Self-Shelving Dishwasher

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ABSTRACT

Home dishwasher technology has not significantly changed in almost a century. In a world of technology, this project set out to build a dishwasher that required even less labor for the end user. We set out to create a dishwasher that, by means of internal conveyors, never needed to be unloaded.

We started this process by researching existing models and types of dishwasher and the methods they both clean and dry dishes. We also researched different methods of conveyance in commercial dishwashers to see how they could be adapted. After our research and customer polls we concluded that our best design was a counter integrated horizontal configuration for our dishwasher-cabinet set up using belting to connect rollers from the dishwasher side to our cabinet side.

Once we began our construction, mounting, or more aptly ‘achieving static equlibrium’ became the core issue. Balancing the forces in the X Y and Z planes on every point within our dishwasher while also managing the very confined space was easier said than done and required multiple solid model revisions to finally get it right.

Once we had decided on where each component needed to be in order to fit the space requirements, we began trying to define where all of the support structures would go to keep those elements in place. We used PVC as our structure because we generally were working with small forces and it is cheap. Once our support structures were decided, we had to find a way to attach the motors to the rollers which we ended up welding.

Finally, once all of our components were decided upon, we began the long and grueling process of mounting every component where it needed to be and both building and installing all of the relevant support structures and unloading mechanisms.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

For our Senior Design Project, we hope to address the inefficiencies of the currently available residential dishwashers. In a world where more and more things are being automated, it seems like the modern dishwasher has not changed in half a century. We hope to make a dishwasher that ensure customers never have a cluttered sink or countertop again. We hope to accomplish this by designing and building a one-step dishwasher that never needs to be unloaded. The basic design will be one that takes loaded dishes, cleans them, and then filters them into a cabinet ready to be used again.

RESEARCH

BACKGROUND AND SCOPE OF THE PROBLEM

Countless millions across the world hate doing the dishes. Couples, parents, and children all fight over who gets stuck doing them because of how unpleasant it can be. And the solution for many decades was the dishwasher as we know it now, where you have to rinse off the dish, then load it into the dishwasher, then wait for hours until it's done, then unload it and hope that the dishes are clean enough. Given the ubiquitousness of this process, and the leaps and bounds we have made in technology in recent years, we believe we can do better.

The problem we have chosen has quite a large magnitude, since it affects all households, as well as restaurants, hotels, and other organizations. Washing dishes can be very tedious and is a time-consuming activity, especially in the 21st century, where time is a more valuable resource than ever before. According to a time use survey conducted by the US Bureau of Labor Statistics, the average person above 15 years old spends 13 minutes doing dishes every day, which translates to 1.52 hours a week (1). If you decide to use a dishwasher to avoid washing dishes manually, you will still have to rinse the dishes and manually load and unload the dishwasher, which takes time and effort in and of itself. In addition, while it may not take too long to load a dishwasher, it will still take anywhere between 2 - 4 hours for the dishwasher to actually clean the dishes. However, time and convenience are not the only costs of our chosen problem.

While washing dishes may seem fairly tame, it is possible to develop injuries like back pain (2) and repetitive stress/strain injuries (RSIs) such as carpal tunnel syndrome (3) while doing dishes. This is of course in addition to more common ways of injuring yourself while washing dishes, like cutting your hands or wrists on sharp objects like knives or shards of broken crockery.

The dishwasher is a device designed to reduce the inconveniences of having to spend time and effort on cleaning dirty dishes, first invented almost a century ago in the 1920s (4). The user has to manually load dishes, add detergent, and set the required washing cycles, but the dishwasher handles the actual cleaning of the dishes. On completing the manual steps, the dishwasher will begin filling up a small basin at the bottom with water. This water is heated to the range of 130 - 140 degrees Fahrenheit. The water is then pumped up to the water jets, which spray the water at the dirty dishes. During this step, the arms holding the water jets rotate to cover more area with the spray. At the end of this cycle, the water drains back down to the basin, where the pump now propels the water out of the dishwasher. Finally, as an optional step, some dishwashers may use the heating element that heats the water up to also heat the air inside the dishwasher, thus drying the dishes. (5)

CURRENT STATE OF THE ART

I. Water Systems

Standard home dishwashers all contain a similar water and heating system. Water is pumped in, heated, and then sprayed on the dishes while detergent helps to dissolve and clear away any food. Three common methods of dispersing the heated water are through a Wash Tower, Spray Arms, and a Spray Nozzle.

Wash Tower
An older way of cleaning dishes that dates back to 1973 and is still being used in dishwashers today is the wash tower. Wash towers include an extendable arm connected to a rotating base that directs heated water from the bottom of the washer to the top via a hollow tower within the arm. As the water is pressurized, the pressure pushes the arm to the top of the washer through a hole in the racks and sprays water up into the dishes on the top rack (6). This method has its issues as the tower can get stuck in the upright position because food gets lodged in the system and requires to be manually unstuck (7).

Singular Spray Arm
Spray arms are the simplest design for wash systems. Spray arms consist of several rotating arms that each contain water jets that spray water up at the dishwasher system. This is the cheapest design, but can have some issues reaching the top rack of a dishwasher. It is however the most compact design requiring the least amount of space to install and operate which makes it very appealing for compact machines. This design is also much more heavily reliant on the operator loading the dishes in such a way that no dish completely blocks another.

Dual Spray Arms
Slightly better at cleaning is a dual spray arm configuration. These dishwashers have Spray arms at the top and bottom of the system. These spray arms are independently supplied with heated and pressurized water and can either both target the lower rack, or split up to each clean one of the racks (8). This system type is a bit more complicated but more fully ensures that all dishes are cleaned as needed. It is less reliant than other systems on how the operator loads the system.

Water Heating Methods
In addition to the method for dispersing water, different dishwashers use different methods for heating the water. Different options for heating the water include an internal water heater, an external water heater, and pumping in hot water.

Dishwashers with an internal water heater usually have a heating coil around the base of the spray arm at the bottom of the washer that heats the water as it sprays onto the dishes. This method is efficient because it can also commonly be used to dry the dishes at the end of the cycle as well. Some debate is to be had as to the value of heat drying vs air/condensation drying however (9).

Dishwashers with an external water heater heat the water as it flows from the water source to the dishwasher. These water heaters may or may not store hot water. Some are instantaneous and heat the water directly as the washer needs it. Others hold a small volume of water and keep it heated to a proper temperature. Both dishwashers with an internal and external water heater can still be paired with the third option to use the hot water from the house.

Some dishwashers simply rely on the hot water from the house. These dishwashers tend to clean slightly less effectively as the water stored in a house is usually not as hot as typical dishwashers use when cleaning and may not reach temperature high enough to kill all forms of bacteria. This method is however the easiest as it requires no specific heating elements.

II. Conveyor Systems

Since most residential dishwashers have no conveyor systems to move dishes, I decided to focus on industrial dishwashers with conveyor systems. These can be classified into three categories: rack conveyors, flight conveyors, and special purpose conveyors.

Rack Conveyor

In rack conveyor dishwashers, the conveyor system is an internal ratchet system that is able to move standardized 20x20” plastic dish racks through the machines various wash zones or tanks (10). Taking the Hobart CLeN series rack conveyor dishwashers as an example, the user simply pushes a loaded rack of dishes into the machine till the conveyor catches on to the rack (11). From there, the dish rack is pulled through the machine’s power scraper (if installed) and the wash and rinse zones, and then brought out to the clean dish table (11).

Rack conveyor dishwashers can move dishes at a maximum speed of 10.9 feet per minute, enabling them to clean up to 288 racks (about 28,000 dishes) per hour, and they can even be fitted with additional tanks or wash zones and have their conveyors extended as needed (10). However, such speed is not required for residential use, and while the conveyor is automated, it can only move dish racks. This means that the user will still have to load the dishes into a rack manually, and furthermore this means that the user will be required to have several plastic dish racks, which does not make economic sense for a single household.

Flight Conveyors

Flight conveyors are similar to rack conveyors in that they have a conveyor system that runs through the machine’s different wash zones. However, flight conveyors have a continuous conveyor belt instead of using a rack conveyor system (10). We used the Hobart FT1000e as a general example of the operation of this type of dishwasher. The user simply pushes a start button to start the conveyor (and other systems) and places the dishes on the conveyor belt (this particular model requires pre-scraping of large food particles before this step) (12). Silverware must still be placed in a rack to prevent damage to the machine, and there are specific positions that plates, bowls, etc. should be placed in on the conveyor (12).

Flight conveyors can be even faster than rack conveyors, with a maximum speed of 13.6 feet per minute (10). They are also good at washing many items of the same kind in succession, since the speed of the conveyor belt can be adjusted to account for the kind of dishware to be cleaned (10) (12). From the operation of the example above, they also require much less effort on the part of the user than rack conveyors. However, they are less flexible than rack conveyors since they need a straight-line length for the conveyor (10), and therefore may be even larger, which is an undesirable trait for a residential dishwasher.

Special Purpose Conveyors

Special purpose conveyors are used in dishwashers that are meant to clean a specific kind of cutlery or dishware. These can be varied in their designs since they are specifically tailored to one particular item to be cleaned. For example, the Champion CG Rotary-Type Conveyor is designed specifically to wash glasses (13).

These dishwashers can be very effective in certain situations. The Champion CG is capable of cleaning up to 2000 glasses per hour, and the rotary conveyor allows it to achieve this number in a limited space (14). However, when considering residential applications, households generally have a small number of different types of dishware, and not thousands of one type of dishware. Specializing a conveyor to work for just one item would make it unable to handle all the other dishes a user would like to have cleaned, making this type of dishwasher unfeasible.

END USER

Anyone who washes dishes and wants to have more time for doing anything else in life can be impacted by the problem, and thus stand to gain the most from our solution. Businesses with primary roles in producing food already have commercial dishwashers that are far more effective at cleaning dishes quickly. Therefore, we will be focusing rather on cleaning dishes with less effort from the user and marketing this product to residential homes. Mainly we would be targeting residential homeowners who already have a dishwasher, with a standard size kitchen cabinet to the right of their current dishwasher, and who are willing to convert that cabinet space. Users will need no skill to operate the machine as it will be completely automated.

CONCLUSIONS AND SUMMARY OF RESEARCH

Due to the extra functions and mechanical apparatuses, our dishwasher will need its water technology to be as compact as possible. It is for this reason at least preliminarily, that we recommend using a single spray arm configuration with an external water heater connected to a home’s hot water system. Without the wash tower or a second spray arm, we will have much more room to fit the conveyor. Similarly, with an external water heater, we will not have to worry about fitting a heating element into the system. It also will give us the flexibility to move the hot water as we see fit. These considerations in mind, it should be reasonable for us to create our dishwasher.

Additionally, it would seem that a suitable conveyor system for our automated dishwasher does not yet exist. Residential dishwashers, not being automated in the way we envision, do not have conveyor systems. Commercial conveyor dishwashers do have automated conveyors, but each type has distinct advantages and disadvantages, and all are unfeasible for residential use. To realize our project, we need a conveyor system that is compact, that allows the user to simply place the dish on the conveyor instead of first having to load a dish rack, and that can handle many different shapes, sizes, and types of dishware.

QUALITY FUNCTION DEPLOYMENT

Based on a survey conducted by our Senior Design team that concluded on the 24th of September 2020, we determined five customer features to be of the highest importance (these will be discussed in the next section). The survey was a google form that received 31 responses, and is represented below:

Automated Dishwasher Customer Poll

The purpose of this survey is discover what priorities are most important to a general dishwasher user. We would like to you to consider the priorities below and decide how important they are to you. If you currently have a dishwasher, we will also invite you to consider the performance of your current dishwasher in a similar follow-up question.
If there are any priorities unseen below that you wish companies would consider, please mention it in the "Comments/Concerns" section below.

When considering a dishwasher, how important are the following priorities? (Ranked 5-Most Important, to 1-Least Important)

- How long it takes to wash a dish
- Low noise level
- Efficiency in power/water
- Cost
- How clean the dishes are
- Operator ease of use
- Size of the dishwasher
- Required cleaning medium (liquid, powder, tablets etc.)
- Appearance
- How often it requires service
- Dishwasher capacity
- Total automation
- Loading orientation

Do you currently have a dishwasher? (Answered yes/no)
When using your current dishwasher, how satisfied or dissatisfied are you with its performance in the following priorities?

- How long it takes to wash a dish
- Low noise level
- Efficiency in power/water
- Cost
- How clean the dishes are
- Operator ease of use
- Size of the dishwasher
- Required cleaning medium (liquid, powder, tablets etc.)
- Appearance
- How often it requires service
- Dishwasher capacity
- Total automation
- Loading orientation

CUSTOMER FEATURES

According to our survey, the five most important features to customers are:

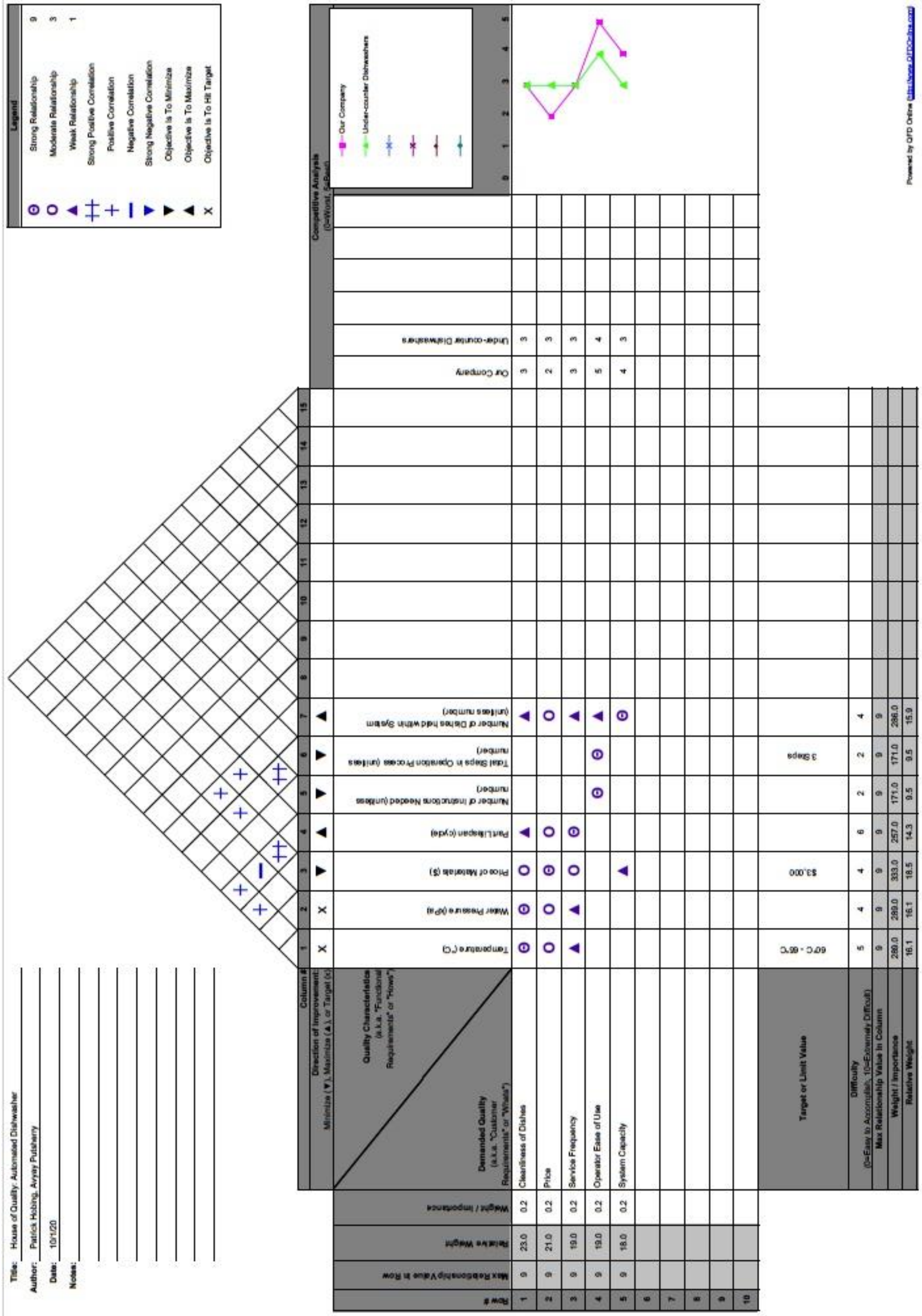
1. Cleanliness of Dishes (23%)
2. Price (21%)
3. Service Frequency (19%)
4. Operator Ease of Use (19%)
5. System Capacity (18%)

ENGINEERING CHARACTERISTICS

To provide our customers with the features they desire, we have chosen to use the following engineering characteristics:

1. Temperature
2. Water Pressure
3. Price of Materials
4. Part Lifespan
5. Number of Instructions Needed
6. Total Steps in Operation Process
7. Number of Dishes Held Within System

HOUSE OF QUALITY



PRODUCT OBJECTIVES

Cleanliness of Dishes (23%)
To ensure the cleanliness of dishes, we will use a water-soap mixture at the appropriate temperature and water pressure, which will allow our dishwasher to thoroughly sanitize the dishes regardless of their location within the washer. To this end, we will also install the water jets at strategic locations.

Price (21%)
While ensuring that we select materials for our device that are best suited to the job and are of high quality, we will also try to minimize the price of the materials we need. This will help us ensure a lower cost of purchase for the end user, our customers.\

Service Frequency (19%)
To keep maintenance intervals few and far between, we will design all components of our dishwasher to be as long-lived as possible, with the ability to withstand a large amount of cycles. This will involve keeping designs for each component simple, sturdy, and fool-proof.

Operator Ease of Use (19%)
To achieve this goal, we will focus on automating all or most processes that occur in our dishwasher. This will include an auto-loading system, automatic washing system, and even a conveyor system that will bring the dishes into a cabinet for storage once they are clean.

System Capacity (18%)
To give our dishwasher a reasonable capacity, we aim to make the attached cabinet large enough to fit an average household's dishes (with some extra margin), and we aim to make the actual washer large enough to wash at least as many dishes as regular dishwashers are able to accommodate at a time.

DESIGN

DESIGN ALTERNATIVES AND SELECTION

I. Water System Concepts

Single Spray-Arm with Internal Heating Ring

Figure 1: Single spray arm with internal heating ring

This design would involve the single arm sprayer with an included internal heating ring to help heat the water to around 140*F and help dry the dishes after the cycle by heating up the air within the dishwasher. The single spray arm is fed water from the house's hot water and will become more pressurized as it flows through the narrower pipes near the nozzles.

Using an internal heating element will drastically improve how clean our dishes can get. The temperature is directly proportional to how sanitary out dishes are after cleaning not to mention that it will help to dry our dishes afterwards. In terms of price, an internal heating element will be about as cheap if not cheaper than an external heater but will still include significant cost.

Dual Spray Arms with No Heating Element

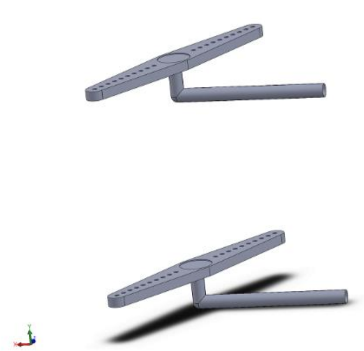


Figure 2: Dual spray arms with no heating element

This design consists of two spray arms and no additional heating elements. The spray arms will intake hot water from the house's supply and pressurize it before spraying it at the dishes. This design is unique as each arm only has to focus on one rack of the dishwasher thereby allowing for greater pressure on the top rack.

In terms of cleanliness, this design focuses on pressure rather than temperature. Higher pressure water and with more coverage will be more effective at cleaning any debris off the dishes. This design will however be expensive and require more frequent maintenance because it essentially has double the amount of moving parts and the top spinner will be at a greater risk of being damaged by the dishes.

Wash Tower

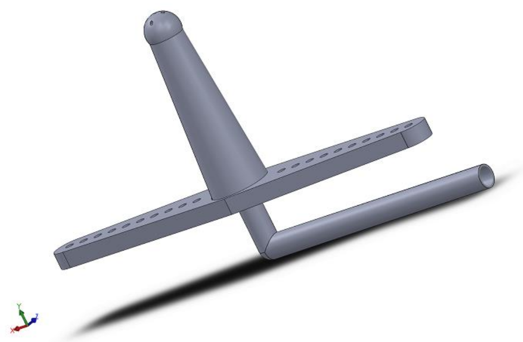


Figure 3: Wash tower

This design will consist of a single spray arm with a collapsible tower in the center of the arm that when subjected to pressure will shoot upwards to more effectively direct the water supply to the top rack. This system will also include an external independent heating system that will take hot water from the house and raise its temperature to 140F.

This design will be somewhere in the middle for how clean the dishes get. It has some additional heating elements, and some additional pressure elements. In terms of price this design is likely also somewhere in the middle. The external water heater can be expensive, and the tower adds cost, but no more than the others. This also requires a medium amount of maintenance as it has slightly more components involved. Overall, this is the most moderate design.

II. Conveyor Systems

Compact Counter-top Automated Dishwasher (C.C.A.D.)

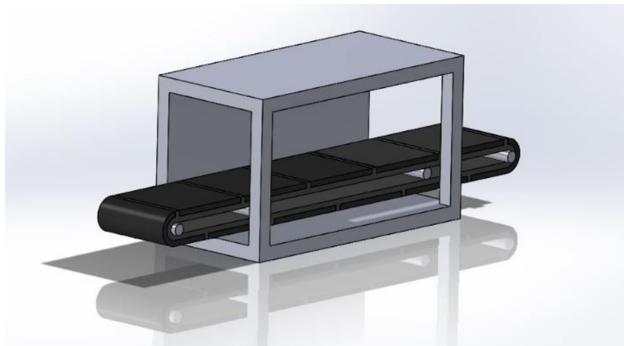


Figure 4: Compact Counter-top Automated Dishwasher (C.C.A.D.). Wash tank has been cut away to show conveyor system. Water systems not included in representation.

This concept seeks to use a conveyor system similar to a flight conveyor dishwasher (see the 'Flight Conveyor Dishwasher' section under State of the Art – Conveyor Systems). This dishwasher is meant to be a counter-top dishwasher, and the conveyor will be a belt-driven conveyor. When dishes need to be cleaned, they will be placed on the conveyor on the left of the dishwasher, and then the start button will be pressed. The conveyor will then move the dish(es) into the wash tank till the wash tank is at full capacity or the user decides to start the cleaning process. The conveyor system will wait for the cleaning process to be completed, at which point it will deposit the dishes on the right of the dishwasher, and the user will need to store the dishes.

This concept is very simple and so would have potentially good reliability and maintenance intervals. Being a counter top dishwasher, it will also be small and easily movable, and perhaps cheaper than the other concepts. However, scaling down a flight conveyor dishwasher to residential use might be inefficient, and while the dishwasher will still need several connections to be made (water, electricity) which limits the benefits of its easy movability. Additionally, it is not as automated and convenient as the other concepts, since the user has to store the plates once clean and does not have a very impressive capacity.

Vertical Layout Automated Dishwasher (V.L.A.D.)

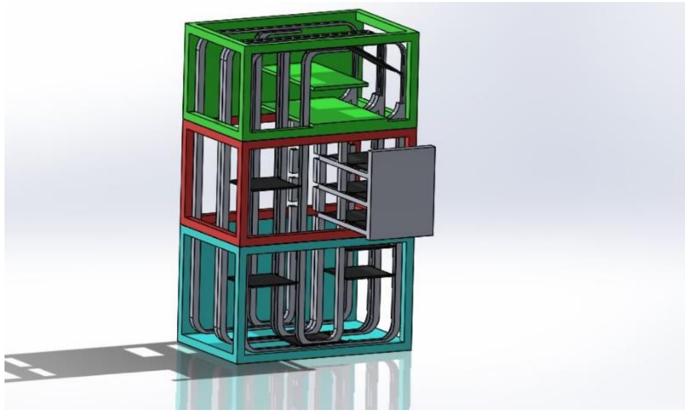


Figure 5: Vertical Layout Automated Dishwasher (V.L.A.D.) with loading drawer in open position

For this concept, the conveyor system is a system of rubberized platforms or 'base plates' that are meant to hold dishes that move primarily vertically through the dishwasher on a set of guide rails. There are two parallel sets of guide rail loops, one directly in front of the other. Figure 2 shows the concept in context of the frame of the dishwasher. There are three color coded segments: the red Loading Station, the blue Wash Tank, and the green Cabinet. Figure 3 shows the forward guide rail system, and Figure 4 shows the system without the loading drawer (see next page).

To begin the loading process, the user opens the loading drawer and places the dirty dishes on it (figures 2 and 3 show the loading drawer opened and closed respectively). When opened, the drawer comes out with four of the base plates, two from each guide rail system. The user can therefore load four dishes at once. Once the drawer is closed, the four base plates move down along the guide rails into the wash tank, freeing up the loading drawer to be used again instantly with the next set of base plates sliding down into place.

Depending on how many dishes are to be washed, the base plates that enter the wash tank may move all the way down, to the left, and then start moving up in the wash tank. Once the wash tank is full, or the system determines that the user has stopped loading dishes, the wash cycle can begin. Once this process is complete, the base plates move up through the left side of the loading station and into the cabinet, where a mechanism will eject the dishes from the base plates onto the shelves on the right. Plates can be stacked by having a base plate eject its dish at a slightly higher height than the previous base plate. If there are a large number of dishes to store, the left side of the loading station can serve as additional storage till slots have opened up on the cabinet shelves. The base plates then move flat against the top and right side of the cabinet (to save space for the shelves) and are then able to start the cycle anew.

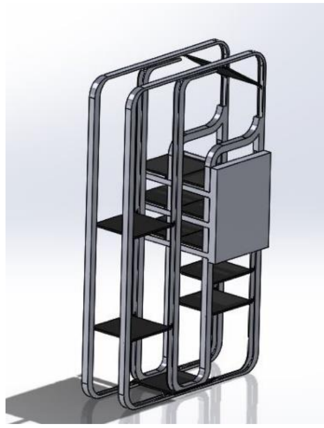
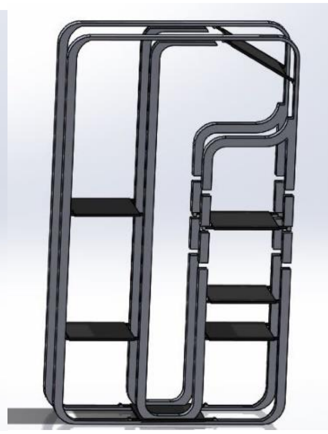



Figure 6 (left): V.L.A.D.'s front guiderail conveyor system (loading drawer closed)
Figure 7 (right): Front guiderail with loading drawer removed

This system is very comprehensive and is a truly automated dishwasher, since all the user has to do is open a drawer, put in dirty dishes, then close the drawer and take dishes out of the cabinet when needed. However, there are a large number of moving parts, and systems that are much more complicated than in the first concept. This could adversely ease of maintenance and reliability. This concept would also potentially have a much higher price, making it more of a luxury appliance than a regular household device.

Counter-integrated Horizontal Automated Dishwasher

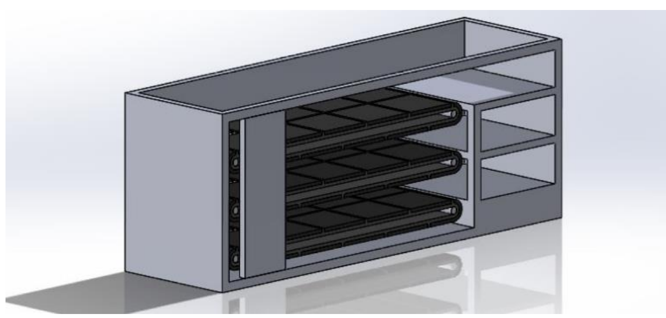


Figure 8: Counter-integrated Horizontal Automated Dishwasher (C.H.A.D.). Loading drawer (closed) is on the left. Area in center (immediately to right of loading drawer) is the wash tank. Storage shelves are located on the right.

This concept attempts to combine aspects of the two previous concepts. Like the C.C.A.D. concept, it has belt conveyors to move dishes from left to right. And C.H.A.D.'s loading design is similar to that of V.L.A.D., with rubberized 'base plates' and a loading drawer with space for six base plates. To start the cleaning process, the user opens the loading drawer and puts in dirty dishes on the base plates (see figure 6). Once the drawer is closed, the dishes move to the wash tank which is immediately to the right of the loading drawer. Once the wash tank is full, or the system determines that the user is done loading dishes, the wash cycle can begin.

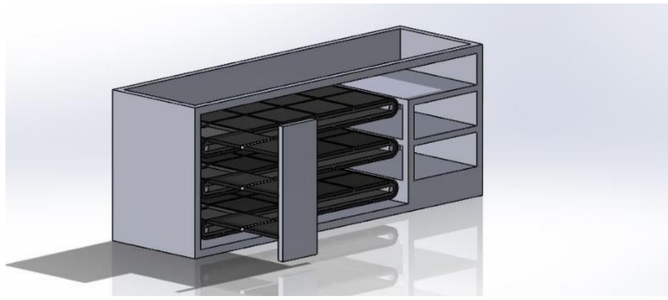


Figure 9: CHAD with loading drawer open. Note that base plates detach from conveyor and attach to drawer mechanism when drawer is opened.

On completion of the wash cycle, the dishes are moved from the wash tank to the storage shelves on the right. A special function of the conveyor belts is that of the two rollers that support a belt, the right roller is able to move up and down slightly, giving the belt a slight incline/decline. This function is used to stack dishes on the storage shelves, with the belt slightly incrementing the incline every time a new dish is to be added to the stack. Once the belt has reached it's maximum incline, it goes to its low position and starts a new stack. The new stack pushes the old stack further to the right, since the shelf floors have rollers that allow the dishes to move laterally (not represented in Figures 5/6).

C.H.A.D. attempts to combines the advantages of both the C.C.A.D. and V.L.A.D., and largely succeeds. C.H.A.D. is much less complex than V.L.A.D., but is just as capable, with a wash tank that can hold even more dishes. C.H.A.D. is also more compact, and can be integrated into a kitchen countertop. And while it is not as simple or compact as the C.C.A.D., it can also provide almost the full functionality of V.L.A.D. (the only exception is storage space, as C.H.A.D. does not have a loading station that can be used for backup storage. Overall, C.H.A.D. is the best conveyor system concept for our automated dishwasher.

III. Design Selection Matrices

To select our final design concepts for our water system, heating system, and conveyor system, we used design selection matrices. We weighted each customer requirement according to the importance it received in our survey. Then, each team member (identified by their initials in the matrix columns) ranked the concept's performance for each customer requirement out of a maximum score of 5, and a minimum of 0. Finally, all team members' scores were averaged and summed to provide a total score out of 5 for each concept. The matrices are displayed below and on the following pages.

Water System

Criteria	Weight	Single Spray Arm				Weighted Average
		T.F.	M.H.	P.H.	A.P.	
Cleanliness of Dishes	0.23	3	3	3	3	0.69
Price	0.21	5	5	5	5	1.05

Service Frequency	0.19	5	5	5	5	0.95
Ease of Use	0.19	-	-	-	-	-
System Capacity	0.18	-	-	-	-	-
Total						2.69

Table 1: Evaluation Criteria Matrix for Single Spray Arm

Criteria	Weight	Dual Spray Arm				Weighted Average
		T.F.	M.H.	P.H.	A.P.	
Cleanliness of Dishes	0.23	5	5	5	5	1.150
Price	0.21	4	5	5	5	0.998
Service Frequency	0.19	5	5	5	4	0.903
Ease of Use	0.19	-	-	-	-	-
System Capacity	0.18	-	-	-	-	-
Total						3.051

Table 2: Evaluation Criteria Matrix for Dual Spray Arm

Criteria	Weight	Wash Tower				Weighted Average
		T.F.	M.H.	P.H.	A.P.	
Cleanliness of Dishes	0.23	4	4	4	4	0.920
Price	0.21	4	4	5	4	0.893
Service Frequency	0.19	3	3	3	3	0.570
Ease of Use	0.19	-	-	-	-	-
System Capacity	0.18	-	-	-	-	-
Total						2.383

Table 3: Evaluation Criteria Matrix for No Additional Water Heater

Heating Systems

Criteria	Weight	Internal Heating Ring				Weighted Average
		T.F.	M.H.	P.H.	A.P.	
Cleanliness of Dishes	0.23	4	4	5	4	0.98
Price	0.21	3	4	4	5	0.84
Service Frequency	0.19	4	4	5	4	0.81
Ease of Use	0.19	-	-	-	-	-
System Capacity	0.18	-	-	-	-	-
Total						2.63

Table 4: Evaluation Criteria Matrix for Internal Heating Ring

Criteria	Weight	External Water Heater				Weighted Average
		T.F.	M.H.	P.H.	A.P.	
Cleanliness of Dishes	0.23	5	5	3	5	1.005
Price	0.21	3	2	1	3	0.478
Service Frequency	0.19	5	5	4	5	0.903
Ease of Use	0.19	-	-	-	-	-
System Capacity	0.18	-	-	-	-	-
Total						2.39

Table 5: Evaluation Criteria Matrix for External Water Heater

Criteria	Weight	No Additional Water Heater				Weighted Average
		T.F.	M.H.	P.H.	A.P.	
Cleanliness of Dishes	0.23	3	2	1	3	0.621
Price	0.21	5	5	5	5	1.050
Service Frequency	0.19	5	5	5	5	0.950
Ease of Use	0.19	-	-	-	-	-
System Capacity	0.18	-	-	-	-	-

Total	2.621

Table 6: Evaluation Criteria Matrix for No Additional Water Heater

Conveyor Systems

Criteria	Weight	C.C.A.D.				Weighted Average
		T.F.	M.H.	P.H.	A.P.	
Cleanliness of Dishes	0.23	2	3	3	2	0.575
Price	0.21	5	5	5	5	1.050
Service Frequency	0.19	4	4	4	4	0.760
Ease of Use	0.19	4	5	4	5	0.855
System Capacity	0.18	1	1	2	1	0.225
Total						3.465

Table 7: Evaluation Criteria Matrix for C.C.A.D.

Criteria	Weight	V.L.A.D.				Weighted Average
		T.F.	M.H.	P.H.	A.P.	
Cleanliness of Dishes	0.23	4	5	4	5	1.035
Price	0.21	1	1	1	1	0.210
Service Frequency	0.19	3	2	2	3	0.475
Ease of Use	0.19	5	4	4	5	0.855
System Capacity	0.18	4	5	4	5	0.810
Total						3.385

Table 8: Evaluation Criteria Matrix for V.L.A.D.

Criteria	Weight	C.H.A.D.				Weighted Average
		T.F.	M.H.	P.H.	A.P.	
Cleanliness of Dishes	0.23	5	5	5	5	1.150
Price	0.21	4	3	4	4	0.788
Service Frequency	0.19	4	4	4	4	0.760

Ease of Use	0.19	5	5	5	5	0.950
System Capacity	0.18	5	5	5	5	0.900
Total						4.548

Table 9: Evaluation Criteria Matrix for C.H.A.D.

ENGINEERING CALCULATIONS

List of equations

In a static system,

$\Sigma F_x = 0$

$\Sigma F_y = 0$

$\Sigma T = 0$

Using joint 2 of the highlighted support beam shown in figure 10 as an example, the equations for the XY-plane would be as follows:

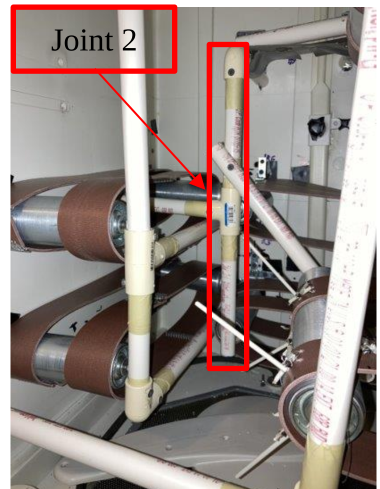


Figure 10: Example of Support Beam Chosen for Analysis

Stability in X-Axis

$\Sigma F_X = 0 \Rightarrow F_{tx} = F_{sx}$

where,

F_{tx} = Tension from cup conveyor

F_{sx} = Support from wall-mounted PVC

Stability in Y-Axis

$\Sigma F_y = 0 \Rightarrow F_{sy} = F_{wy}$

where,

$F_{sy} = Support\ from\ upper\ PVC$

$F_{wy} = W_{BR} + W_{LP} + W_{BB} + W_B$

W_{BR} = Weight of the bowl roller

W_{LP} = Weight of lower PVC pipe

W_{BB} = Weight of bowl belts

W_B = Weight of bowls

Torque

$\Sigma T = 0 \Rightarrow T_w = T_t$

$T_w = W_{cup} \times \frac{24}{2}$

$T_t = Tension\ from\ the\ bowl\ belts$

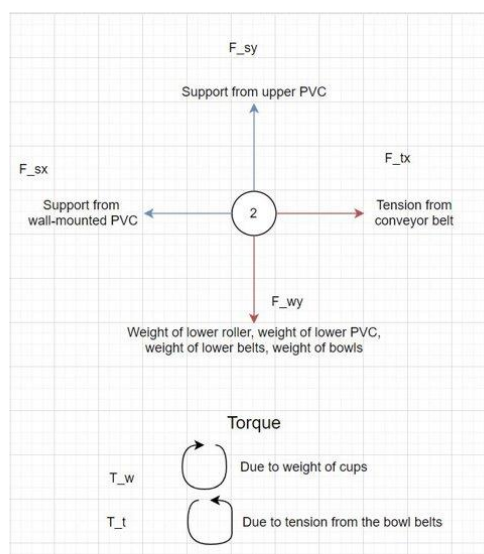


Figure 11: Free Body Diagram to Analyze Joint 2 of Support Beam

Similar static analysis was conducted on every joint in the system, and on every plane (the XY-plane, YZplane, and ZX-plane) to ensure structural integrity and rigidity.

Loading Conditions

Our support structures will need to handle many different forces in all directions. The greatest of these forces will be the tension applied to the structures by the belt. However, we did not have the tools necessary to measure this tension for our specific application. Therefore, we decided to pick a material that would be able to handle the maximum rated tension of our belts, with an additional safety factor of 1.5.

Our belts are rated for a maximum tension of 50 PIW (pounds per inch width). As our belts are two inches wide, this brings our maximum allowable tension to 100 lbs. Furthermore, we are using two belts across every roller. This once again doubles our maximum allowable tension to 200 lbs. With a safety factor of 1.5, this means that the material we use must have enough tensile strength to be able to support a maximum of 300 lbs. in order to ensure our support structure is rigid and secure.

Additionally, our structures will also have to contend with torques applied to it. Once again, the largest source of these torques is tension applied by the belts. As our structures will be attached to the dishwasher and cabinet walls using mounting brackets and screws that will go through the brackets and walls, our screws will need to have a good shear strength in order to be able to oppose the torques on our structure. We will also require a safety factor of 1.5 on these screws.

Material Selection

For our support structures, we decided to use PVC pipes of inner diameter 1/2 inches, and outer diameter 7/8 inches. The tensile strength of our PVC was found to be 1160.3 psi (15). Using this figure, we calculated the maximum load our PVC could handle as follows:

$$1160.3 = \frac{Load}{Area}$$

$$1160.3 = \frac{Load}{\frac{\pi D_{outer}^2}{4} - \frac{\pi D_{inner}^2}{4}}$$

$$Load = 1160.3\left(\frac{\pi}{4}\right)(D_{outer}^2 - D_{inner}^2)$$

$$Load = 1160.3\left(\frac{\pi}{4}\right)(0.875^2 - 0.5^2)$$

$$Load = 469.89\ lbs$$

Thus our PVC pipes can support a load of up to 469 lbs, which easily exceeds the 300 lbs. safety factor requirement.

For our belts, we chose to use brown neoprene rubber. This was ideal for our application, as brown neoprene rubber resists shrinking and is resistant to oils (16). These also have a maximum temperature tolerance of 250F. Hot water from the dishwasher reaches temperatures of up to 140F, which with a safety factor of 1.5 is 210F. Therefore our belts exceed our temperature requirement as well. Additionally, the temperature requirement is also exceeded by our aluminum and galvanized steel rollers (10” long and 7” long respectively), both of which have a maximum temperature tolerance of 220F (17) (18). Finally, our screws have a shear strength of 1000 lbs, which easily exceeds our requirement of 300lbs (200lbs tension from belts with a safety factor of 1.5).

Factors of Safety

PVC: 1.5 factor of safety for tensile strength
Screws: 1.5 factor of safety for shear strength
Belts: 1.5 factor of safety for max. temperature
10” long Rollers: 1.5 factor of safety for max. temperature
7” long Rollers: 1.5 factor of safety for max. temperature

MANUFACTURING DRAWINGS

PVC Support Structure

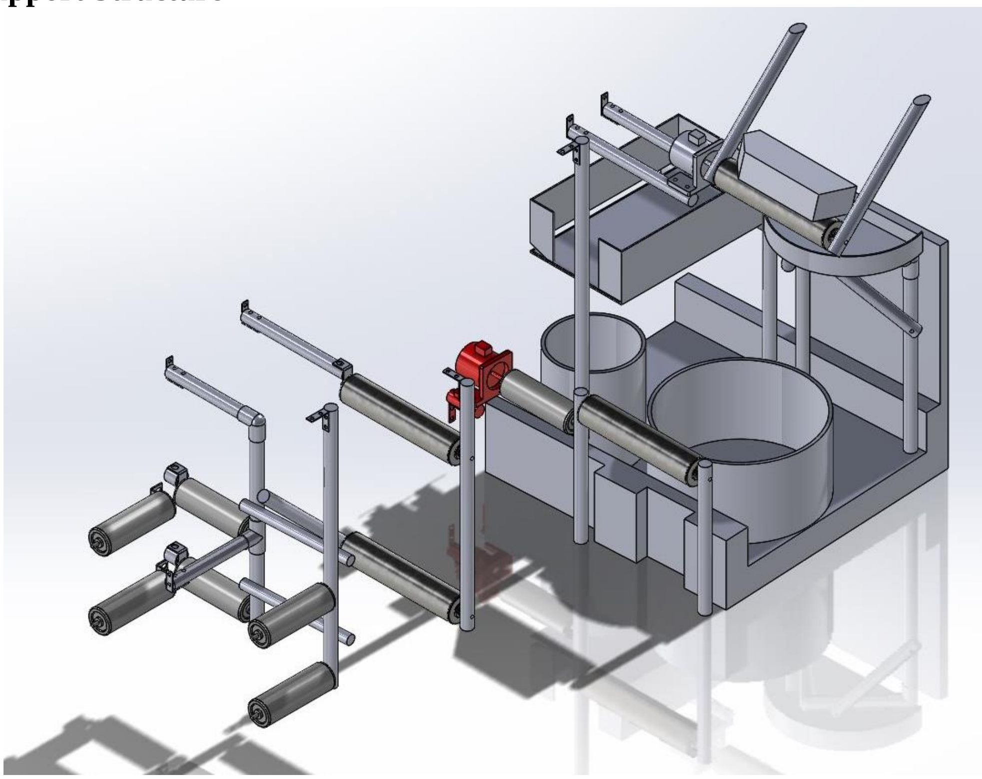
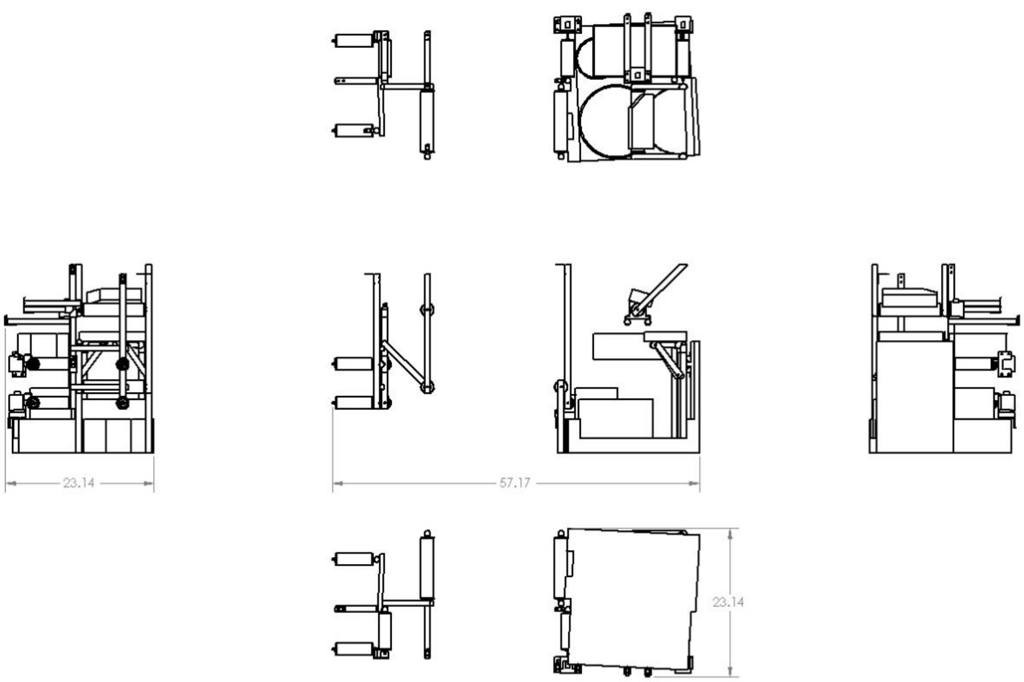


Figure 12 (Top): CAD Model of PVC Support Structure
Figure 13 (Bottom): Engineering Drawing of PVC Support Structures



PVC Structure with Belting:

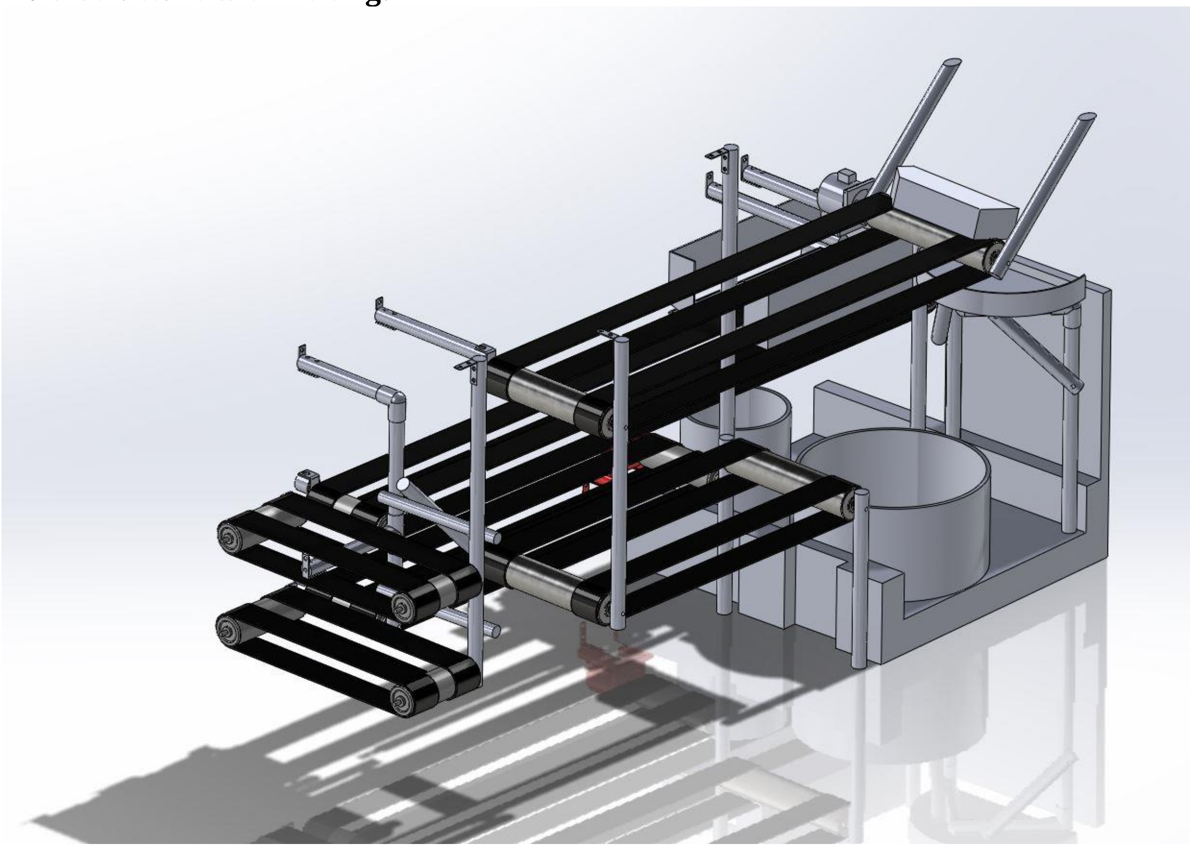
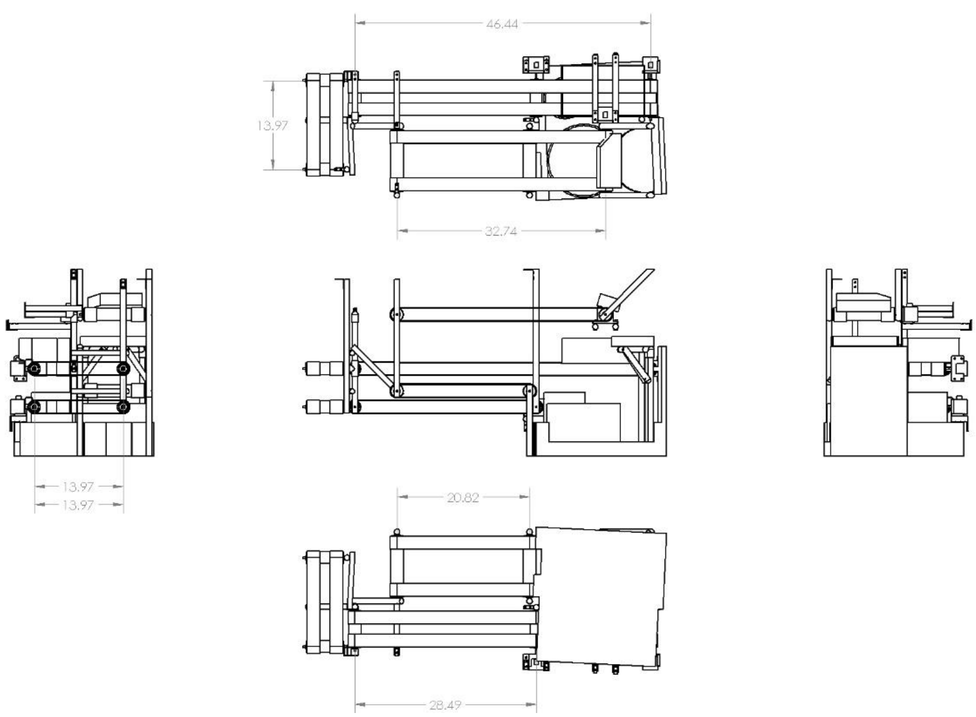


Figure 14 (Top): CAD Model of PVC Support Structures with Belting
Figure 15 (Bottom): Engineering Drawing of PVC Support Structures with Belting



Structure and Frame:

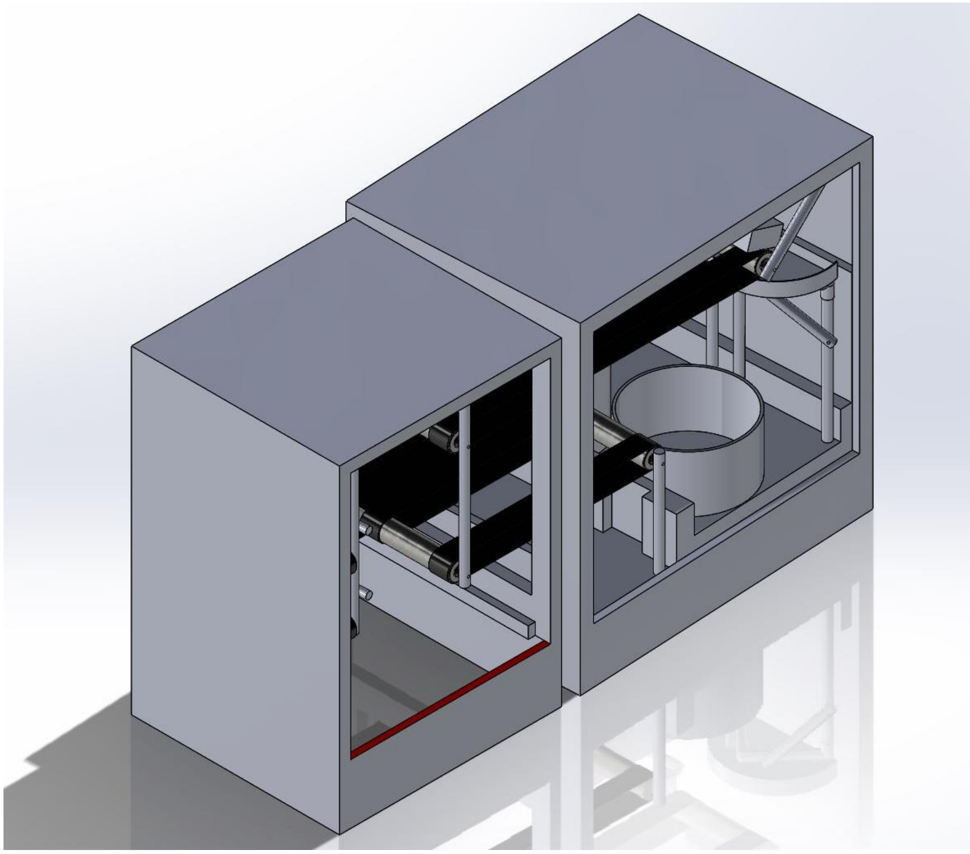


Figure 16 (Top): CAD Model of Finished Product with Frame
Figure 17 (Bottom): Engineering Drawing of Finished Product with Frame

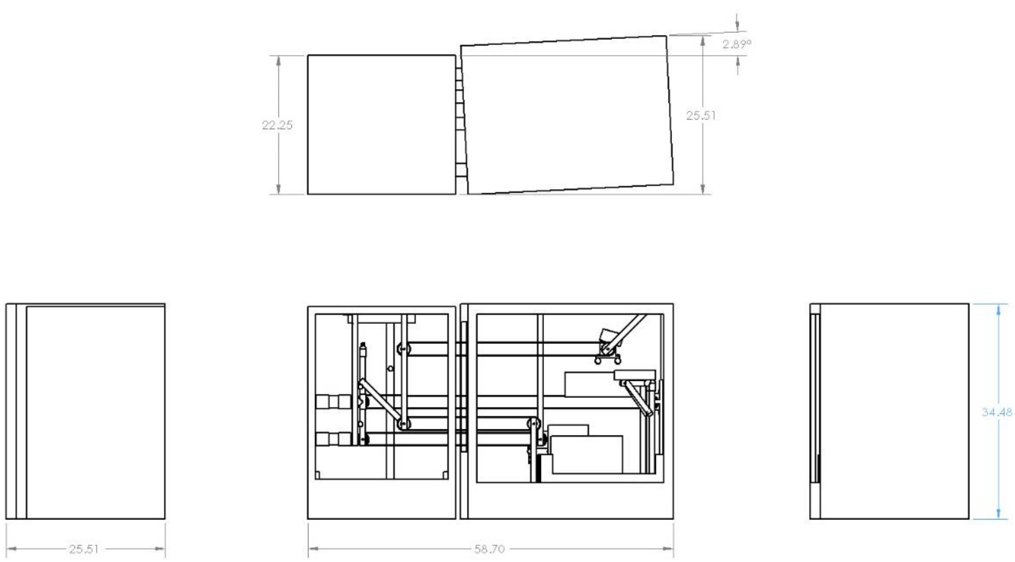


Figure 18: Finished Product

BILL OF MATERIALS

Item	Description	Source	Qty.	Price
Extension Cord	Extension cord	Home Depot	1	$ 8.00
Big Bucket		Home Depot	1	$ 8.68
Small Bucket		Home Depot	1	$ 4.98
Plastic Sheeting		Home Depot	1	$ 2.98
3/4" x 24" x 4' stain grade panel		Lowe's	1	$ 27.08
16 quart storage box		Home Depot	1	$ 5.69
Fine drywall screw		Home Depot	1	$ 4.10
8' Dishwasher supply line		Home Depot	1	$ 21.53
1" x 16" x 6' paint grade panel		Lowe's	1	$ 15.78

Bowls		Walmart	4	$ 4.05
PVC	10' by .5 "	Home Depot	5	$ 13.38
PVC	.5" cap slip	Home Depot	16	$ 9.07
2 Drill bits		Lowe's	1	$ 2.23
Flat Washers		Home Depot	2	$ 9.74
PVC	3/4" T joint	Home Depot	8	$ 4.71
PVC	3/4" L joint	Home Depot	10	$ 5.07
Machine screws		Home Depot	5	$ 5.90
Coarse screws	200 pack	Home Depot	1	$ 4.80
Machine Screw Nuts	100 pack	Home Depot	3	$ 7.69
Target Bowls		Target	5	$ 3.30
Large mounting brackets	4 pack	Home Depot	1	$ 2.30
Corner brackets	20 pack	Home Depot	2	$ 20.96
Galvanized hex nuts 5/16	100 pack	Home Depot	1	$ 24.26
Hex Nut		Home Depot	6	$ 2.53
Bolts		Home Depot	8	$ 3.00
Silicone		Home Depot	1	$ 7.03
Gorrila Tape		Home Depot	1	$ 13.88
Cabinet		Restore	1	$ 54.33
Dishwasher	Box designed for washing dishes	Restore	1	$ 21.56
Mounting Brackets	Galvanized steel (corrosion resistant) mounting brackets for rollers with 1/4"	Ashland Conveyor	32	$ 181.76

	diameter axles.			
Conveyor Belt Material	Made of brown neoprene rubber (resists oils, shrinking). One belt is 30' long, 2" wide, 0.110" thick. Belts will be cut into multiple segments based on design req.	McMaster-Carr	3	$ 478.68
Rollers (7" long)	1.9" diameter, galvanized steel (corrosion resistant) rollers, with temperature tolerance up to 220 degrees farenheit, and 1/4" round axles.	McMaster-Carr	11	$ 91.96
Rollers (10" long)	1.9" diameter, aluminium (corrosion resistant), with temperature tolerance up to 220 degrees farenheit, and 1/4" round axles.	McMaster-Carr	10	$ 104.40
Conveyor Belt Lacing	Hammer-on-hook style conveyor belt lacing. Made of galvanized steel, suitable for selected belt thickness, lace #7.	McMaster-Carr	2	$ 64.38
Connecting Pins for Lacing	Galvanized steel connecting pins, suitable for selected conveyor belt lacing.	McMaster-Carr	2	$ 23.76
Motors	110V, 60RPM AC motors	Amazon	7	$ 195.93
Motor Brackets (Potentially)	Fits aforementioned motors	Amazon	7	$ 90.23
Total				$ 1,549.70

BUILD AND TEST

A majority of this project was figuring out the exact locations and distances needed for all of our mountings and supports and making sure that we had support for the forces in the X, Y, and Z directions. In designing our system, we didn't know the exact sizes of the dishwasher or the cabinet and so when we finally purchased both of them, we have to essentially remodel everything. Before we began modeling however, we first wanted to make sure that the dishwasher and cabinet would stay connected, so we cut out matching holes in both of them and then bolted then together. After we had it all modeled, we simply had to go through the painstaking progress of mounting every single roller, belt and motor along with the drawer mechanism meant to assist the user unload the dishes. To do this, we primarily used screws, bolt, and PVC with a few parts being made of scraps of the dishwasher we had cut out to join the two halves.

DISCUSSION OF THE MANUFACTURING PROCESSES UTILIZED

Welding – Upon receiving the rollers for the conveyor belts, we had to figure out how to attach the rollers to the motors. We also had to find some way to prevent the rollers from moving independently of their axial pins. At first, we considered some sort of clamp, and then potentially hot glue, in the end, we used a MIG welder. The trouble with using a MIG welder was that the rollers and the motor pins were not the same diameter. This made it very hard to get them to be concentric which was necessary to have them rotate in parallel.

Lacing Belts – For our belting we ordered neoprene rubber belting and alligator lacing clips. Having never worked with either before, we had to do some research on their use. The basic setup requires a spacing bar in the crook of the alligator lacing and then pressing the belt against that bar. After the belt is in the right position, simply hammer the teeth of the alligator clips into the belt. Now to get our sizing, we originally based the lengths of the belt on the distance between the two rollers times two and then adding one circumference of the roller. This should have given us a perfect distance around the rollers. What we did not account for was the massive tension the belt was required to be under in order to be parallel which ended up being around 50lbs of force. This force caused the supports for the rollers to bend towards each other and make our belts too loose once again. We ended up having to redo our belts multiple times to accommodate this and ended up having to simply stretch the length of belt around both rollers, pulling tight, and marking where the cut needed to be to have the right length.

Wiring – While we were not directly responsible for the wiring of the motors, we can briefly discuss what our electrical counterparts did for the project. After all the motors were mounted our two electrical engineers soldered all the wires and attached them to a circuit board which also was attached to the dishwasher's circuit board. The program they wrote was meant to begin when the dishwasher's "clean" light came on and then the motors would convey all the clean dishes to the cabinet side.

TEST PROCEDURE AND CRITERIA

When we attempted to finally test our project after months of assembly; disaster struck. The motors we had welded and mounted were not strong enough to rotate the rollers while under the tension from the belts. We heard them tying to move and a few of them sputtered forward but then they all stopped moving. At this point we were only about 2 weeks before the tech expo and we had no way of procuring better motors or of salvaging the rollers we had already used in the process. Additionally, we at this point were already over our budget and so with a heavy heart, we admitted defeat to this critical failure. Without the motors working, the belts wouldn't move. We couldn't reduce tension on the belts without sacrificing all of our positioning as the tension on the belts was the only thing keeping them straight. The space within the dishwasher was already so tight that we knew we couldn't have moved anything to accommodate looser belts not to mention that dishes would simply fall on untightened belts. We stopped construction at this point. We did manage to get all of our unloading mechanisms working, but a small consolation it is. The unloader mechanisms basically equate to various shapes and structures of buckets for dishes to fall into all mounted on a drawer for easier unloading.

TEST RESULTS AND FINDINGS

In this section we can only speak to hypotheticals. Due to time and budget constraints, we are not delivering a finished product. We cannot quantify the true effort of unloading one's dishes, we cannot measure noise output or the cleanliness of dishes. We can say that when operated by hand, the unloading receptacles work exactly as intended and are able to be unloaded with relative ease.

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

We had originally planned to spend no more than $1500. We ended up spending $1550. Though over budget, we were only 3% over budget and this is an acceptable margin.

SCHEDULE, PROPOSED /ACTUAL

Proposed:

PROJECT TITLE	Automated Dishwasher					
WBS NUMBER	TASKS	OWNER	START	END	DURATION (DAYS)	% COMPLETE
1	Planning					
1.1	Initial Research		8/31/20	9/14/20	14	100%
1.2	Market Research		9/21/20	10/5/20	14	100%
1.3	Final Research		10/5/20	10/12/20	7	100%
1.4	House of Quality		10/5/20	10/19/20	14	100%
1.5	Design Considerations		10/12/20	10/26/20	14	100%
1.6	Cost Research		10/12/20	10/19/20	7	100%
1.7	Design		10/12/20	11/16/20	35	100%
1.8	Part Research		11/16/20	12/21/20	35	100%
2	Implementation					
2.1	Order parts		12/21/20	12/28/20	7	100%
2.2	Receive parts		1/18/21	1/25/21	7	100%
2.3	Assembly		1/25/21	3/15/21	49	100%
2.4	Buy Cabinet/PVC/Curtains/ Spring		2/11/21	2/12/21	1	100%
2.5	Cut hole		2/18/21	2/19/21	1	100%
2.6	3D Print		2/21/21	3/7/21	14	0%
2.7	Mount		2/21/21	2/28/21	7	100%
2.8	Electrical Connections		2/21/21	3/7/21	14	100%
2.9	Test		3/15/21	4/13/21	29	25%

Above we have listed our proposed schedule for design, building and testing. Our design phases went as intended, but as you can see below our build phase took much longer than expected. About a month into assembly the two electrical engineers informed us they would need 2 weeks to complete their portions of the project in addition to telling us their project was due 2 weeks before ours. That meant that we had essentially 1 month to do the remaining 2 months of work. As a result, both of us mechanical engineers had to devote 35-45 hours per week exclusively to the assembly of this project as opposed to the 16-20 we had planned.

Actual:

PROJECT TITLE	Automated Dishwasher					
WBS NUMBER	TASKS	OWNER	START	END	DURATION (DAYS)	% COMPLETE
2.3	Assembly		1/25/21	4/8/21	49	100%
2.4	Buy Cabinet/PVC/Curtains/ Spring		2/11/21	2/12/21	1	100%
2.5	Cut hole		2/18/21	2/19/21	1	100%
2.6	Mount		2/21/21	4/8/21	14	100%
2.7	Electrical Connections		3/29/21	3/29/21	7	100%

Sustainability and Material Usage

Had we been concerned with it and had the time and money, we could purchased or designed a dishwasher that reuses its water or refilters it. We also could have spent effort on ensuring that our motors and dishwasher used as little energy as possible.

CONCLUSIONS

Although our product failed to meet its objective of creating a system that is able to wash dishes and shelve them automatically, we were still able to use our prototype to prove most of our concepts. While our motors were not able to function as intended, and we did not have the budget to rectify this, we were able to demonstrate our other processes. Thanks to our structural analysis, we were able to build a rigid and secure support structure to support all our rollers, motors, belts, and other equipment, which were in turn able to support and move dishes as necessary. We also were able to build a functional drawer mechanism for the user to be able to easily access their dishes once they are washed and stored.

Due to the accelerated timetables we were given by our electrical counterparts, our schedule needed to be greatly sped up. Instead of having two and a half months to finish the build phase of our project, we had only one and a half months. In addition to this, we also underestimated the amount of time and effort we would have to put into this project. In spite of this, we were able to meet our schedule. However, this came at the expense of doubling or tripling the amount of hours we worked on our project per week. In terms of budget, we stayed within an acceptable margin of our planned figure. Our original plan was to finish the project with a budget of under $1,500. Due to the extra parts required, we finished with a budget at $1,550. As this was only a 3% increase over our initial estimate, we were satisfied with this budget.

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