"Designs That Keep Your Needs Covered"

Product Design Specification

Fall 2021

January 23, 2022

Contents

Meet the Team

We are the Good Umbrella, a team made up of seven undergraduate Mechanical Engineering students. The following report is a summary of the work done by the students listed below in the Fall 2021 semester. Throughout the semester each member contributed to the research, design, testing, and manufacturing of our product. The summary for the work done throughout the report is listed below.

- **Nnenna Dara:** Project Deadlines and Financial Requirements
- **Elliot Hare:** Use of TRIZ Throughout Iterations
- **Ning Ting Ni:** Product Description Executive Summary, Warranties, Capital Investment Required, Future Timeline
- **Mofoluke Obiri:** Customer Requirements, Market Identification
- **Tyson Reed:** Legal Requirements
- **Austin Stasko:** Special Features, Mechanical Analysis
- **Yuki Oyama:** Engineering Characteristics of Concept, Embodiment of Our Solution, Environmental Targets

1 Product Description

1.1 The Good Umbrella

1.2 Sanitable

Our product is called the Sanitable, a portable self-sanitizing table cleaner. The purpose of Sanitable is to disinfect round dining tables in communal areas to help relieve the task from food service workers.

1.3 The Problem

Sanitable tackles the problem of maintaining clean and sanitized surfaces for social gatherings involving food consumption. In the new normal, people are starting to socialize and grab meals together again. With safety measures in mind, food service workers are given the additional duty of disinfecting and cleaning the tables after every use. This task can prove quite tedious. In most cases, there is no way to ensure nor indicate that the table is actually clean before the next group arrives.

1.4 Basic Functions of Sanitable

With a push of a button, the Sanitable includes those basic components and functions:

- a retractable arm that extends onto the table when the product is activated
- disinfectant spray built into the base of Sanitable; disinfectant solution will be sprayed out through multiple holes to make sure solution is evenly distributed on the table.
- rotation of the arm for a full 360° coverage of the table
- replaceable sponges at the bottom of the
- portability of the product
- ability to refill disinfectant solution

Our product is designed to prevent reduction of the functionality of the table. The retractable arm with the built-in spray ensures that there no additional protruding components of Sanitable when not in use. This maximizes the amount of table space for customers and adds onto the sleek look of Sanitable. The portability of our product allows food service employees to purchase one Sanitable for several tables.

1.5 Special Features of Sanitable

In addition to the core functions of our product, Sanitable has a few helpful features to further assist the table sanitation process. Sanitable comes equipped with a useful "Installation Mode," where the food service employee can set Sanitable and optimize it for the tables at his or her restaurant. The employee will place Sanitable in the desired location and pull the extendable arm to the edge of the table. Sanitable will remember the dimensions of the table so that it can more effectively clean the surface. There is a helpful infographic located on the side of the housing to inform both the employee how to activate installation mode and the customer how to initiate a regular cleaning.

1.6 Service Environment Conditions

Sanitable is intended for the disinfection of indoor food service tables, though it can also operate in residential units. The product is designed to disinfect various small dining tables made up of different materials such as wood, glass, plastic, etc. under a wide range of temperatures. However, it is only intended for solid tables, as the disinfectant solution would drip onto the floor otherwise. Additionally, Sanitable can also be customized to cover larger tables. The primary function for Sanitable is to disinfect surfaces and therefore should not be used to clean up large spills or piles of leftover food scraps.

1.7 Picture of highest level product refinement

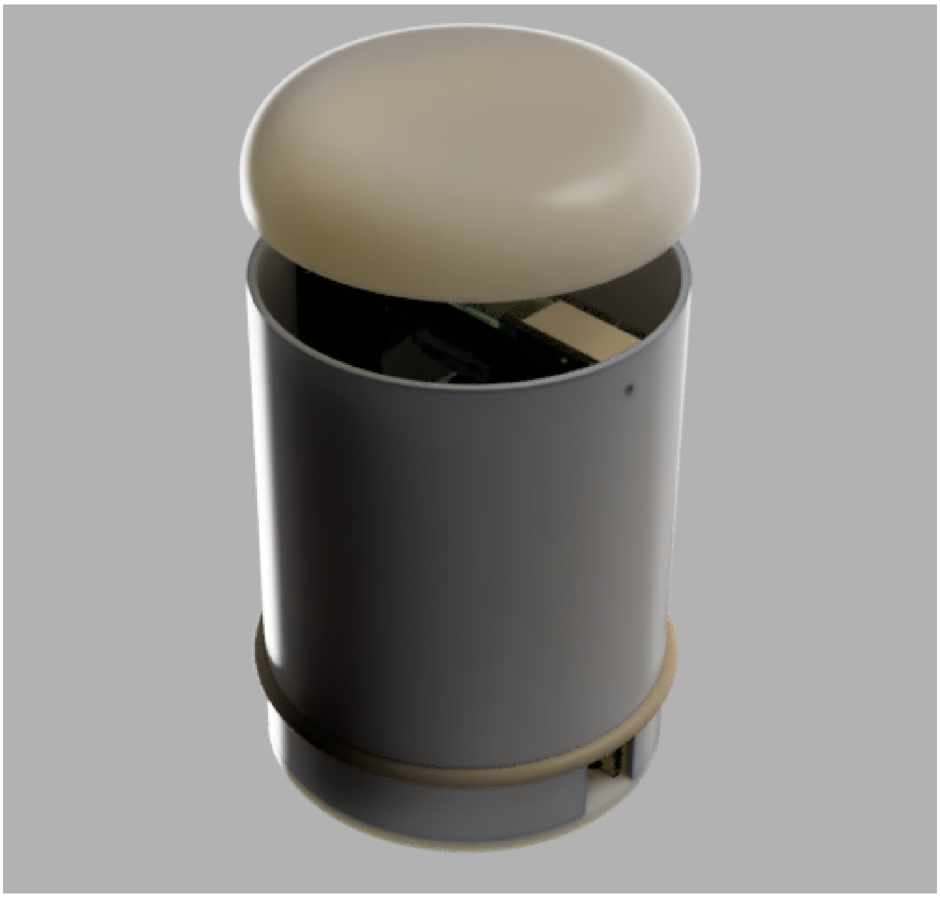

Figure 1.7.1: Highest Level Product Refinement

2 Physical Description

2.1 List of Requirements from Customer

2.1.1 Empathy Field Work

Our team conducted two rounds of field work in order to arrive at the final Sanitable design. In our first round of fieldwork, we focused on discovering the problems and needs of people from a wide demographic during the return from COVID. We immersed ourselves and observed our surroundings in unique environments and interviewed dozens of people to arrive at a total of 23 episodes to glean conclusions from. After unpacking each episode, we identified the needs of the users, insights we found, and anything we were surprised by. We then took each need, insight, and surprise and grouped them into five general categories. Within these categories, we further grouped each need, insight, and surprise into subcategories and projected our results into the donut of empathy fieldwork as shown in 2.1.1.1.

Across each category, one addressable problem that stood out to our team was a general fear of disease and uncleanliness that people have developed as a result of the pandemic. Specifically, from our fieldwork we observed the new norm of cleaning public tables after use and its attributed problems. We noticed that wiping down a table after use was often an inconvenience for both users and employees. Additionally, this issue was expressed in our interviews with multiple dining hall workers. Using our empathy field work, we decided to design and develop a device that would simplify this task.

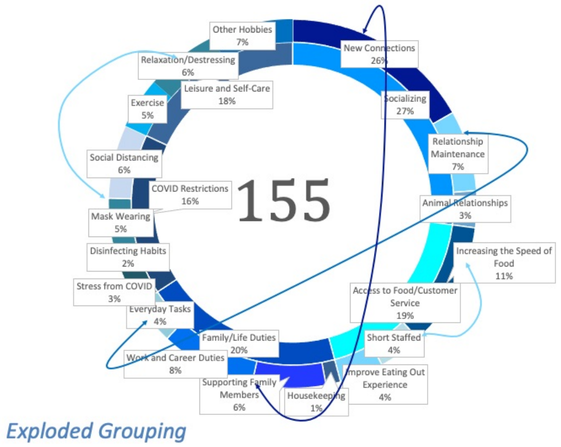

Figure 2.1.1.1: Donut of Empathy Fieldwork

2.1.2 Conjoint Analysis

To refine our product concept and determine the most important attributes of our product, we conducted a survey and shared it online using the Sawtooth software. Our conjoint analysis, shown in Figure 2.1.2.1, indicated that price is the most important attribute for our product. We found that people were most likely to purchase our product at $10 or $35. However, at a price of $75 there was a drastic decrease. The second most important attribute was the footprint size. Consistent with our testing results, it was important for the device to have a small surface area and not take up a lot of table space. Although price and footprint size were our most important attributes, we still incorporated the feedback of the other attributes in our future design. From the conjoint analysis, we focused on designing our product to be relatively inexpensive, small, easy to use, and fully automatic.

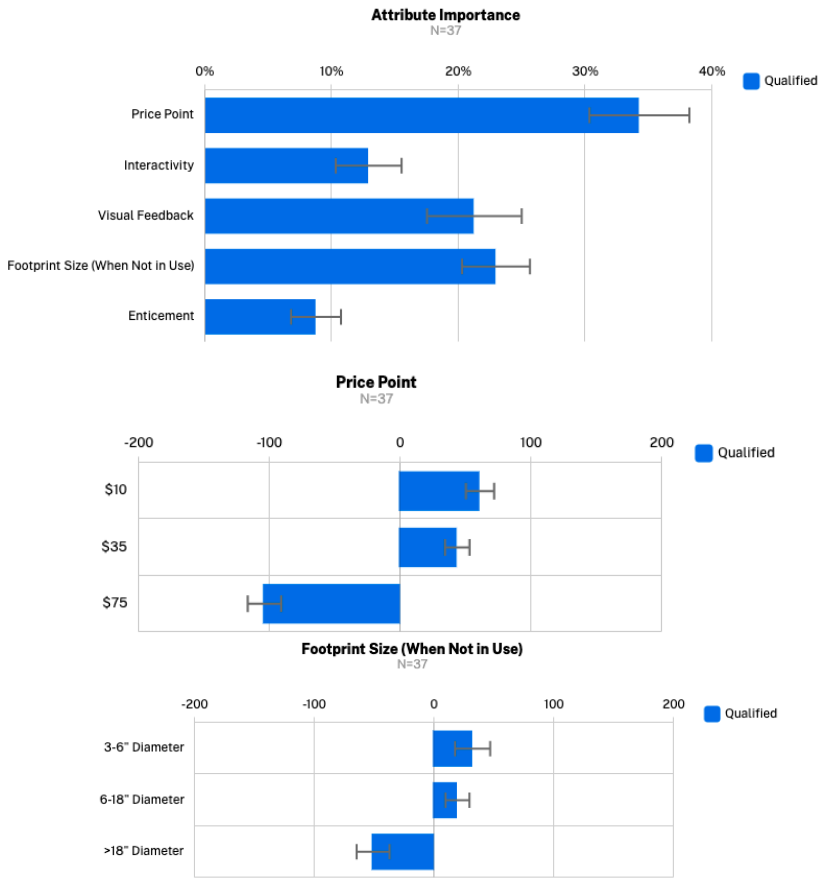

Figure 2.1.2.1: Conjoint Analysis and Attribute Utility Scores

2.1.3 Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) is a tool used across fields to organize and analyze complex data. We used the AHP to analyze five important categories identified through our empathy fieldwork categories and determine the importance of each category relative to each other.

As a team, we made pairwise comparisons and assigned them a rating from 1-9 scale as shown in Figure 2.1.3.1. A rating of 1 indicated that the categories are of equal importance while a rating of 9 would indicated that one categories demonstrated much more importance than the other. The category in each row was compared to another category in each column across the matrix and given a rating on this scale. If a category in a row was determined to have less importance than the category in the column, it was rating on an inverse scale from 1/3 - 1/9.

	Socializing/Connecting with People/Animals	Access to Food/Customer Service Field	Family/Life Duties	COVID Restrictions	Leisure/ Self Care
Socializing/Connecting with people/animals	1	5	0.33	5	5
Access to Food/Customer Service Field	0.2	1	0.33	0.2	0.33
Family/Life Duties	1	3	1	5	3
COVID Restrictions	0.2	3	0.2	1	0.33
Leisure/ Self Care	0.33	3	0.3	3	1
Sum	2.73	15	2.16	14.2	9.66

Figure 2.1.3.1: Analytical Hierarchy Process Matrix

In Figure 2.1.3.2, we normalized the AHP matrix and averaged the rows to get the criteria weight vector. Socializing/ Connecting with People/Animals had a weight of 34%, Access to Food/Customer Service had a weight of 6.8%, Family/Life Duties had a weight if 34%, COVID Restrictions had a weight of 9%, and Leisure and Self Care had a weight of 15%. From this matrix we were able to determined the category of Socializing/ Connecting with People/Animals to be our most important category.

	Socializing/Connecting with People/Animals	Access to Food/Customer Service Field	Family/Life Duties	COVID Restrictions	Leisure/ Self Care	Weights
Socializing/Connecting with People/Animals	0.3663003663	0.3333333333	0.1527777778	0.3521126761	0.5175983437	0.3444244994
Access to Food/Customer Service Field	0.07326007326	0.06666666667	0.1527777778	0.01408450704	0.03416149068	0.06819010309
Family/Life Duties	0.3663003663	0.2	0.462962963	0.3521126761	0.3105590062	0.3383870023
COVID Restrictions	0.07326007326	0.2	0.09259259259	0.07042253521	0.03416149068	0.09408733835
Leisure/Self Care	0.1208791209	0.2	0.1388888889	0.2112676056	0.1035196687	0.1549110568
Sum	1	1	1	1	1	1

Figure 2.1.3.2: Normalized Analytical Hierarchy Process Matrix

We then divided the whole matrix by our weighted averages to calculate the weighted sum vector which allowed us to determine the matrix consistency ratio in Figure

2.1.3.3. The consistency ratio measured how consistent our pairwise comparisons were across the matrix. A low ratio value below 0.1 indicates a high consistency. We used the AHP method to determine the importance of our categories from our empathy fieldwork.

weighted sum vector		consistency vector
2.042034702	0.04680291702	5.928831151
0.3186808302	0.07863550332	4.673417633
1.822551673	0.1246236974	5.385997869
0.4863405967	0.4453440005	5.169033424
0.8569195666	0.2716349418	5.531687564
	average consistency (l)	5.337793528
	consistency index (l-n)/(n-1)	0.08444838207
	consistency ratio, CR/RI	0.06755870566
		Consistent/Informed!

Figure 2.1.3.3: Analytical Hierarchy Process Consistent Matrix

2.2 Engineering Characteristics of Concept

2.2.1 What manufacturing and assembly methods did you use and why?

We decided to primarily rely on rapid prototyping to manufacture our design, since many of our unique design required custom parts. Within the realm of rapid prototyping, we chose to focus on using laser cutting to build out as much of our product function as possible because of speed and low cost. Our group wanted to avoid excessive 3D printing due to the time associated with printing large parts. The main mechanical challenge of building the final prototype was designing the chain storing and releasing mechanisms. We designed an acrylic ”maze” assembled via laser-cut parts. The contours of the maze needed to fit the turn radius of the chain wiper contained within it. A few pieces—the corners and some edges—within the maze were 3D printed as curved surfaces to ensure that the chain wiper would not catch when reeled back into the maze after deployment. The gear mechanism at the bottom of the prototype, which was used to rotate the wiper to sweep the table, was also laser-cut along with the motor gear that meshed into it. We decided to 3D print the spur gear that drove the chain in and out of the device because of its unique geometry (required to mesh with the chain). For the outer shell of the product, we chose to use 3D printing in order to achieve the ID we desired exactly (although we did not end up getting enough Rapid Prototyping Lab (RPL) time to fully print out our ID).

Our group also purchased off the shelf (OTS) parts where necessary. We acquired motors and motor hubs that clamped onto the motor axle. It was important to find these OTS motor hubs because designing an axle clamping mechanism out of 3D printed plastic would be unreliable and potentially too weak to handle the loads of operation. We also purchased an OTS chain and dimension-ed our CAD to accommodate the OTS chain. We decided to buy this part because it would be extremely time consuming to print a custom chain in the RPL. Finally, we bought a motor pump, tube, and water bottle in order to carry out the disinfectant deployment function.

2.2.2 House of Quality

The House of Quality matrix uses customer requirements in order to arrive at the most important engineering requirements. As shown in Figure 2.2.2.1, the most important engineering characteristic was adaptability to table size, followed by large cleaning area and profile/size. These requirements are what motivated the chain design, which allows wiper extension to any table size. The chain also can fit space efficiently within the ID of the cleaning robot, which maximizes cleaning area while minimizing product size. Our chain design also addresses other important engineering needs such as water resistance and time to service. Because the laser cut chain assembly serves as a watertight wall between the two halves of our enclosure design, our design places all the electronics on one half of the wall and the disinfectant container on the other half in order to ensure disinfectant doesn't spill into electrical components. And while we did not have the time to implement waterproofing from external spills, it would be a simple task to design a simple of gasket that prevents water and dust ingress. Our design is also easily serviceable— by simply screwing off the top of the enclosure, the disinfectant bottle can be refilled. Furthermore, the sponges attached to the chain can be easily replaced since they are adhered by Velcro.

		Spray Warning	Cleaning Area	Time to clean	Power consumed per clean	Material Rigidity	Water Resistance	Time to install	battery life	Time to service	Profile and size	Number of moving parts	Stationary	Adaptability to table size
Improvement Direction		↑	↓	↓	↓	↑	↑	↓	↑	↓	↓	↓		↑
Units		n/a	m^2	s	W	MPa	n/a	s	s	s	m^3	n/a	n/a	n/a
Customer Requirements	**Importance Weight Factor**													
Avoid getting sprayed	**4**	9												
Table clean	**5**		9	1							3			9
Table dry after	**4**		9	1							3			9
Don't get hurt	**5**					1	1					3		
Easy install	**2**							9			3		1	
Maintenance	**3**									9				
Low power	**2**	1	1		9				3			3	3	
Non-obtrusive	**3**										9		3	
Doesn't break easily	**3**					3	3	1				3	3	
Mostly automated	**3**													3
Water Resistant	**2**						9							
Raw Score		38	83	9	18	14	32	21	6	27	60	30	17	90
Relative Weight (%)		8.54	18.65	2.02	4.04	3.15	7.19	4.72	1.35	6.07	13.48	6.74	3.82	20.22
Rank Order		4	2	12	9	11	5	8	13	7	3	6	10	1

Figure 2.2.2.1: House of Quality Matrix

2.3 Use of TRIZ throughout iterations

2.3.1 Functional Decomposition

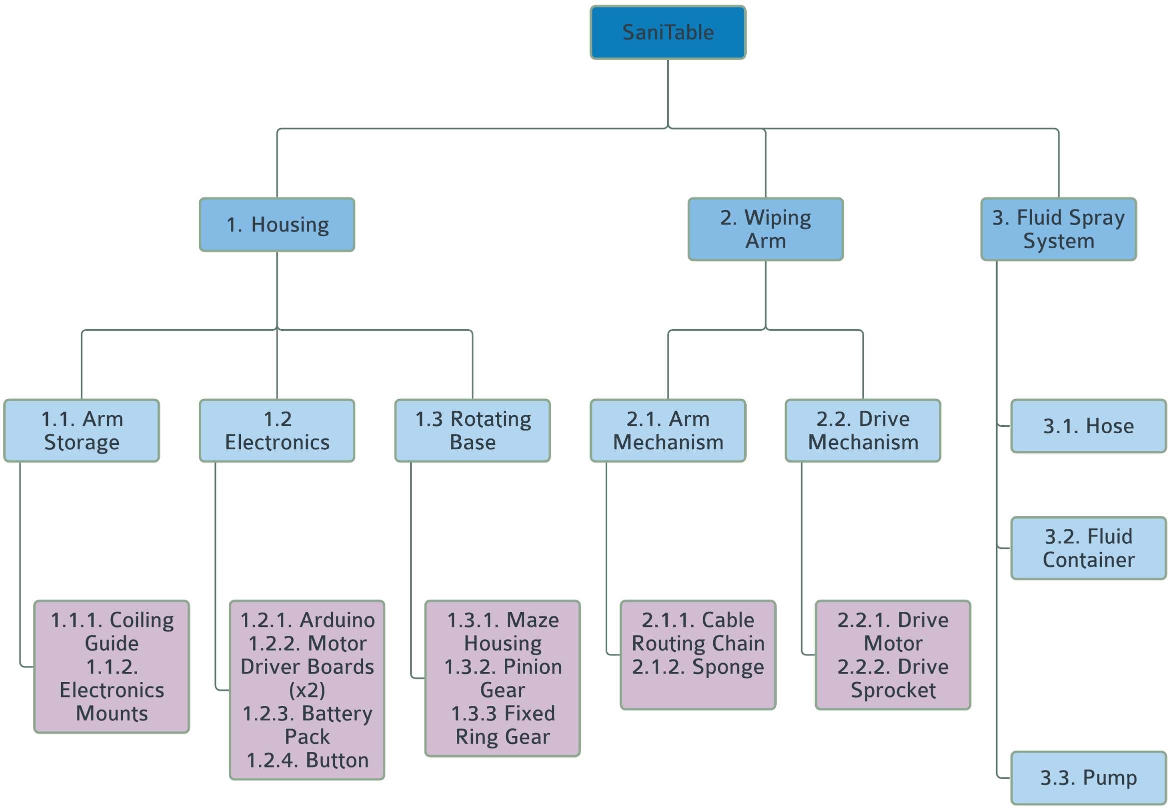

Figure 2.3.1.1: Functional Decomposition of SaniTable

2.3.2 Engineering Contradictions and Solutions

During the design process, the TRIZ contradiction matrix was used to identify and solve several areas of difficulty. The table below shows the contradicting features and the proposed principles which we took to solve the problem. The specific problem

Feature to Improve	Feature to Preserve	TRIZ Principle
Volume of Stationary Object	Length of Moving Object	14: Spheroidality
Device Complexity	Reliability	1: Segmentation

Figure 2.3.2.1: Table of TRIZ contradictions

in the first case is maximizing the length of reach that the wiping arm can cover, while minimizing the volume of the device while not in use. The concept of spheroidality was used in two ways. First, we chose to focus on round tables, allowing for rotary motion to cover the extents of the table from the center position. Secondly, we used a curvilinear path to coil the chain inside the housing of the device, compactly and neatly storing a large length of arm in a relativlely small volume. In the second example we wanted to reduce the complexity required to distribute fluid through the hose onto the table, while keeping it mechanically reliable. Initially we proposed to use the cavity inside the drag chain to carry the hose. We decided to segment the wiping arm and the hose into two seperate pieces, which reduced the complexity of the mechanism, without hindering the reliability of either the spray or wiping actions.

2.4 Embodiment of Our Solution

2.4.1 Static Renderings

Our product utilizes a symmetrical circular design to sweep out the radius of a circular table. The product is made up of a static component (base plate) and a dynamic component. The static base of the product is installed at the center of a table via VHB sticker pads on the bottom of the base plate. The base plate has a hole and its center which fits into an axle on the dynamic side, keeping the dynamic side centered. The base plate also has an internal gear feature, which interfaces with a small motorized gear, as shown in the "360 Degree Motion" section in Figure 2.4.1.1 below. The motor turning the small gear is mounted via a laser-cut assembly to the crux of the dynamic component of the assembly. This mechanical mechanism allows for the entire product to turn in a full 360 loop in order to fully clean a table. Furthermore, since the base plate has no electrical components on it in this design, there is no need for any sort of slip ring mechanism. The crux of the dynamic component is the acrylic wiper storage, held together by ABS printed spacers. This large rectangular piece sits along the diameter of the entire product, mounted via screws to the outer, cylindrical shell. The wiper storage was carefully designed both store and allow for the inward and outward movement of the chain wiper. The storage features lasercut and 3D printed walls that guide the chain through curves sized to match the turn radius of the chain. The chain itself is made up of small individual links. Each link has a velcro pad on it that attaches to another velcro pad with a sponge side. This allows the chain to effectively wipe the table, and it allows users to easily service the chain by simply replacing the velcro sponge pads when they get too dirty. Another motor, as shown under "Wiper Deployment" in Figure 2.4.1.1, is mounted via a laser cut hole pattern to this wiper storage block, and this motor is used to drive a custom spur gear designed to retract and protract the wiper from the product. This function can be understood more clearly by watching the dynamic rendering under section 2.4.2 below.

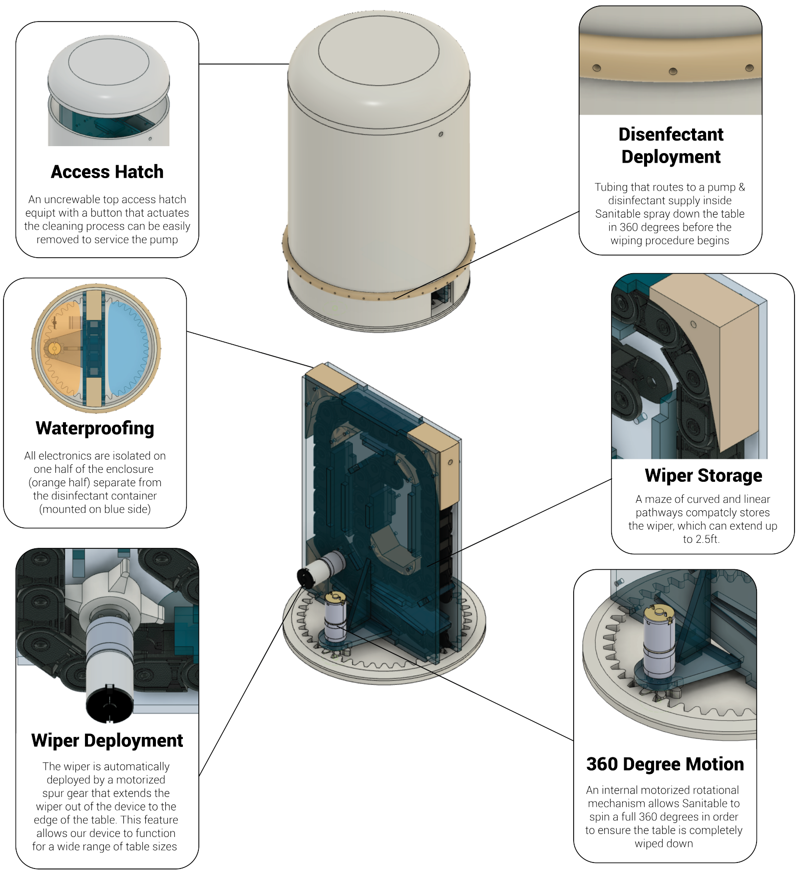

Figure 2.4.1.1: Static Render

Another large component of our solution is the disinfectant deployment. Originally we chose a cable carrier chain to pass a disinfectant tube through its center. However, this ultimately resulted in the added mechanical complexity of adding a tension-providing reel to ensure the tube didn't bunch up, and ultimately the group decided to simplify the design. Instead of passing the tube through the chain, we instead designed a groove on the outer shell of the product, around which we wrapped our tube (see "Disinfectant

Deployment" in Figure 2.4.1.1). This disinfectant tube connects to a pump within the product that pumps disinfectant from a container (also mounted within the product). The pump pushes disinfectant out small holes poked in the tube around the entire diameter of the loop, allowing for the disinfectant to spray radially as the wiping action occurs. Finally, there is a hatch at the top of the product which can be removed in order to refill the disinfectant bottle and or replace the chain sponge pads. All of these components are mounted on the dynamic component of the product.

2.4.2 Link to dynamic renderings

Linked here is a dynamic rendering demonstrating the sweeping action the robot will use in order to clean the table. The chain wiper is deployed out of the device by the custom spur gear and motor out of a small hole in the external profile. The device then sprays disinfectant (not shown in the animation) and spins 360 degrees in order to wipe the table. The wiper then retracts back into the device.

2.4.3 Pictures of physical prototype Iterations

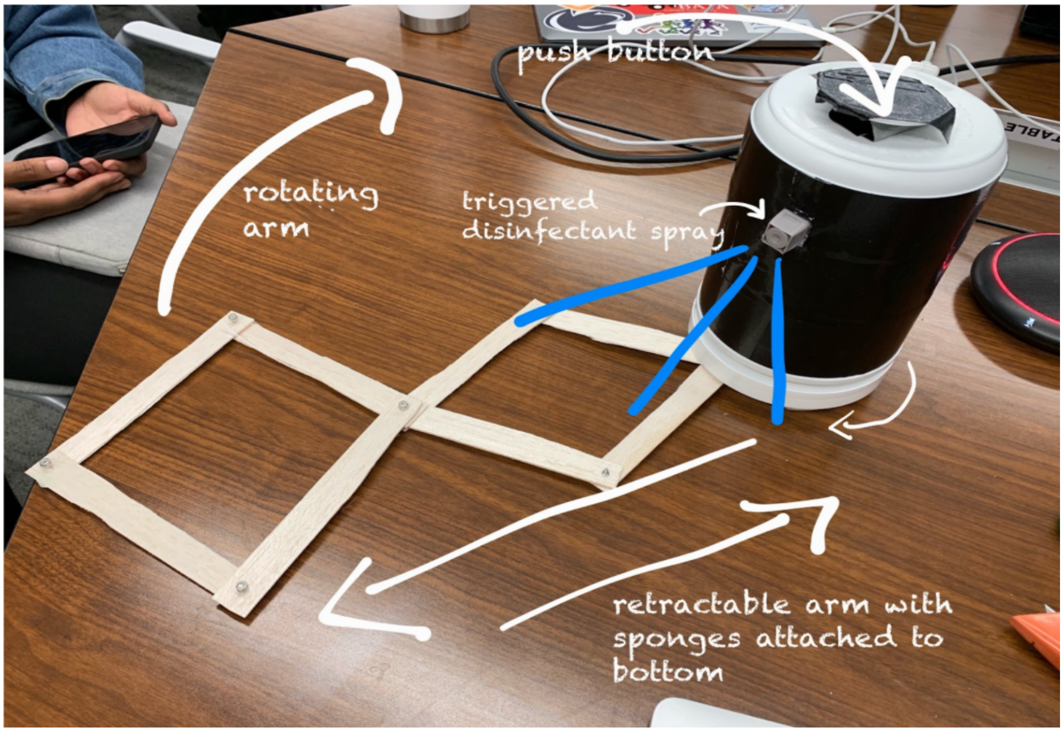

Figure 2.4.3.1: Iteration Version 1

In our first iteration, we imagined a retractable arm that took the form of the mechanism used in a fork lift in order to wipe the table surface. Our first iteration also has a small spraying head used to deploy disinfectant. The entire device would spin in a circle in order to clean the table, and the spinning was activated by a push button at the top. We used iteration 1 to conduct our second round of fieldwork to determine what users liked and disliked about our product. We found that users were afraid of getting sprayed by disinfectant, thought the arm was a bit bulky looking, and wished overall that the product took up less space.

2.4.4 Final Works Like Prototype

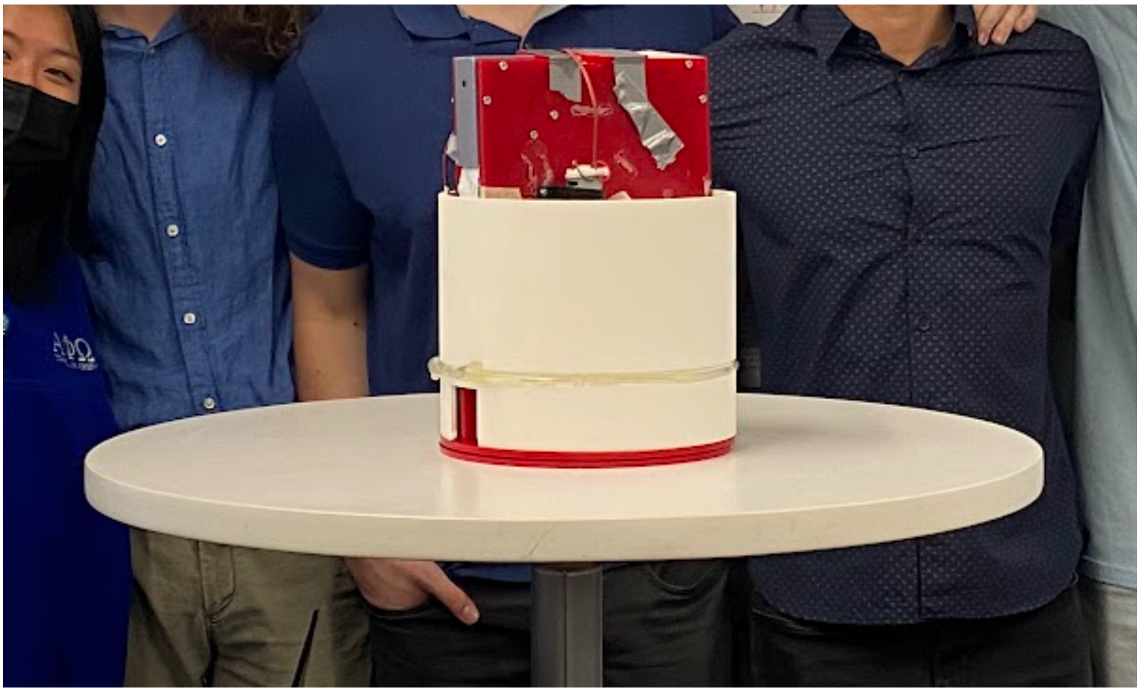

Figure 2.4.4.1: Final Works Like Prototype

In our final works like prototype, our group responded to the feedback from iteration version 1. Our works like prototype is a sized up version of what our product would actually look like. We increased our works like prototype size in order to ease difficulties in the assembly process. This prototype, explained in detail in section 2.4.1, addressed the concerns of our user testing with iteration 1. The chain was used in order to both decrease the profile of the overall device and provide a less bulky wiping arm. The disinfectant spray was originally intended to route through the chain so that users would not get sprayed, but this became too mechanically challenging to accomplish. Instead our group lowered the disinfectant spraying tube closer to the table surface to lower the odds that users would get sprayed (as long as their hands are above the plane of the tube they won't be sprayed).

2.4.5 Final Looks Like Prototype

Figure 2.4.5.1: Final Looks Like Prototype

The final looks like prototype is a significantly smaller version of the works-like prototype, and features a hatch button at the top which can be used to begin the cleaning motion. This prototype is what our team envisions the actual size of the product to be. The final looks like prototype also features a set of instructions that users can read if they are new to using Sanitable.

2.5 Mechanical Analysis

2.5.1 Analytical

During its use, the Sanitable does not really experience any intense loading. The only case where loads could be concerning is when a clean is initiated and there is still an item on the table. This is expected to happen throughout the product life cycle of the Sanitable, and a detailed analysis of the load case involved in this situation is presented in the next subsection of this report.

At the time of writing this product design summary, we still have not chosen a spray nozzle for the disinfectant spray function of Sanitable. To do this, we can perform an analytical flow rate calculation to determine the nozzle factor that we need for Sanitable's nozzles.

From our industry research, we found that the average disinfectant spray bottle sprays $0.85mL$ of disinfectant per spray, and the average table takes 4 sprays to be disinfected. This means that Sanitable must spray $3.4mL$ of disinfectant per spray. We would like this spray to last for a duration of $1s$. To calculate the flow rate of our nozzles, we can use the equation.

$$Q = V/(nT) = 0.85mL/s \tag{1}$$

Where Q is the volumetric flow rate per nozzle, n is the number of nozzles on the sanitable, and T is the duration of the spray. We can then use the nozzle factor equation to determine the nozzle factor that we need for Sanitable's nozzles.

$$K = P/\sqrt{Q} \tag{2}$$

Where K is the nozzle factor and P is the pressure differential present at the nozzle. According to the data sheet of our pump, it will supply a pressure of $36.75kPa$ at $9V$. Plugging this value into equation 3, we can caluclate the nozzle factor to be $K = 39.9kPa * s^{1/2}/mL^{1/2}$. Now that we know this value, we can select the correct nozzles for Sanitable.

2.5.2 Finite Element Analysis (FEA)

We found that the best application of FEA to our project was to perform a static structural analysis on a chain link to analyze how it would react to a side loading. This loading scenario could arise if the cleaning process is initiated while there are still objects on the table that could block the chain from making its sweep. This would result in Sanitable not being able to perform its sweep around the table, and the motor would put a torque on the base which would result in a side load on the chain. In this analysis, only a single chain link was analyzed. The load case is shown below.

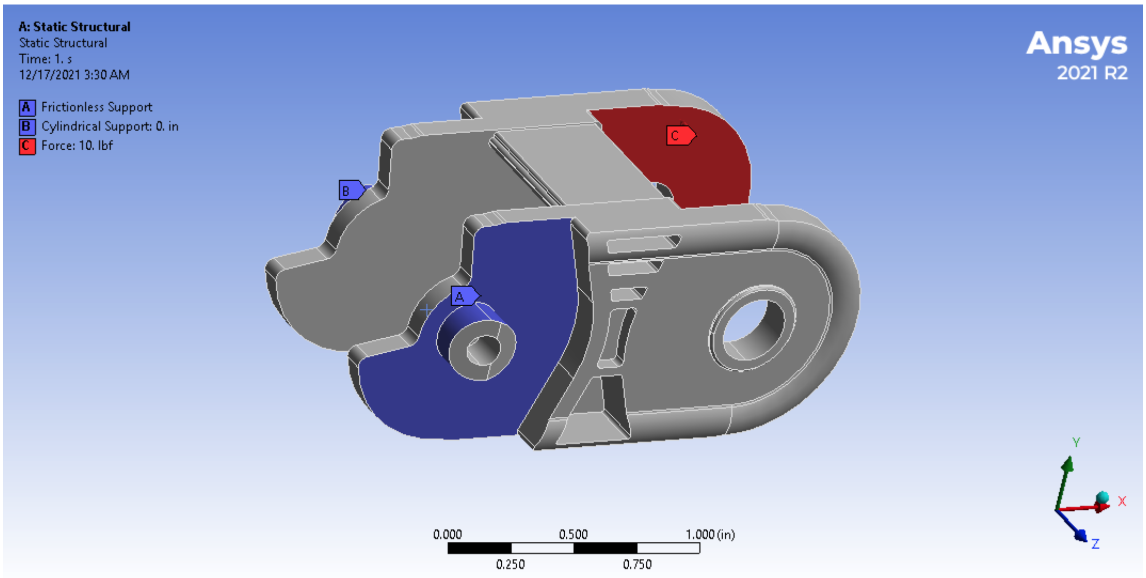

Figure 2.5.2.1: Chain Link Side Loading Setup

The magnitude of the load applied on the side face of the chain link is 10 lbf. This load value is an estimation of what a realistic load would look like under the loading scenario described above. The motors used to rotate the upper housing around the base are not that strong and the gear mesh between the driving pinion and the internal gear on the base is imperfect, so the maximum torque that the drive motor is low. We believe that the 10 lbf load is an overestimation of the actual load that the chain would typically see in use. The results are from the analysis are shown in the figures on the next page.

The maximum stress in the chain link from this analysis is 422.1 psi. We are unsure what type of plastic is used to make the chain, but yield strengths for plastics range from 2000-9000 psi. This puts our minimum factor of safety at 4.74 which is an acceptable value.

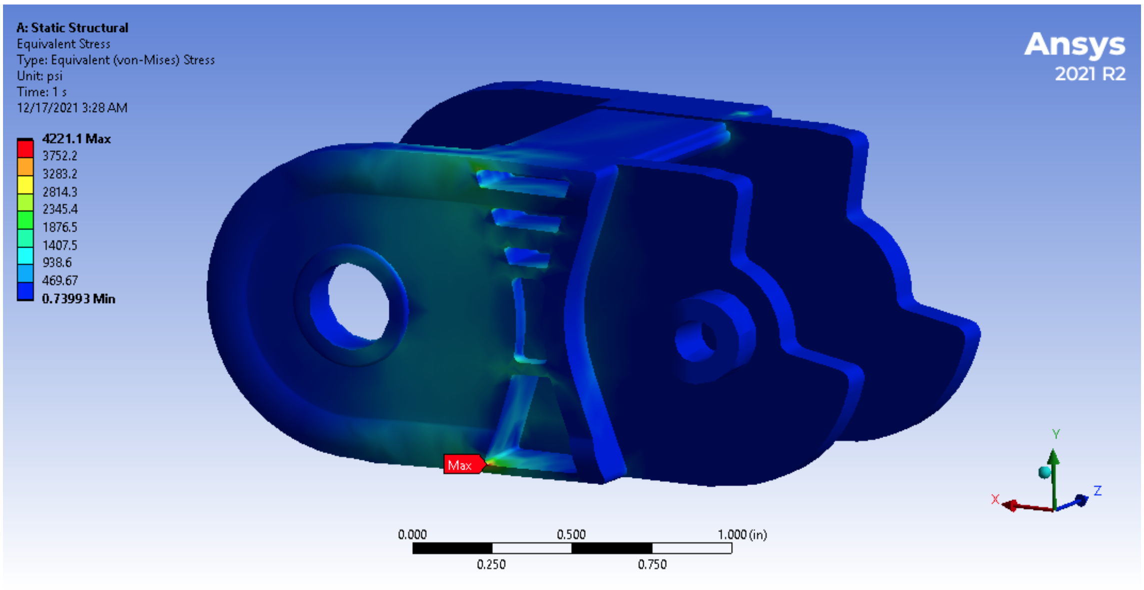

Figure 2.5.2.2: Chain Link Side Loading Equivalent Stress

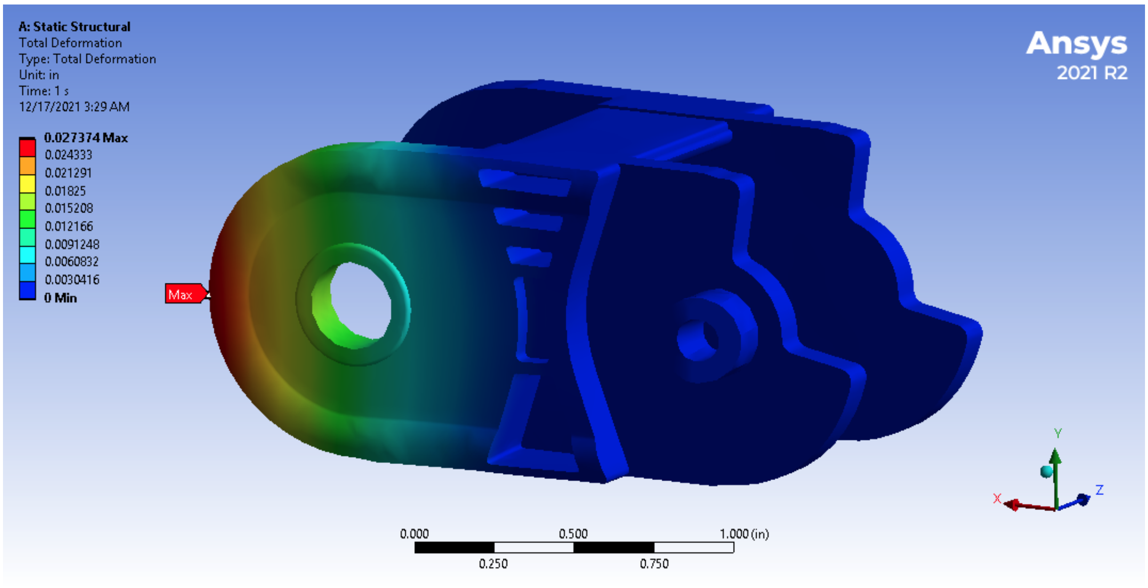

Figure 2.5.2.3: Chain Link Side Loading Total Deformation

The maximum deformation in the chain link calculated from the analysis was determined to be 0.0274 in. This value is fairly small (i.e. it is much smaller than the manufactured gap between chain links), so deformation is not worrying at all. It was determined that FEA was not applicable to any of the other loading scenarios of the Sanitable.

2.6 Project Deadlines

2.6.1 Gantt Chart

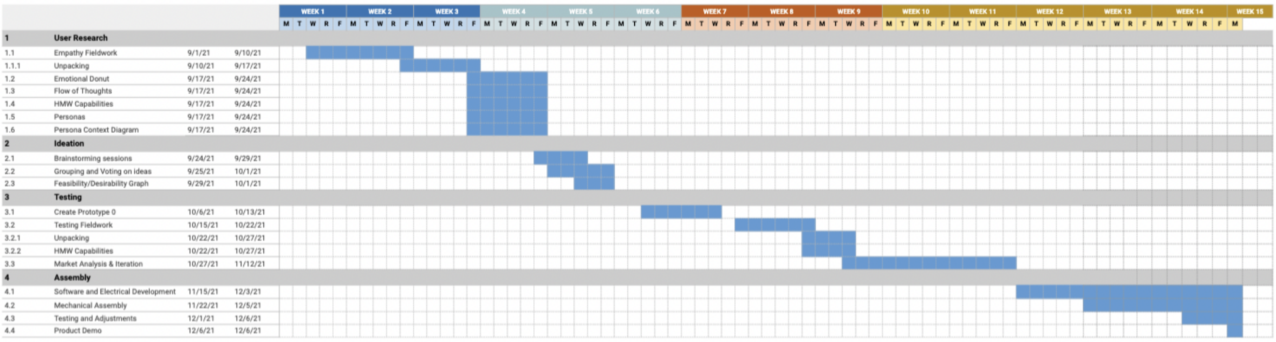

Figure 2.6.1.1: Gantt Chart

2.6.2 Gate Review Dates

Review Dates	Gate Review 1	10/4/21
	Gate Review 2	11/8/21

2.6.3 Total Completion Timeline

User Research		
Empathy Fieldwork	9/1/21	9/10/21
Unpacking	9/10/21	9/17/21
Emotional Donut	9/17/21	9/24/21
Flow of Thoughts	9/17/21	9/24/21
HMW Capabilities	9/17/21	9/24/21
Personas	9/17/21	9/24/21
Persona Context Diagram	9/17/21	9/24/21
Ideation		
Brainstorming sessions	9/24/21	9/29/21
Grouping and Voting on ideas	9/25/21	10/1/21
Feasibility/Desirability Graph	9/29/21	10/1/21
Testing		
Create Prototype 0	10/6/21	10/13/21
Testing Fieldwork	10/15/21	10/22/21
Unpacking	10/22/21	10/27/21
HMW Capabilities	10/22/21	10/27/21
Market Analysis & Iteration	10/27/21	11/12/21
Assembly		
Software and Electrical Development	11/15/21	12/3/21
Mechanical Assembly	11/22/21	12/5/21
Testing and Adjustments	12/1/21	12/6/21
Product Demo	12/6/21	12/6/21

3 Market Identification

3.1 Target Market

We envision the Sanitable to be a business to business product. Our target market includes schools, business cafeterias/break rooms, and cafes. The identified need for a device to sanitize tables came from interviewing and observing workers at Cornell Dining Halls during our empathy fieldwork. We determined that there was a need to have a clean table in areas where a number of people use the same table throughout the day. Currently, our product is designed to clean circular tables. In our market research, we found that educational institutions have a large percentage of circular tables. Circular tables are also commonly found in school, work, and hospital cafeterias. We also found that cafes and coffee shops tended to have more circular tables than restaurants. In future prototypes we plan to incorporate a switch that allows the device to work for both square and circle tables. However, we are initially marketing our device to as an automated sanitizer for circular tables. Cleaning a circular table poses an increased difficulty in ensuring the center gets clean. Our product can easily reach these areas without taking up usable table space.

3.1.1 Market Size

In our initial launch, we plan to limit our market to the United States. As we are planning to sell our product from business to business, our market includes schools, colleges, restaurants, libraries, hospitals, and workplaces. In the United States, there are 130,930 K-12 schools and nearly 6,000 colleges and universities. Initially we will only focus on markets that tend to have circular tables, so we will include cafes and coffee shops and temporarily exclude full service restaurants. The United States has approximately, 63,630 cafes, 7,247 hospitals, 116,867 libraries, and 5.9 million commercial buildings [2]. Assuming each entity buys one Sanitable, which generally won't be the case, our total market size is approximately 6.3 million entities. While this market may seem small, as a business to business product, we expect to sell multiple Santitables to each business depending on their number of tables. In future iterations, our product will also have the capability to clean square tables which grows the market even further. In a more in depth Market Size analysis, the number of tables at each business/institution could be determined to get a better estimate on the market size.

3.2 Consumer Behavior

3.2.1 Sociological research

The COVID-19 pandemic brought about a need to have clean surfaces in an intensity that did not previously exist. In places where food is served, the task of wiping down tables after each use is often placed on an employee. Other places task the user to wipe down the table after each use. Placing this task on the user often leads to tables not getting wiped down as many people simply forget to do it.

Overall, the pandemic has significantly changed cleaning habits. One survey found that 75% of respondents said they would feel more comfortable and confident that COVID-19 prevention measures were being enforced if they could see visible evidence of cleaning happening [3]. Seeing a surface getting wiped down has become even more important to consumers. Another survey also found that costumers will spend twice as much at a restaurant with increased cleaning of touched surfaces [4]. As a direct result, businesses are looking to hire more cleaning staff which is an added expense. The use of robots to clean in retail locations has increased by 13.8% [5]. From a business standpoint, using a cleaning robot can lead to lower expenses.

3.2.2 Historical solutions to stated problem

In pre-pandemic life, sanitizing surfaces existed mostly in the food service industry. In most cases, workers would simply spray the table with disinfectant spray and then use a microfiber cloth to wipe down the table. In some cases workers carry around a medium size bucket full over soapy water to wet the cloth before wiping down the table. As the pandemic encouraged cleaning touched surfaces everywhere, many other businesses began sanitizing surfaces. The general solution to wiping down surfaces is leaving a roll of paper towel or disinfectant wipe and disinfectant spray on a table and hoping each user will wipe down the table after use. The Sanitable offers a novel solution to a problem that will only continue to grow.

3.3 House of Quality - Competitor Analysis

The House of Quality matrix uses customer requirements in order to arrive at the most important engineering requirements as mentioned earlier in section ??. We found that the top engineering characteristics were adaptability to table size, large cleaning area, and profile/size. After doing a competitor analysis based on the on the intellectual property area that we are pursuing, we found that there are other automated cleaning products in the market but there are not any that offer the same capabilities and functions as the Sanitable in terms of efficiency, ease of use, and size.

One competitor table cleaning product is the Desk/Wall Washing Tool made by Parish Maintenance Supply. This tool has a microfiber cloth that can be attached to a hand trowel or swivel tool. The Desk/Wall Washing Tool has a low cost but does not offer a significant improvement from the historical solution. Although it has a large profile size, users are still required to spray the table and manually wipe it down with this product. The Desk/Wall Washing Tool does not offer the same functionalities as the Sanitable.

Another competitor product is the Starfrit Handheld Table Vacuum Cleaner. This device is a handheld table vacuum cleaner used to remove crumbs and dirt from the table. Although it also has a low cost, the small profile size increases the time it takes to clean the table. Users need to manually move the vacuum cleaner across the table. This device is designed to clean tables while the Sanitable is designed to sanitize tables.

The Unger Desk and Table Cleaning Kit features an ergonomic 16" microfiber cloth with a handle. It also comes with a roll-able dual-compartment bucket that separates the dirty and clean water to ensuring the use of clean solution every time cloth is wet. Unger claims their product makes cleaning tables four times faster. Despite shortening time spent cleaning, this product is still manual and requires users to move it across the table. Additionally, the bucket with the solution is an additional component that users will need to push around to each table to clean. In addition to the other two products, the Desk and Table Cleaning Kit scores poorly against the costumer requirements criteria for automation. The Sanitable's competitive advantage lies in this requirement as shown in Figure 3.3.2.

(a) Parish Desk/Wall Washing Tool

(b) Starfrit Handheld Table Vacuum Cleaner

(c) Unger Desk and Table Cleaning Kit

Figure 3.3.1: Competitor Products

	Competitor Rankings 1-Poor, 3-OK, 5-Excellent			
	CR	Desk / Wall Washing Tool	Starfrit Handheld Table Vacuum Cleaner	Desk and Table Cleaning Kit
	Avoid getting sprayed	5	5	5
	Table clean	3	2	4
	Table dry after	2	5	1
	Don't get hurt	5	3	4
	Easy install	5	3	3
	Maintenance	4	2	4
	Low power	5	2	5
	Non-obtrusive	3	5	2
	Doesn't break easily	4	5	5
Competitive Advantage	**Mostly automated**	1	1	1
	Water Resistant	5	1	1

Figure 3.3.2: Costumer Assessment of Competing Products

4 Financial Requirements

4.1 Financial Executive Summary

For our Financial Executive Summary we are considering our price per unit, production costs and competitor prices. We are assuming a salary of around 80,000 dollars and a 4500 dollar rent. We are also assuming we will sell 1000 units in our first year. It will cost approximately 145.22 dollars to produce one unit.

Year	2021	2022	2023	2024
Sales	$150,000.00	$1,500,000.00	$7,500,000.00	$15,000,000.00
Gross Margin	$5,000.00	$50,000.00	$250,000.00	$500,000.00
Headcount	7	7	7	7

4.2 Pricing Policy

Our price will be 149.99 dollars per unit. This is obtained from comparing our product with the price of competitors and our cost of production. Most surface cleaning robots and automated devices retail roughly for 120-250 dollars. Our device is stationary unlike these competitors that make obstruct users of the table. Our price accounts for these differences.

4.3 Bass Model Forecasting to predict product demand

In order to predict product demand, we would like to focus on the target market in the United States of America. The Bass model below shows our predicted product demand. Our product is innovative because there is nothing on the market that does what it does in the same way that it does it. This makes our product new to consumers. Our imitation factor is also low because all the other products that accomplish the same task are still very different.

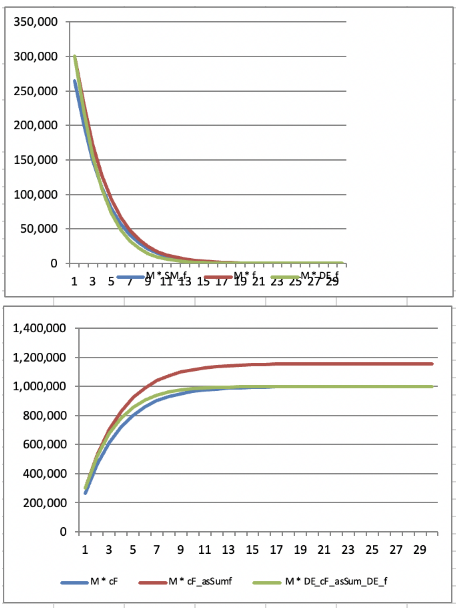

Figure 4.3.1: Bass Model

4.4 Production Costs

Component Item	Unit Price ($)	Quantity	Total Cost ($)
Chain	10.59	1	10.59
Screws ¾" long	0.16	5	0.80
Screws 1 ½ " long	0.16	10	1.60
Support pieces	6.50	12	42.00
Inner wall supports	17.50	2	35.00
Bottom Plate	12.75	1	12.75
Bottom Gear	0.50	1	0.50
Chain Gear	0.50	1	0.50
Corner Supports	1.50	4	6.00
Motor	16.99	2	33.98
Arduino	21.00	1	21.00
Motor mounts	2.50	1	1.50
Outside Housing	26.33	1	26.33
Sponge	6.98	2	13.98
		Total Cost:	145.22

Figure 4.4.1: Production Costs

4.4.1 What manufacturing process will you use?

We will be using injection molding to manufacture all of our internal and external parts including the inner wall supports, the support pieces in between them, the corner supports, the bottom plate, the motor mount, the gears and the housing. These parts will be outsources to a third-party company for injection molding using Acrylonitrile butadiene styrene (ABC) plastic.

4.4.2 Ashby charts

According to an Ashby Chart, our plastic of choice has an appropriate young's modulus for our use and manufacturing needs.

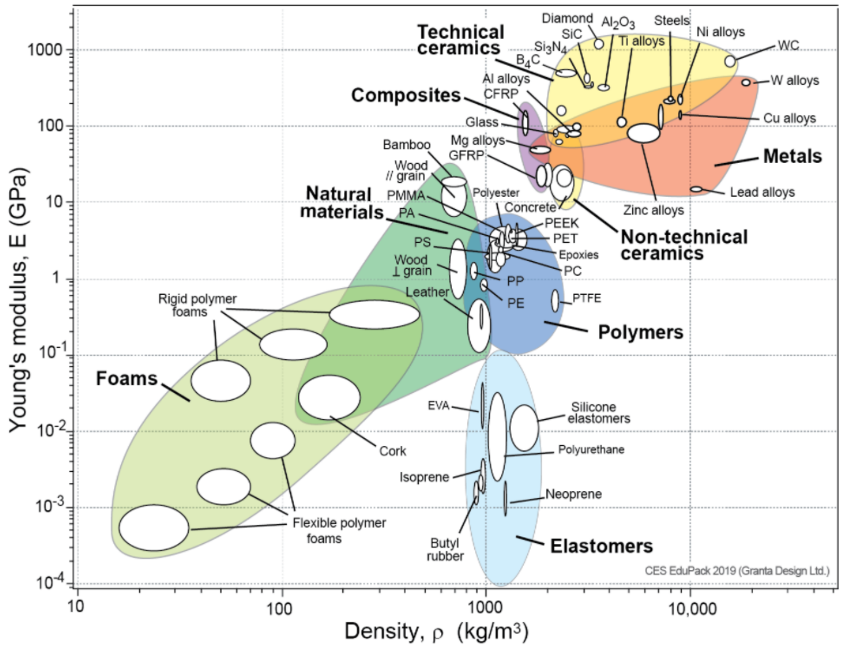

Figure 4.4.2.1: Ashby Chart

4.4.3 Tooling parameters and costs

In order to use injection molding as a manufacturing method, the molds are a form of tooling. Because we will be outsourcing this work instead of making it in house, we will not have direct control of those costs.

4.5 Cost of Goods Sold

Cost of goods sold is calculated by taking the value of current inventory, adding purchased items to it and then subtracting the value of the ending inventory from after the product has been made. We start with a current inventory of 0 dollars.

4.5.1 Materials, labor, off the shelf components

Once all of our materials have been made and/or purchased, labor will be involved in the assembly of these parts to make the complete product. Assuming each of our employees are paid about 80,000 dollars per year. The rent of our company location will be roughly 4500 dollars a month.

4.6 Warranties

Our warranty policy includes replacement of our arm within a year of purchase of Sanitable. Additionally, we will repair and replace any other component of the product that breaks during the lifetime of the product. These condition apply only under proper usage of our product. However, this warranty does not apply under the use of parts or services not provided nor sold by the Good Umbrella.

4.7 Capital Investment Required

In order to start up our production for Sanitable, we would need a capital investment of $1,000k for the first year. This cost will cover the salary of the workers, product development, marketing and promotion, manufacturing costs for the production of 1,000 Sanitables. With 7 workers, $560,000 would go to the salary. Additionally, we will dedicated $50,000 for marketing and launching of the product, which will include website development, advertisement, and sampling of the product. The production cost for 1,000 Santiables is estimated to be around $40k based the cost analysis. With miscellaneous charges, such as office rent, research and testing, etc., the total cost would be around $1 million USD.

5 Legal Requirements

5.1 Safety and Environmental Regulations

Safety: Our Sanitable meets the safety regulations set forth by the U.S. Department of Health and Human Services (DHHS), National Institute for Occupational Safety and Health (NIOSH) Workplace Safety and Health Topics.

Environmental: Our Sanitable meets the environmental regulations set forth by the U.S. Environmental Protection Agency.

5.2 Potential Liability Issues

Disclaimer: The following sections outlining the potential liability issues concerning the use of the product Sanitable are not to be interpreted as an admission of guilt from The Good Umbrella or any of its associates in the court of law.

There are several features of Sanitable which could cause damage to personal belongings or bodily harm if the product is misused or placed in circumstances not intended for the product.

If a user is to seat themselves at a table before Sanitable has finished its operating cycle, the user is at risk of getting disinfectant on their body. Contact with the disinfectant can potentially have harmful effects such as skin irritation, rashes, or injury to eyes. Any objects a user places on the table during the cleaning cycle run the risk of being damaged by the cleaning fluid and/or rotating arm. Therefore, it is important for the user to follow the instructions printed on the device to practice safe usage of Sanitable.

5.2.1 Prediction of Misuse Cases

We predict that the product Sanitable can be potentially misused by a user in the following cases:

- Attempting to manually pull out the cleaning arm (The user should only attempt to operate the device by pushing the button. If the arm does not extend when the button is pushed then the batteries must be replaced.)

Item Ref	Item Description	FM Ref	Failure Mode	Possible Causes	Effects	Detection Method	Severity Class 5 = Most Severe	Freq/Prob 5 = Most Probable	Recommended Action
1	Pump	1.1a	Low/high voltage	Input voltage is outside the spec range.	Pump no longer runs.	Visual/Hearing	5	1	Replace the pump
1.2	Tubing	1.2a	Blockage	Fluid compartment is contaminated with dust or debris or incorrect cleaning fluid is in use.	Pump flow rate is reduced or completely stopped	Visual	3	2	Check that fluid depart-ment is clean and using the correct cleaner.
		1.12b	Leakage	User causes an accidental puncture in the tubing inside the housing.	Excess cleaner is spilled on table. Potential damage to electronic components.	Visual	4	1	Replace tubing
2	Electronics board	2.1a	Connection Loss	User accidentally disconnects a wire while refilling the fluid comparment.	Effects may include: device no longer rotates, arm does not extend, pump does not run, circuit fries.	Visual and DMM	5	1	Replace device or take in for servicing.
3	Arm	3.1a	Blockage	Incorrect are used on the bottom of the arm.	Arm does not fully extend or retract.	Visual	5	2	Take in device for servicing.
		3.1b	Misalignment	Pockets of arm are not aligning with internal gear due to interference during previous operation.	Arm does not fully extend or retract.	Visual	4	3	Empty fluid compartment, then press button to start device and gently pull the arm outward some.
4	Base	4.1a	Misalignment	Gear teeth on base and motor are not interfacing properly due to tolerancing or interference.	The arm does not rotate.	Visual	5	2	Take in device for servicing.

Figure 5.2.2.1: FMEA

- Improper placement of Sanitable on the table during initial setup. The device should be seated directly in the center of a circular table in order for sweep to cover the entire table area.
- Improper calibration of arm length to table radius during initial setup. (During initial setup, the arm should be extended in one motion to the length of the table radius. If not set in one motion, the device must be reset.)
- Filling fluid compartment with a cleaner other than those approved by Sanitable.
- Replacing cleaning sponges with a different type. (Sanitable cleaning sponges are ensured to work properly.)
- Attempting to clean a large spill. (Sanitable is designed to be used only for liquid spills and disinfecting.)
- Occupying the table before Sanitable has finished its cleaning cycle. (Users should wait for the cleaning arm to fully retract into the compartment before occupying the table.)

5.2.2 Failure Mode and Effect Analysis

See Figure 5.2.2.1 above for a Failure Mode and Effect Analysis of the device Sanitable.

5.3 Intellectual Property Considerations?

The Good Umbrella would pursue a utility patent, Trademarks, and trade secrets in regards to company product Sanitable and company name The Good Umbrella.

5.3.1 Pursue Utility Patents

The Good Umbrella seeks to be the sole makers and sellers of the product Sanitable and for this reason would seek a utility patent on its functionality.

5.3.2 Trade secrets

The Good Umbrella seeks to keep the cleaning fluid used and the cleaning sponge type as trade secrets. We will do this by keeping knowledge of the fluid composition and cleaning sponge type reserved to our executive body and engineers assigned to those components. This the company can make money off of selling replacement sponges and cleaner fluid.

5.3.3 Trademark

The company name "The Good Umbrella" and the product name "Sanitable" will be trademarked so as to not be used without the company's express permission.We would also trademark each respective logo (seen on the cover page).

6 Environmental Targets

6.1 How will the products reduce environmental impact on production?

In order to manufacture this product on a large scale, we would transition from rapid prototyping manufacturing to injection molding for the majority of our product architecture. In order to meet sustainability goals and minimize environmental footprint of our product, a huge step is finding a sustainable injection vendor. If we are able to find an affordable U.S. injection molding vendor, we would prefer to source from them in order to cut out the environmentally harmful effects of overseas transportation. If we are not able to find a U.S. vendor, we will search for a vendor experienced with recycling plastics and or metals. Furthermore, we will look for a vendor experienced with maximizing part quality while minimizing energy consumption. Both of these factors are equally important for the sustainability of our product; higher part quality translates to longer mechanical product lifetime and low energy consumption minimizes use of fossil fuels in the molding process. A capable injection molding vendor operates molds under low melt temperature, low injection pressure, low holding time, low cooling time, and high mold temperature in order to achieve quality parts and low energy use [1]. Furthermore, such vendors know exactly what percentage of recycled material to use without significantly decreasing the strength of materials.

6.2 How will the products reduce environmental impact upon end of life?

Designing for end of life sustainability starts at the production and design phase. First, our group will further iterate the design, performing more in depth Finite Element Analysis and cyclical stress analysis to maximize the lifetime of the product. In addition, we plan to place a large emphasis on design for disassembly. This will include using thread forming holes as opposed to ultrasonically or thermally inserted inserts, using magnetic steel fasteners over nonmagnetic ones, and avoiding any paint/coating finishes. Moreover, welded components, nonmagnetic metals, and sticky finishes make separating a product into separate, recyclable materials extremely challenging, and can seriously hinder the recyclability of a product. We also plan to reduce the number of materials used in general, and avoiding unnecessary fasteners by using snap fits to reduce part count. Apart from design for disassembly, we plan to design our product with sustainable materials. While it is tempting to try to design a fully biodegradable product, we would have to evaluate the reduction in mechanical life resulting from the use of biodegradable materials. It is more likely that we would use a recyclable plastic like Polycarbonate or HDPE, which would allow for a more sustainable end of life.

7 Future timeline

Sanitable is a feasible idea that relieves duties of food service ideas. As a result, Sanitable has a lot of potential to be altered to fit the user's needs. For the future timeline, our product would've gone through major design changes and adjustments to become smaller, more dynamic, and overall more efficient.

7.1 Future Plans

Our mechanical designing and manufacturing process for Sanitable has been challenging but rewarding. We have encounter numerous issues and made adjustments to account for such issues. However, despite having ideas for future iterations of Sanitable, our team has decided the best plan for us is to call it a semester. Though we have made significant progress on the mechanical assembly of our product, our product would require major research and development in order before it is ready for the market. We hope that our prototype for Sanitable will give others further insight into the research and development of similar products.

Agreement of Submitted Document

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