquire and provide excellent environmental protection for a multi-compartment system. This design offers a secure cart a vendor can customize to their needs. This will allow for easy electrical integration.

Our electrical system reflects from the design in compactness and simplicity. An electrical circuit with a 120V inverter acts as a bridge between the Solar Panels and the various outlets of the cart. This circuit powers a mini fridge and a switch bank that feeds into phone chargers. It attaches to a 100AH Lithium Iron battery that is rechargeable and provides an emergency supply of power in the case of cloudy skies. With the above mentioned frame material, this will not overload the frame with excess, as we have proven with in depth analysis.

Detailed Engineering Analysis

In designing the cart there were several aspects that required analysis. The first being the design of the cart itself structurally, second being solar considerations which is the focus of the cart. When designing the cart's structure several qualitative criteria were considered. One of the first was a design that is towable and ergonomically practical. This was accomplished by designing a cart that generally resembles a typical cart with installed solar panels to provide the electrical energy demands and client shading requests. Additionally, the interior design of the cart was focused on ergonomics for the client, a vendor, as well as the refrigeration needs as specified by the sponsor. This leads to a simple cubicle design where vendor products are stored above the batteries next to the refrigeration system of the panel. This design allows for space behind the counter to be of maximum use as well as freeing counter space for the use by the vendor. One of the major decisions to be made was the method for installation of the solar panels. A sponsor request was to maximize shading and to accomplish this it was decided to use solar panels as shading. Also in order to maximize qualitative efficiency it was decided to to have folding panels that fold down into the cart. In the design four panels were used to maximize solar energy generation while also minimizing weight and thus resulting in a lower center of mass, lowering the risk of rollover. To lower costs and comply with the sponsor request canvas awnings are used in order to provide shade to the edges of the roof of the cart.

In addition to the above design considerations that shaped out features, we also wanted to ensure that the final design was structurally sound. To accomplish this ANSYS was used to find the maximum principal stresses the hinges use in our folding panel design would experience. The deformation of the columns supporting the roof and folding frame were also calculated and an eigen buckling analysis was used to make sure no buckling would occur, which was a concern because of the thinner walls in the t-frame cross section. In the hinge analysis, the weight of one solar panel and the frame around it was placed on the two supporting bolts being attached to the frame around the solar panel while the hinge was in the downward mounted position, which was the worst case load scenario because the entire weight of the panel was on the hinges. It was found that the maximum stress the hinge experiences is only 5.35 MPa which is far below the 276 MPa yield strength of the aluminum it was made of, so we confirmed that the standard McMaster Carr hinges were suited to the task. In the buckling analysis we found a load multiplier of 1397 in ANSYS, which confirmed that the beams we selected were highly unlikely to buckle because a load nearly 1400 times larger than the weight of the roof is basically impossible for the cart to experience, outside of an unrealistic disaster.

The other area of analysis is the MATLAB simulation code we wrote. This code was written to determine if an adequate amount of power would be generated by the solar panels, to power the fridge and phone chargers. This code runs through every hour of every day for an entire year and checks the battery level of the cart. If the battery level reaches zero any hour of the day, that day is marked as a failure. The results of this simulation can be seen in Figure 5, which shows how many days failed out of the year for every location and every battery size. Our cart is designed to be able to fit different size batteries, but the current design is for a 2000 Watt-hour battery. So for example in Boston, the cart failed 30% of the year with our 2000 watt-hour battery. However in Miami, with the same size battery cart only failed 2% of the days of the year. This code also produces graphs for each location that compare the battery level, power in and, power out for an entire year. An example of this can be seen in Figure 7 for

Boston. Figure 6 shows the same thing but for a single day. Both of these figures show how much the energy production can vary throughout an entire year depending on the season, and even throughout the day depending on the cloud coverage. These calculations were all based on the model discussed in the Model and Methods section above, and the analysis portion of the code can be found in the appendix.

Final Design

The final design of this project was originally intended to be a quarter-scale prototype and a corresponding analysis of the performance. After careful consideration and situational conditions (i.e. cancellations due to COVID-19), the project goals shifted and the final design of the project was a completed CAD model of the solar powered street cart with an in-depth, detailed analysis of the expected performance in different locations with different battery sizes, to allow for variation in budgeting, cost of manufacturing, and use cases. The final design included sliding solar panels for easy and effective compact storage of the cart, as well as increased counter space and storage space. The space below the counter was specifically designed for the optimization of space and storage for the vendor while still holding the essential skeleton of the cart to keep the solar panels working (this included the storage of the batteries and electrical components.

The final design can be seen in an exploded view with all of the components easily seen in Figure 12. The performance of the cart was then analyzed, and it was of interest to the potential future market expansion to investigate the performance in areas of lower sunlight than certain places in Africa, Miami, or southern California. The analysis allowed for the user to input a certain location and battery size and understand the average day-to-day broadband output of solar power after a night-long battery charge, so that the battery is able to act as a back-up in cases where solar activity is low. The overall design and analysis of the project consisted of a CAD model and a MATLAB code, as explained in previous sections, that allowed for the complete overview, both visually and comprehensively, of a solar powered street cart in many different locations.

Design Evaluation

Evaluations for the design was done primarily through simulation of the battery level of the cart. Using the program, Matlab, battery levels were monitored taking into account battery drainage from continuous usage by the refrigerator and the connected phone charger cables. Charge gain for the battery was also monitored using data collected by a national solar database for a given year for a given city across the continental United States. From this data battery level was recorded hourly for a year in a variety of locations to evaluate the performance of the system. To determine the success of the cart in a certain area the percentage of the number of days of failure was the criteria used. For target locations such as Miami a total failure percentage of less than five percent is the objective, while in non target locations such as Seattle, less than twenty-five percent. These percentages are to ensure that in a worst case scenario where as much charge is being drawn and/or the cart is being used outside of target conditions, i.e. winter or a cloudy day, that the vendor will still have a large certainty in the performance functionality of their cart. The idea being that if the cart works well even outside of its target conditions it will perform exceptionally when it is in its target conditions.

Discussion

The original goal included building a physical prototype, and due to circumstances outside of our control, the designs and goals need to be shifted accordingly. The design of the street cart was completed in SOLIDWORKS and can be seen in the Appendix (Figures 1, 3, 4 and 12). Despite the design not being able to be physically evaluated, a variety of different simulations and analyses were performed to ensure that the design was adequate and provided a comprehensive look at the improved design. With the MATLAB analysis and simulation outputting the performance of the cart, there were many challenges and questions that were tackled. Location, battery size, and battery charge were all variables in this situation to evaluate the performance, and it was necessary to think about how to provide a way to display different inputs to the same system. This challenge was undertaken by Team 27, and the result was an extremely simple-to-understand model of the performance. The inputs were location and battery size, and the assumption was that the battery was fully charged before the cart was taken out for the day (overnight charging). Defining the analysis as a goal of our project was a change that needed to be made once circumstances changed at UMass and this aspect of our project provided engineering analysis for a design that wasn't able to be physically prototyped.

Conclusion and Recommendations

The design of this project included an improved solar panel sliding mechanism, countertop storage addition, and underneath counter storage. The design itself required performance evaluation and therefore, a MATLAB simulation was generated. The design of both of these aspects were a result of Team 27 undergoing the engineering method, which included obtaining an in-depth understanding of the problem and marketplace, brainstorming and generating solution ideas, and bringing forth an implemented version of these solutions in the form of tangible design and analysis. The future holds the requirement of a few more modifications, where future teams can take the current design and carry out our original goal of a physical prototype. The physical prototype can be based off of our bill of materials and scaled to whatever dimensions realistically and financially attainable. This prototype would need to be tested to ensure the quality of the solar panels and structural support. Another recommendation is to further delve into the MATLAB simulation analysis, allowing for more information to be inputted such as weather conditions or humidity. The output of our simulation is an average, but with more information, there is a possibility for more valuable output. The potential furthering of the simulation and the physical prototype would allow for a more comprehensive closure of the current design and would be adequate recommendations for future teams.

The current design and simulation lays a foundation for an efficient, viable street cart to store adequate solar energy for the vendors to provide cold beverages and food items to customers, along with providing extra power for features such as phone charging. The ergonomic design of this street cart provides a strong foundation for a prototype to be developed and tested under the groundwork framed in this project. A simulation that provides a hypothesis of how much energy will be provided versus stored in different locations as well as a design that is customer friendly has the potential to drive future projects to perfect a groundbreaking idea helping street cart vendors connect the future.

References

[1] “Individual Site-Year Files.” *National Solar Radiation Data Base*, 2010, rredc.nrel.gov/solar/old_data/nsrdb/1991-2010/hourly/list_by_state.html.

[2] Wilcox, Stephen. “National Solar Radiation Database 1991–2010 Update: User’s Manual .” *National Solar Radiation Data Base*, 2012, ftp://ftp.ncdc.noaa.gov/pub/data/nsrdb-solar/documentation-2010/NSRDB_UserManual_r20120906.pdf.

[3] “The Circuit Designer's Guide to Photovoltaic Cells for Solar-Powered Devices - Technical Articles.” *All About Circuits*, www.allaboutcircuits.com/technical-articles/circuit-designer-guide-to-photovoltaic-cells-solar-powered-devices/.

Appendix

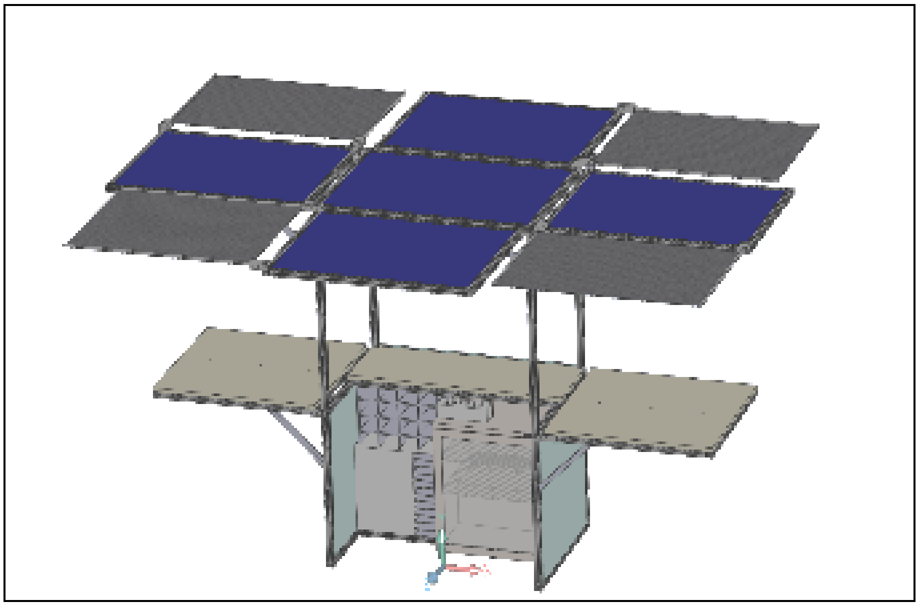


Figure 1: Final Design

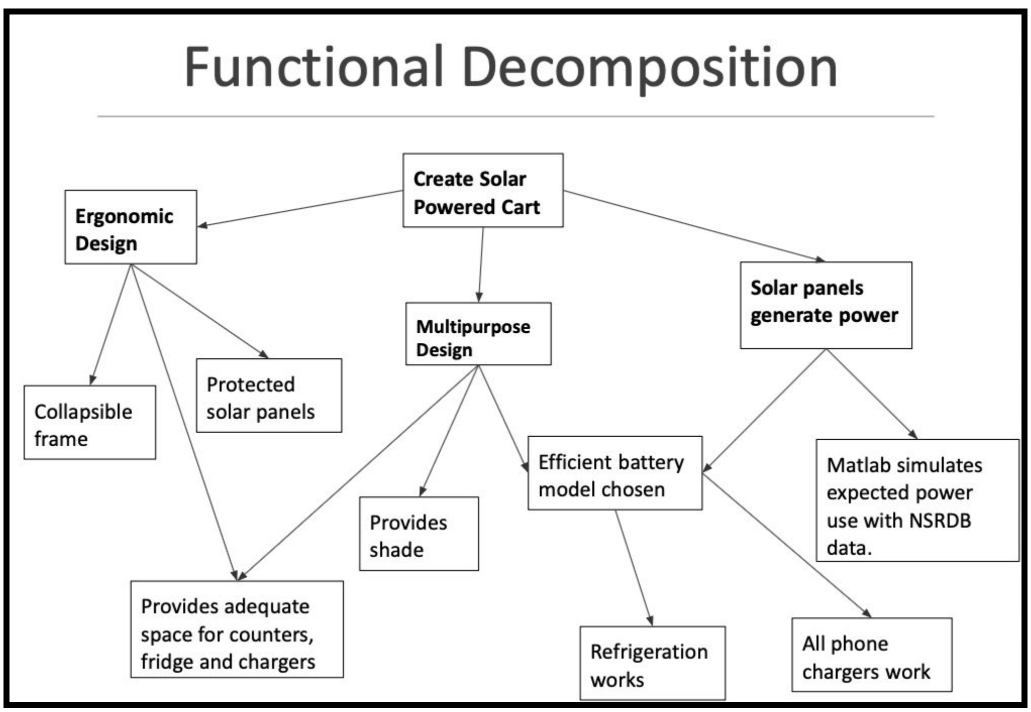


Figure 2: Functional Decomposition

Table 1: Power consumption and generation.

Item	Rating (W)	Total Power (Generated/Consumed)
Solar panel (5)	783 W	783 W
Mini Fridge	60 W	-60 W
Fast charging ports (11)	324 W	-324 W
Total		399 W

Table 2: House of Quality

	1: low, 5: high Customer importance rating	Desired direction of improvement (↑,0,↓) Functional Requirements (How) → Customer Requirements - (What) ↓	Generating enough Energy to Power Fridge	Generating enough Energy to Power Chargers	Collapsable	Towable	Storing Energy Produced	Weighted Score	Competitive evaluation (1: low, 5: high) Satisfaction rating	Competitor rating 1	Competitor rating 2	Competitor rating 3
1	5	Solar Powered	9	3	0	0	9	105		2		
2	4	Ergonomic	3	3	9	9	2	104		4		
3	5	Refrigeration	9	1	2	2	5	95		3		
4	1	Phone Charging	5	9	0	0	5	19		0		
5	3	Provides Shade	3	3	9	2	0	51		0		
6								0				
7								0				
8								0				
9								0				
		Technical importance score	116	50	73	52	83	374				
		Importance %	31%	13%	20%	14%	22%	100%				
		Priorities rank	**1**	**5**	**3**	**4**	**2**					
		Current performance										
		Target										
		Benchmark										
		Difficulty	3	2	4	2	3	1: very easy, 5: very difficult				
		Cost and time	5	4	4	2	3	1: low, 5: high				
		Priority to improve										

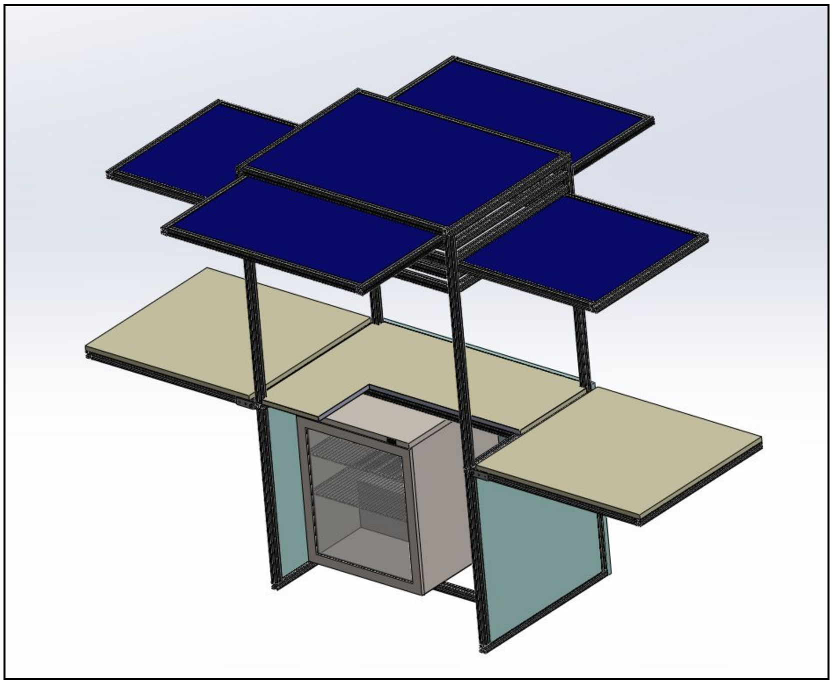


Figure 3: One design consideration for solar panel inclusion.

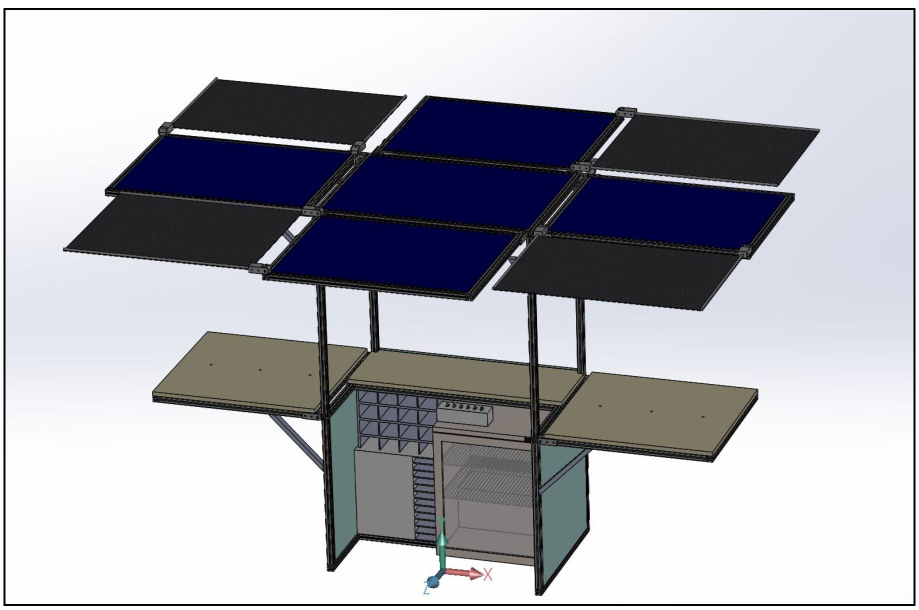


Figure 4: Current design concept.

Battery Size:	500 Wh		1000 Wh		2000 Wh		3000 Wh	
Location	Days Failed	Percent	Days Failed	Percent	Days Failed	Percent	Days Failed	Percent
Albuquerque_NM	134	0.367123	51	0.139726	13	0.035616	4	0.010959
Austin_Texas	211	0.578082	132	0.361644	72	0.19726	34	0.093151
Boston_MA	247	0.676712	195	0.534247	117	0.320548	28	0.076712
LosAngeles_California	173	0.473973	98	0.268493	39	0.106849	3	0.008219
Miami_Florida	137	0.375342	43	0.117808	7	0.019178	0	0
NewYorkCity_NY	241	0.660274	187	0.512329	121	0.331507	16	0.043836
PoncaCity_Oklahoma	203	0.556164	132	0.361644	58	0.158904	21	0.057534
SaltLakeCity_Utah	176	0.482192	133	0.364384	71	0.194521	13	0.035616
Seattle_Washington	235	0.643836	204	0.558904	154	0.421918	63	0.172603

Figure 5: Failures per year for different locations and battery sizes.

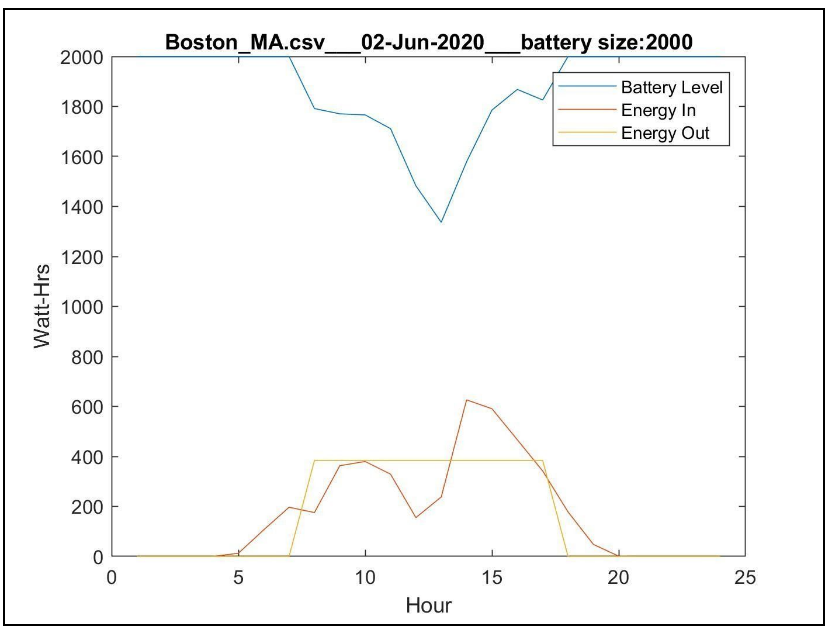


Figure 6: Battery Level, Energy in, Energy out versus hrs throughout a day in Boston.

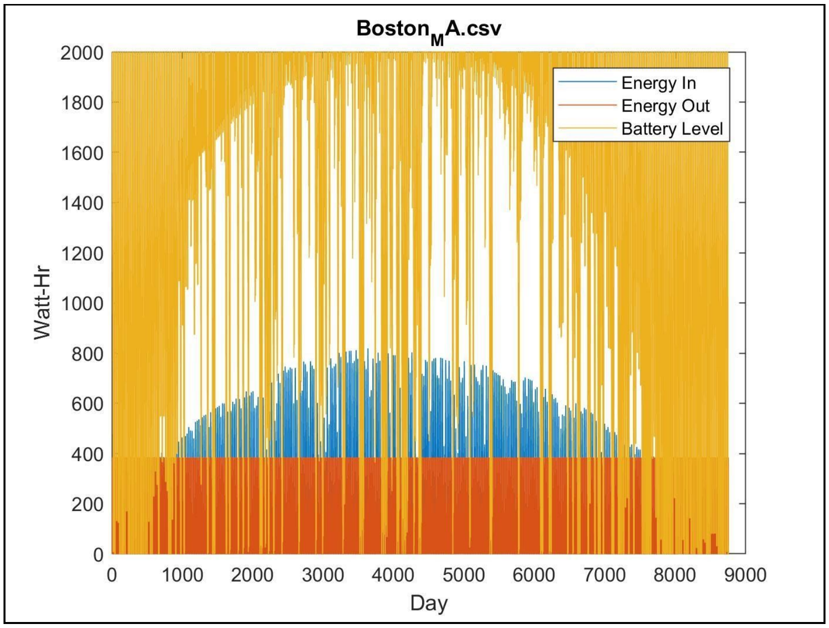


Figure 7: Energy in, Energy out and battery level throughout a year in Boston.

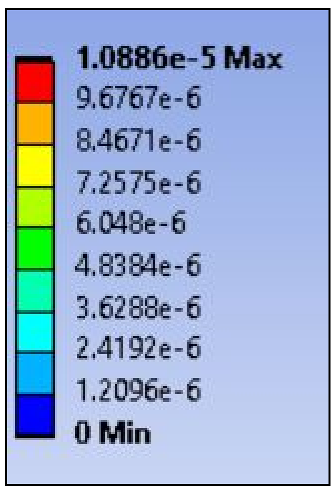


Figure 8: Maximum deformation value in the hinge in ANSYS.

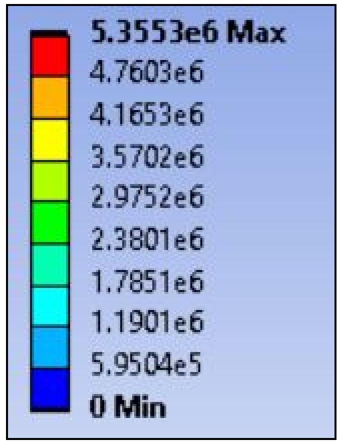


Figure 9: Maximum stress value in the hinge in ANSYS.

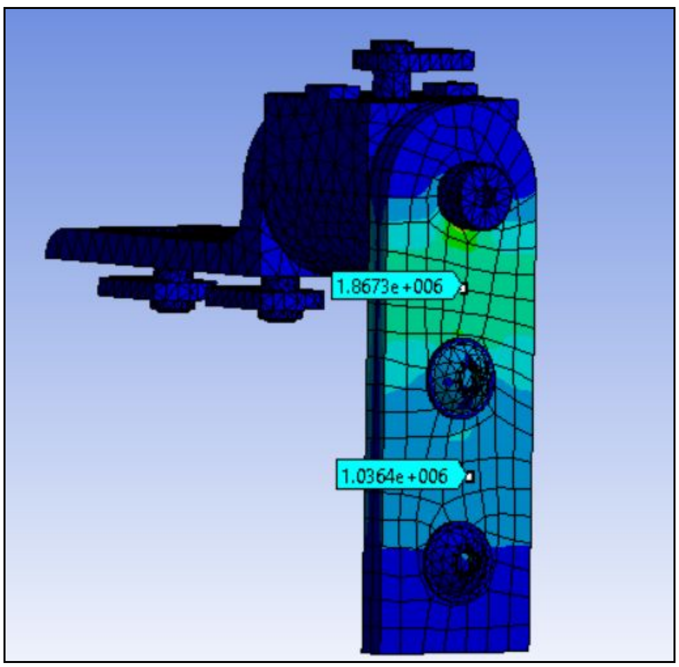


Figure 10: Stress distribution in the Hinge. Highest stress values are along the edges of the bolt holes hidden from view.

Results	
Load Multiplier	1397.6

Figure 11: Load multiplier found in ANSYS with eigenvalue buckling analysis.

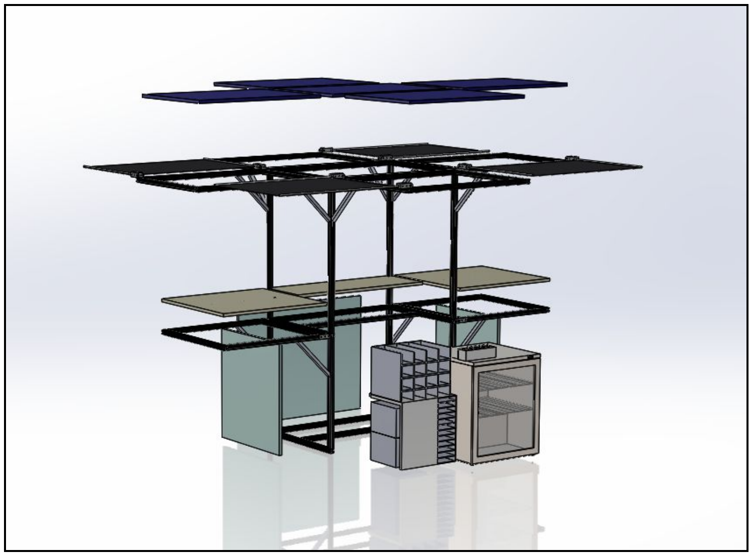


Figure 12: Exploded view of the final design

A.) Prototype Bill of Materials

For the Smaller Model to be used in the Senior Design Competition. Unused due to COVID-19 Outbreak.

Scale Model			
Item	**Cost Per Unit**	**Quantity**	**Total Cost ($)**
Wood (506 in^2)	$9	1	$9.48
1/4" screws	$4.77	1	$4.77
Brackets	$0.68	20	$13.60
9" T Frame	$3.72	6	$22.32
18" T Frame	$7.42	2	$14.84
24" T Frame	$9.93	7	$69.51
Screws	$8.12	2	$16.24
Hinges	$1.98	16	$31.68
Wooden Rods	$10.54	1	$10.54
Nuts Plate	$8.12	2	$16.24
3D Printed Parts	$5	1	$5
Solar Panel Kit	34.99	1	34.99
Total before tax			$249.21
Total after tax			$266.65

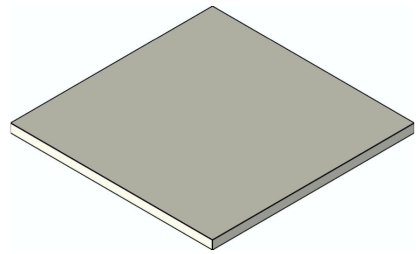
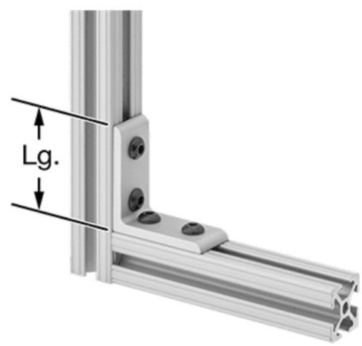
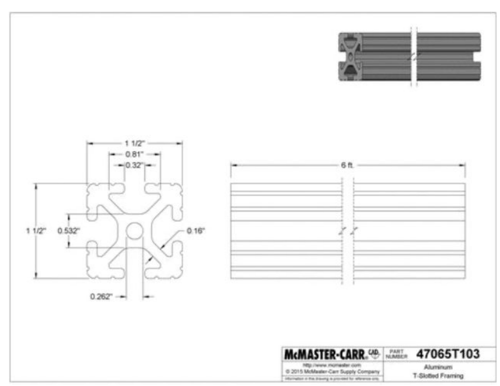
B.) Commercial Product Bill of Materials

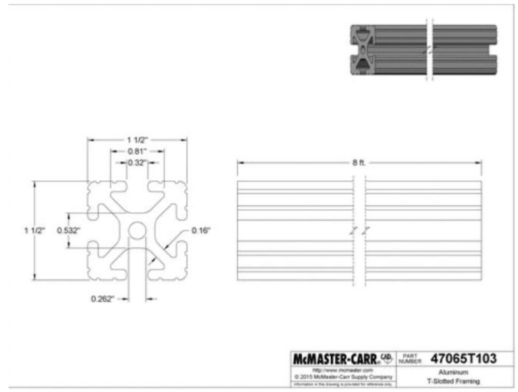
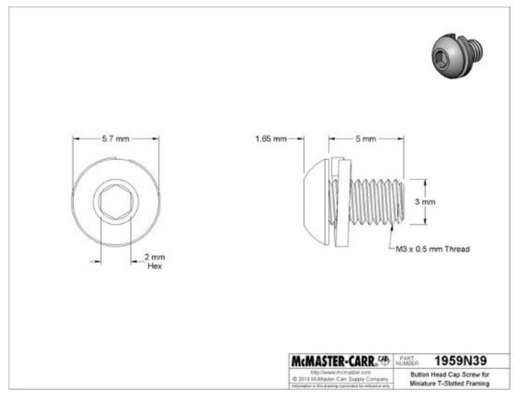
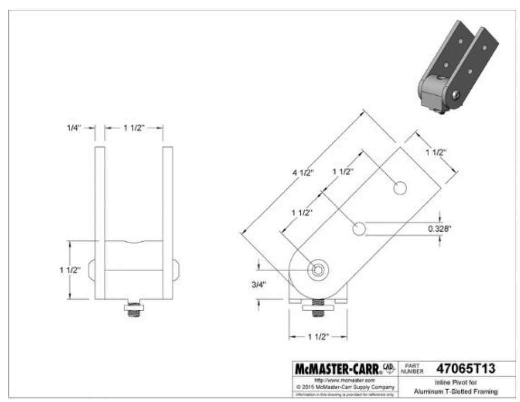
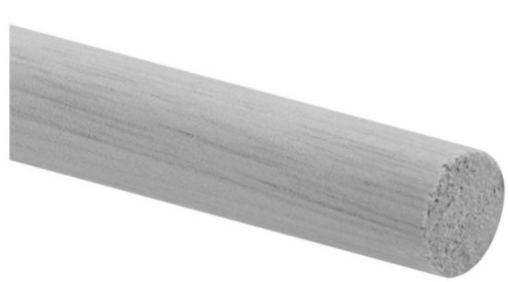
For a Large Scale Model for real life application.

Full Scale Model			
Item	**Cost Per Unit**	**Quantity**	**Total Cost ($)**
Wood (in^2)	$9	3	$9.48
1/4" screws	$4.77	1	$4.77
Brackets (corners)	$5.21	20	$104.20
8' T Frame	$55.18	7	$386.26
6' T Frame	$38.57	2	$77.14
Screws	$8.12	2	$16.24
Hinges	$18.43	16	$294.88
Wooden Rods	$10.54	2	$21.08
Single nuts and bolt	$2.38	8	$19.04
Double Nuts and bolt	$6.76	4	$27.04

Solar Panels	$79.99	5	$399.95
Refrigerator	$119.00	1	$119.00
120V inverter	131.11	1	131.11
4 Switch Bank	25.69	2	51.38
Chargers + Cables	13.99	4	55.96
2000 Whr Battery	699	1	699
Charge Controller	15.99	1	15.99
Total before tax			$2,432.52
Total after tax			$2,602.80

C.) Component Models

Part w/ Sourcing	**Image**
Lowes 1⁄4 CAT Utility OSB, Wood Board 4x8 in^2, with 1⁄4” Thickness **https://www.lowes.com/pd/Utility-1-4-CAT-Utility-OSB-Application-as-4-x-8/3602786**	
1⁄4” Phillips Flat Head Screw **https://www.mcmaster.com/92114a077**	
T-Slotted Framing, Single Four Slot Rail, Silver, 1.5” High x 1.5” Wide, Solid, Corner Bracket **https://www.mcmaster.com/t-slotted-framing/t-slotted-framing-structural-brackets/**	
T-Slotted Framing, Single Four Slot Rail, Silver, 1.5” High x 1.5” Wide, Solid, 6’ Model **https://www.mcmaster.com/47065T103**	

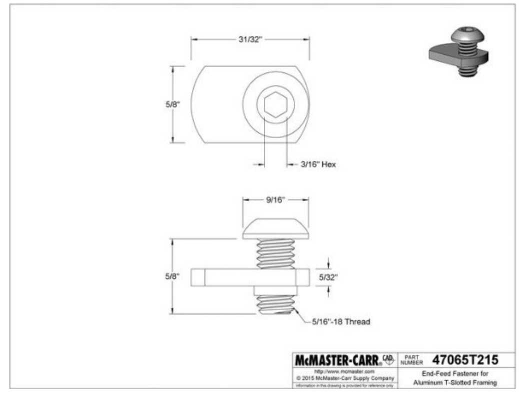
T-Slotted Framing, Single Four Slot Rail, Silver, 1.5” High x 1.5” Wide, Solid, 8’ Model **https://www.mcmaster.com/47065T103**	
Button Head Cap Screw for miniature T-Slotted Framing **https://www.mcmaster.com/1959n39**	
T-Slotted Framing, Inline Pivot for 1-1⁄2” Single Rail **https://www.mcmaster.com/47065T13**	
Birch Rod, 36” Long, 1⁄4” Diameter **https://www.mcmaster.com/9683k13**	

<table>
<tr>
<td>

T-Slotted Framing, End-Feed Single Nut with Button Head 5/16"-18 Thread

https://www.mcmaster.com/47065T215

</td>
<td>

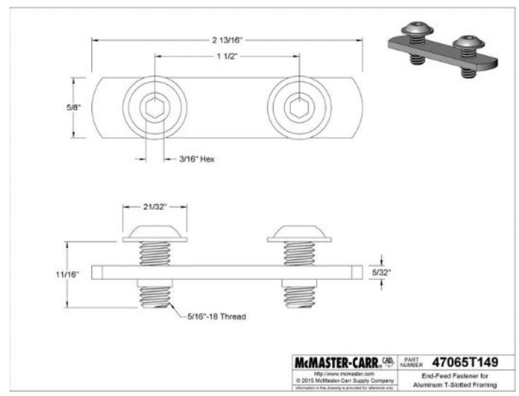


</td>
</tr>
<tr>
<td>

T-Slotted Framing, End-Feed Double Nut, Flanged-Button Head 5/16"-18 Thread

https://www.mcmaster.com/47065T149

</td>
<td>



</td>
</tr>
<tr>
<td>

Home Depot 100-Watt Polycrystalline Solar Panel for RV's, Boats and 12-Volt Systems

https://www.homedepot.com/p/Grape-Solar-100-Watt-Polycrystalline-Solar-Panel

</td>
<td>

</td>
</tr>
<tr>
<td>

Best Buy InsigniaTM - 2.6 Cu. Ft. Mini Fridge - Black

https://www.bestbuy.com/site/insignia-2-6-cu-ft-mini-fridge-black

</td>
<td>

</td>
</tr>
</table>

12V DC to 120V AC Transformer, with 3 Outlets, 700W and 5.8A Outputs https://www.mcmaster.com/6987k29	
Global Industrial Buyers Black 4-Switch Panel 3-On/Off, 1-Momentary-6391204 https://www.gl...oCIQoQAvD_BwE	
iPhone Charger YOKERSU Nylon Braided Lightning Cable Fast Charging 2Pack 6FT Data Sync Transfer Cord with Port Plug Wall Charger(ETL Listed) https://www.amazon.com/YOKERSU-Charging-Lightning-Transfer-Compatible/	
TalentCell Rechargeable 12V 100Ah Lithium Iron Phosphate (LiFePO4) Deep Cycle Battery Pack, Over 2000 Cycles, Built in Cell Balance Board BMS Charger Module https://www.amazon.com/TalentCell-LF120A1-Rechargeable-153-6Wh-Phosphate/dp/B07VTL9KC3?th=1	

Binen 30A Solar Charge Controller, Solar Panel Charge Controller 12V 24V Dual USB Charge Regulator Intelligent, Adjustable Parameter Backlight LCD Display and Timer Setting ON/Off **https://www.amazon.com/Controller-Battery-Intelligent-Regulator-Adjustable/dp**	

D.) Simulation Code

```matlab
%% Main Code
clear all
close all
clc

%% Find Names
names = Finding_Names();
%% GUI Selecting locations
[selected,dates,batterysize] = GUI(names);
dates = datestr(dates);
%% Finding Data
data = Finding_Data(selected);
%% Fixing bad Data
%Some of the measured data has big chunks of days that meausurements
%weren't taken, this accounts for the function below counts how many of
%those days occured for each location.
numbad_days = BadData(data);
%% Analysis Full Year
%Creates a vector of hours for d days, x is hours
d = 365;
t = 24*d;
x = 1:1:t;
%At times of the day when power is on = 384, when off zero, this has it on
%from 8 AM to 5PM
on = [384;384;384;384;384;384;384;384;384;384];
offam = [0;0;0;0;0;0;0];
offpm = [0;0;0;0;0;0;0];
p = [offam;on;offpm];
power_out = p;
Area = 4.85;
%This loops repreats this cycle for every single day of the year, so
%power_out is just 0 0 0 0 0 0 0 384 384 384 384 384 384 384 384 384 384 0
%0 0 0 0 0 0 repeating
for q =1:1:(d-1)
    power_out = [power_out;p];
end
% This loop runs through the analysis for an entire year, e corresponds to
% the location, so if 3 locations are selected, this loop will loop 3
% times, each loop does an anaylsis of one location.
for e=1:1:length(selected)
    % initial variables, power in comes from the data imported by
    % Finding_data.m, multiplies the Wh by area to get the energy produced
    % from the solar panels for that hour.
    power_in(:,e) = (.174*Area).*data(1:t,e+1);
    j = 0;
    % battery full determines the max amount of energy stored, which is
    % determined by the input from the GUI. str2num just makes it a number
    % value instead of string.
    battery_full = str2num(batterysize);
    battery(1,e) = 0;
    %This loop runs through every hour of the year.
```

```
for i = 1:1:t
    % This if statement sets the battery level to full at 1 AM every
    % day
    if data(i,1) == 1
       battery(i,e) = battery_full;
    else
        % Sums the battery level by subtracting power out from the
        % previous battery level and adding the new energy produced.
        battery(i,e) = battery(i-1,e) - power_out(i) + power_in(i,e);
    end
    % This if statement sets the battery level equal to the max level
    % if it is ever over it (excess energy), the else if sets the
    % battery level = to 0 if it ever goes negative.
    if battery(i,e)>battery_full
        battery(i,e) = battery_full;
    elseif battery(i,e)<0
        battery(i,e) = 0;
    end
end
count = 0;
j = 0;
d = 0;
% This loop goes through all the hours of the year again and determines
% at which hours the batteyr failed or not.
for i=1:1:t
    %This if statement makes it so it only checks for failure when the
    %cart is actualy being used so when the power out is not zero.
    if power_out(i)>0
        j = j+1;
        if battery(i,e)==0
            %if the battery level equals zero, it adds a 1 to count
            count(j,e) = 1;
        else
            %if the battery level is not zero it adds a 0 to count
            count(j,e) = 0;
        end
    end
    % this if statement checks if its the last hour of the day and then
    % checks to see if at any time of operation that day the battery
    % hit zero. This keeps track of how many days failed.
    if data(i,1) == 24
        d = d+1;
        % loops through the hours of day that the cart is operating
        for z = (j-9):1:j
            if count(z,e) == 0
                % if the hour did not fail daily equals 0
                daily(d,e) = 0;
            else
                % if an hour did fail daily equals 1 and the loop
                % breaks because that day failed so don't need to check
                % anymore hours.
```

```
                    daily(d,e) = 1;
                    break
                end
            end
        end
    end
    %Creates a figure for every location displaying battery level, power in
    %and power out.
    figure(e)
    plot(x,power_in(1:t,e))
    hold on
    plot(x,power_out)
    hold on
    plot(x,battery(1:t,e))
    title(selected(e))
    xlabel('Day')
    ylabel('Watt-Hr')
    legend('Energy In','Energy Out','Battery Level')
    hold off
    % writes to command window how many days failed for specific location.
    disp(selected(e))
    disp('failed this many days in a year:')
    days_failed(e) = sum(daily(:,e))-numbad_days(e+1);
    disp(days_failed(e))
end
%% Analysis Specific Day
% analyzes the day selected in the GUI if no day is selected then tf will
% equal 1 and the analysis won't happen.
tf = isempty(dates);
if tf == 0
    i = 0;
    % Creates a vector of strings contianimg the date for every single day of the year
    for m = 1:1:12
        % determines how many days are in each month
        if m == 1 || m == 3 || m == 5 || m == 7 || m == 8 || m == 10 || m == 12
            ms = 31;
        elseif m == 2
            ms = 28;
        else
            ms = 30;
        end
        %this loop creates a date for every day of the month.
        for d = 1:1:ms
            i = i+1;
            alldates(i) = (datetime(2020,m,d));
            strdates = datestr(alldates(i));
            % converts from weird char date format to strings so it can be
            % compared to input from gui
            datematch(i,1) = convertCharsToStrings(strdates);
        end
    end
```

```
    % below looks at every date in datematch and checks to see if it
    % matches with the dates variable which is a string of the date from
    % the GUI if the date matches it make a 1 in the corresponding location
    % of day, if not 0
    day = contains(datematch,dates);
    % looks to find where the 1 is in day array
    numday = find(day == 1);
    % finds the location of the data that corresponds to the day selected
    stop = numday*24;
    start = stop - 23;
    % below plots the data of the specfic day selected, it plots the
    % battery and power in vs the hour of the day. It does this for the
    % specific day at every location selected one loop is one location.
    for e = 1:1:length(selected)
    figure()
    plot(1:1:24,battery(start:stop,e))
    hold on
    plot(1:1:24,power_in(start:stop,e))
    hold on
    plot(1:1:24,power_out(start:stop,1))
    titleplot = strcat(selected(e),"___",dates,"___", "battery size:", batterysize);
    xlabel('Hour')
    ylabel('Watt-Hrs')
    title(titleplot)
    legend('Battery Level','Energy In','Energy Out')
    end
end
```

GUI CODE BELOW

```
%% GUI
function[selected,dates,batterysize] = GUI(names)
global selects;
global date;
global battery;
fig = uifigure('Position',[200 200 700 450]);

% Create text area
txt = uitextarea('Parent',fig,...
    'Position',[495 120 200 300]);
%create date selecter
d = uidatepicker('Parent',fig,'Position',[70 50 150 22],...
    'ValueChangedFcn', @updateEditField1);
% Create list box locations
lbox = uilistbox('Parent',fig,...
    'Position',[5 120 200 300],...
    'Items',names,...
    'Value',names(1),...
    'Multiselect','on',...
    'ValueChangedFcn', @updateEditField);
%battery size
lbox1 = uilistbox('Parent',fig,...
    'Position',[450 10 150 75],...
    'Items',["500" "1000" "2000" "3000"],...
    'Value',"500",...
    'ValueChangedFcn', @updateEditField2);
% Titles
text1 = sprintf('%s\n%s','LOCATION','Hold Ctrl to select multiple.');
label1 = uilabel('Parent',fig,'Text',text1,'Position',[50 410 200 50] );

text2 = sprintf('%s\n%s','Locations Selected');
label2 = uilabel('Parent',fig,'Text',text2,'Position',[550 400 200 50] );

text3 = sprintf('%s\n%s','Battery Size');
label3 = uilabel('Parent',fig,'Text',text3,'Position',[475 55 200 75] );

text4 = sprintf('%s\n%s','Date');
label4 = uilabel('Parent',fig,'Text',text4,'Position',[135 70 200 22] );

text5 = sprintf('%s\n%s\n%s','Directions:','1.) Select Locations, date, battery↙
size','2.) Close Gui Window');
label5 = uilabel('Parent',fig,'Text',text5,'Position',[250 200 250 50] );
% ValueChangedFcn callback
    function updateEditField1(src1,event1)
       date = src1.Value;
    end
    function updateEditField(src,event)
        txt.Value = src.Value;
        selects = src.Value;
    end
    function updateEditField2(src2,event2)
```

```
        battery = src2.Value;
    end
uiwait(fig)
selected = convertCharsToStrings(selects);
dates = convertCharsToStrings(date);
disp(dates);
batterysize = battery;
if isempty(batterysize)
    batterysize = "500";
end
end
```

DATA GATHERING CODE BELOW

```
function[bad_data] = BadData(data)
for e = 2:1:length(data(1,:))
    for i = 1:1:365
        stop = i*24;
        start = stop - 23;
        for j = start:1:stop
            if data(j,e) == 0
                c(j) = 1;
            else
                c(j) = 0;
            end
        end
        csum(i,e) = sum(c);
        clear c
        if csum(i,e) == 24
            bad_day(i,e) = 1;
        else
            bad_day(i,e) = 0;
        end
    end
    bad_data(e) = sum(bad_day(:,e));
end
end
```

```
function[file_name] = Finding_Names()
%Lists all the files in the folder SolarData
file = dir('SolarData');
j = 0;
%Loops through and gets all the names of the data files
for i = 3:1:(length(file))
    j = j+1;
    file_name{j} = file(i).name;
end
%Outputs the file names as strings
file_name = string(file_name);
```

```matlab
function[data] = Finding_Data(selected)
%% Finding Data
%This loop gets the data for all of the locations selected by the GUI
for i= 1:1:length(selected)
    %Creates a string for the file path of the selected locations
str{i} = strcat('SolarData/',selected{i});
end

% a and be are used to make the first column 1 to 24 repeated for every
% single day of the year, this represents the hours.
a = [1:1:24]';
b = [1:1:24]';
for q =1:1:364
b = [b;a];
end
data(:,1) = b;
%The loop grabs the correct column of data from the excel sheets and stores
%the data in the data variable.
o=0;
for j = 2:1:(length(selected)+1)
    o = o+1;
    % some locations don't have measure data, they only have modeled data
    % so the data is in different columns, this looks for a 1 in the title
    % of the excel sheet which means there is measured data and uses the
    % column with measured data, if there is no 1 it uses the column with
    % modeled data.
    if strfind(str{o},'_1')
        r1 = 1;
        r2 = 8760;
        c1 = 2;
        c2 = 27;
    else
        r1 = 1;
        r2 = 8760;
        c1 = 2;
        c2 = 15;
    end

    data(:,j) = csvread(str{o},r1,c2,[r1 c2 r2 c2]);
end
% below just gets rid of negative data, theres bad data someetimes this
% cleans it up
lengthv = length(data);
for j = 2:1:(length(selected)+1)
   for r = 1:1:lengthv
      if data(r,j) <0
          data(r,j) = 0;
      end
   end
end
end
```