Project Lavotica- Automating the Dishwashing Process

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Abstract

Alexandre Brunet, the Co-President of Pizza 900, currently spends around $100,000 CAD annually to have the dishes of his restaurant washed and unloaded. The purpose of this project was to assess the current procedure and identify a way to eliminate the need for an employee to operate the dishwashing station. The name "Lavotica" is derived from the combination of two Italian words: 'Lavare' meaning to wash, and 'Robotica' which translates to robotics. This title helps to encapture the vision our team had, to automate the unloading and stacking of dishware in an efficient manner with minimal human interaction. The project design is a multi-phase system concept comprised of a linearly actuated tray retrieval system, a robotic arm assisted unloading system, a conveyor belt transportation system as well as redesigned washing trays for the dishware used at the facility. Testing was focused and conducted on a model of the robotic arm system for proof of concept and concept analysis. Environmental, social and economic analyses were performed. Lavotica's innovative process and technological modifications limit waste production, while decreasing water and energy consumption. The following report will describe the details and function of this procedure.

Acknowledgements

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1. Introduction

Pizza 900, located 2049 Peel Street in downtown Montreal boasts the Neapolitan way of making delicious pizzas. The art of making a Neapolitan pizza originated in Naples, Italy. This approach to making pizza begins with fresh ingredients: a simple dough, fresh raw tomatoes, fresh basil, fresh mozzarella cheese, and olive oil. Despite their simplistic nature, the products of this company demonstrate incredible depth of quality. Completely modernizing this process could jeopardize the products' historical integrity, but in a continuously evolving world more and more companies are looking to technological advances to assist them in their craft. Alexandre Brunet, the Pizzaiolo and Co-President of Pizza 900, came to the realization that though the crafting of the pizza must remain traditional, other more monotonous and tedious tasks would benefit from automated assistance. He approached the Bioresource Engineering students with an idea to restructure the dishwashing process and handle the demand for clean dishes at the Peel location. The cost of having someone wash the dishes manually could be eliminated, while simultaneously diminishing water and energy consumption.

The current process used at Pizza 900 is a basic system used by most restaurants. After dishware has been used typically a waiter will retrieve the dishes and bring them to someone working in the dishwashing area. The individual working in the dishwashing area will scrape the larger pieces of food into the trash and then rinse the dish and then loads them into the dishwashing trays. Once the trays are full they are placed into the dishwasher where they go through the wash cycle and air dry. Afterwards, they are taken out and placed for pickup to be used again by the customers. This project aims to automate the stacking and transport of the dishes and optimize the tray geometry to reduce the number of daily wash cycles, ultimately decreasing energy and water consumption as well as labor and energy costs.

1.1. Vision Statement

To integrate an automated portion to the pre-existing dishwashing system of Pizza 900, capable of unloading and stacking the dishware to increase their profitability, while reducing water and energy consumption.

1.2. Mentor Information

Dr. Viacheslav Adamchuk pursued his undergraduate studies at the National Agricultural University of Ukraine and then went on to obtain his Masters and PhD at the University of Purdue. Today, however, he continues his devotion to knowledge, and works at McGill University as a full professor and was department chair of Bioresource engineering. This professor's knowledge and insight was an asset to this project because of his knowledge of robotics.

1.3. Funding

This project has been supported and funded by Alexandre Brunet. He has offered to reimburse the purchases that are deemed necessary for the construction of the testing model. Initially, there was some controversy as to whether the client or McGill University would receive intellectual property, but the client took ownership and funding was given to begin later in the semester.

1.4. Customer Needs Assessment

Table 1. Initial Customer Needs List Obtained from Interviews and Observations

Safe
Small in size
Clean surfaces
Affordable
Discrete
Lightweight
Low noise
Easy maintenance
Durable
Easy to operate
Easy to Clean

Table 2. Hierarchical Customer Needs List (With weighting factors)

1. Maneuverable (0.09)
    1.1. Lightweight
    1.2. Small in size
    1.3. Discrete
2. User Friendly (0.21)
    2.1. Low noise
    2.2. Safe
    2.3. Easy to operate
3. Reliable (0.34)
    3.1. Affordable
    3.2. Easy maintenance
    3.3. Durable
4. Sanitary (0.36)
    4.1. Clean surfaces
    4.2. Easy to clean

1.4.1. Weighting of Customer Needs

In our decision making process a large weight was dedicated to making our project clean and reliable for the restaurant. We believed that two of the main priorities of the establishment was to maintain a clean environment and have the ability to rely on a service that will deliver consistency that will better serve the customer in the long run. Figure 1 illustrates the use of one method, the Analytical Hierarchy Process (AHP), to create a weighted hierarchical client needs list.

Table 3: AHP Pairwise Comparison Chart to Determine Weighting for Main Objective Categories

	Maneuverable	User Friendly	Reliable	Sanitary	Total	Weighting
Maneuverable	1.00	0.33	0.50	0.20	2.03	0.09
User Friendly	3.00	1.00	0.50	0.50	5.00	0.21
Reliable	2.00	2.00	1.00	3.00	8.00	0.34
Sanitary	5.00	2.00	0.33	1.00	8.33	0.36

2. Literature Review

2.1. Life Cycle Analysis (LCA)

The term lifecycle analysis is defined by ISO as a compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product system through its lifecycle (International Organization for Standardization, 2006). The LCA technique follows standard ISO 14040:2006, and involves phases of goal and scope definition, inventory analysis, impact assessment and interpretation (International Organization for Standardization, 2006). The International Organization for Standardization develops and publishes international standards. The ISO creates documents that provide requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose (International Organization for Standardization, 2006). In terms of life cycle assessment, the international standard that exists is ISO 14040, titled "Environmental management – Life cycle assessment – Principles and framework."

The LCA technique outlined in the standard involves four phases:

i. The goal and scope definition phase

ii. The inventory analysis phase

iii. The impact assessment phase

iv. The interpretation phase

These standard phases must be respected in the elaboration of a Life cycle assessment to be in line with ISO standards. When considering the life cycle assessment of our design the goal and scope definition phase involves outlining the lack of current data related to the impact on the environment. The 'goal' for this design project was to automate the stacking process of the Pizza 900 sanitation location. The 'scope' for this project includes the entire dishwashing process and how it is done from insertion to extraction. The 'inventory analysis' phase reviews current or similar projects that involve our design and their respective impacts on the environment. The "impact assessment" phase is the core of the LCA data collection. It involves analyzing the impacts of our design, as well as the manufacturing, usage, and raw materials. In the "interpretation phase" the data that is collected helps to showcase potential issues that may arise in our design and leads to more strategic action.

2.2. Proximity Sensors

Proximity sensors perform detection without physical contact. Using a transducer they monitor specific physical phenomena such as electromagnetic fields, light or sound, and convert changes in these physical phenomena into electrical signals (voltages). There are a wide variety of proximity sensors available on the market. Their applications range from being mounted on the bumpers of cars to identify other parked cars to being used in touch screens for identifying the presence of faces, among other uses. The differences between proximity sensors are determined by the physical phenomenon whose change is measured. This includes capacitance, Doppler Effect, eddy-current, inductive, photoelectric, laser, radar, ultrasonic sensing etc. The most commonly used in the applications of robotics however are mainly, capacitance, inductive and photoelectric (Benet, Blanes, Simó, & Pérez, 2002).

Inductive proximity sensors detect ferrous targets in a magnetic field. The oscillator in the sensor establishes a symmetrical oscillating magnetic field which is radiated outwards from the ferrous core of the sensor. The introduction of ferrous material, ideally mild steel with a thickness greater than one millimeter, induces the formation of individual and small electrical currents on its metallic surface. The induced current alters the reluctance of the magnetic circuit which consequently decreases the oscillations amplitude. A component known as a Schmitt trigger then interprets these fluctuations in magnetic field and output a resulting signal. Various manners of magnetic oscillation interpretation exist. Normally open configurations output an “on” signal when an object is introduced into the field and conversely, a normally closed configuration has an “off” signal when an object is present in the field. Electrical outputs are then read externally using microcontrollers or programmable logic controllers (PLC) among other devices. The single “on” and “off” switch is repeated and the speed of one of these cycles is measured by cycles per second which gives a frequency rating for the unit. Typical ranges of frequency ratings for inductive sensors 500 Hz to 5000 Hz for DC and 10 Hz to 20 Hz for AC power. Their ranges are limited to extreme close proximities in most cases, less than a millimeter to 60 millimeters. A clear advantage of inductive sensors however is their abilities to withstand environmental disruptions. They avoid issues of degradation from tear as they have no moving parts and they are known to operate regardless of sizeable buildup of grease, non-metallic dust or fluids that may be present (Cheng, Chen, Razdan, & Buller, 2011).

Another commonly used sensor is the capacitance sensor as it can detect both metallic and non-metallic objects. These sensors are usually reserved for applications in sight glass monitoring, tank liquid level detection, and hopper powder level recognition. They use conduction plates at different potentials configured to operate as an open capacitor. As an object enters the sensing zone, the capacitance of the plate in the air filled (insulated) environment increase. This is a similar process to the inductive sensors, except that when an object is introduced, it creates changes in the oscillator's amplitude which is changes the Schmitt trigger state and then an output signal is sent. The sensing range of capacitance sensors are between 2 mm to 60mm with sensing frequencies ranging from 10 Hz to 50Hz (slightly slower than inductive sensors). False readings can be problematic with these sensors as they are sensitive to most material types therefore must be kept away from any non-targeted objects (Jachowicz, Wójtowicz, & Weremczuk, 2000).

The industrial sensor world is heavily dominated by photoelectric sensors as their low cost and wide range of versatility position them as attractive options for companies. As photoelectric sensors are a general category of optic sensors, many different types exists. However, the majority of them follow a similar overall design with an emitter light source (which can be an LED, laser diode, etc.), a phototransistor receiver (or photodiode) for emitted light detection, and amplifiers to increase the received signals. A beam of visible or infrared light is emitted to the detecting receiver. The variations of the photoelectric sensors are classified as either the output is sent with a void of light, this is called darkon sensor, or the output is from light detected which is a light-on sensor. The way the light is received can also vary as far as the configuration and technique of light detection but usually fall under three main categories. Through beam sensors have two separate housing parts with detection occurring when an object obstructs the beam passing between them. Retro-reflective sensors use a similar technique to through beams except that the receiver and detector are house together on the same side of the target. Lastly, diffuse sensors have a similar configuration to retro-reflective sensors but the signal diverges until the object moves into the beam path and reflects some light back to the receiver. In general, photoelectric sensors have sensing ranges from less than 1mm to a staggering 60 m maximum distance. Their simple designs and high reliability make them a suitable choice for most proximity detection applications (Benet, Blanes, Simó, & Pérez, 2002).

2.3. MAPAQ Regulations for Dishwasher

The MAPAQ is the Ministry of Agriculture, Fisheries and Food of Quebec. This is the specific branch of the provincial government that handles food inspection and the hygiene of the services involved. The design is to adhere to the following descriptive overviews of the regulations that govern the use of dishwashers in commercial applications (MAPAQ, 2018):

2.3.1. Pre-Cleaning Step: Disassembly

This preliminary step helps to ensure efficient cleaning and sanitation of all rooms and surfaces. It reduces the accumulation of water and food, which reduces the risk of the appearance of biofilms. Equipment should be removed daily, or more frequently, if there is a risk of contamination.

2.3.2. Pre-Wash

Food debris should be removed over a trash bin, scupper or garbage container or in a dishwasher using the prewash cycle. Depending on the situation, for an efficient cleaning, utensils and equipment can be rinsed or soaped or rubbed with a non-metallic abrasive.

2.3.3. Wash-Automatic

In most food establishments, a dishwasher is used. This appliance must be used and maintained in accordance with the manufacturer's instructions. It is advisable to display these instructions near the device. In particular, the user must ensure that the detergent supply is sufficient, that the openings of the wash arms are not obstructed and that the washing temperature is appropriate. The wash water must be at a temperature at least 60 ° C

2.3.4. Rinse-Automatic

The flushing water temperature must be at least 82 ° C or as recommended by the manufacturer.

2.3.5. Drying-Automatic

Whether during the manual or automatic procedure, drying is an important step to prevent the accumulation of stagnant water, which is conducive to the growth of microorganisms. Generally, dishwashers offer a drying cycle.

2.4. Pre-Rinse Phase

Originally there was a lot of focus on the pre-rinse phase and how there could be control of the amount of water used and the dishware could be properly pre-cleaned. Upon further review, it was found as far as water consumption is concerned, savings in the consumption of energy and water for dishwashing is controlled by the consumer. “Through such decisions as machine versus manual washing, the extent of pre-rinsing dishes, the selection of dishwasher cycles, and how fully and efficiently the dishwasher is loaded, consumers ultimately decide the water and energy use involved in the dishwashing process” (Emmel et al., 2003). Furthermore, it was found that dishwasher manufacturers advise against a pre-washing phase and suggest rather a scrape or wiping of the dishes before being placed inside the dishwasher because most modern dishwashers are designed to handle food remnants. This was further supported by a study where “In general, no major differences can be seen between the selected pretreatment routines in terms of ‘dissatisfied’ and ‘very dissatisfied’ dishwasher users (each less than 5%). Also, the proportion of respondents claiming to be ‘satisfied’ and ‘very satisfied’ together is quite balanced (around 85%). ‘Very satisfied’ respondents follow the recommended practice to scrape off dishes (39%); the difference between the extremes ‘pre-rinsing’ and ‘no pretreatment’ is about 5%, just marginal” (Richter, P., 2010). This states that there is no clear difference between the satisfaction levels of the surveyed dishwasher operators for the two treatments, and considering the energy and water usage it would be logical to use the scraping technique in a sustainable practice.

2.5. Wash Phase

The washing will be done by the dishwasher present at the Pizza 900 location. The dishwasher will run the typical desired wash cycle of 2.1 minutes while also running a cycle to dry the dishes thoroughly. The designed system will work in conjunction with the current dishwasher used at Pizza 900 and seamlessly integrate automated aspects to its function.

2.6. Linear Actuator

Linear actuators use supplied energy to extend or retract in a straight line direction. Various types of linear actuators exist such as hydraulic, mechanical, piezoelectric as well as electro-mechanical. Applications are varied among many different industries, the type used is predominantly decided by the requirements of the task (for example, a required value of force or length of motion) (Art-Linear Actuator, 2018). Two desired uses could be found for a linear actuator in the design. The first use for the linear actuator would be to open the dishwasher up once the proper cycles had concluded. This actuator would be on a timer and need to be calibrated. The second use is to extend and bring the trays to the unloading area. The advantage of the linear actuator is the obvious lack of interaction needed, it is a simple component and can perform monotonous functions consistently and accurately.

2.7. Unloading Phase (Robotic Arm)

Robotic arms are often used to automate human functions. Their precise and consistent movements are very useful in many industrial applications. During the unloading phase of the design the tray will utilize a robotic arm to move the dishware from the unloading zone to the conveyor belt. This multi-axis robotic arm will be programmed to stack the dishes in their respective piles and the utensils in the designated location to be easily accessed by the operator.

3. Design Approach

3.1. Design Criteria

After meeting with Alexandre Brunet the following criterias were agreed upon.

Function: The system implemented will clean, sanitize, and prepare the dishes ready for use in a timely fashion.

Limited User Interaction: The design will involve very limited human interaction. It will only be deemed necessary at the designated drop-off and pick-up stations.

Handle Capacity: The process designed will be able to handle maximum capacity of dishes in case of under estimated lunch or dinner rush.

Durable: The additions to the dishwasher area will not corrode and remain durable through consistent use.

Safe: The design chosen will not cause harm due to the lack of users and will be contain proper warnings for moving parts and maintain ample distance for any employee nearby

Practical: The design will also consider failure and given a malfunction will not render manual washing impossible. It will be designed to make use of the facilities already on site.

3.2. Design Parameters

The conditions below must be met to improve the current process done at Pizza 900 and fulfill the design goals.

Automated Dishwashing Process: In order to deem the design project a success the cleaning operation applied to the dishes must be of limited contact with employees. The plates will be scraped and placed in the trays at the desired location. Once these plates are properly entered into the washable trays they will be placed in the dishwasher and the dirty dishes will begin their journey to be cleaned. The dishwasher will be locked into place by an employee where the washing, sanitizing and brunt of the drying will be done by the dishwasher. Next, The dishes will exit the dishwasher at a temperature of 82 ° C. Following this, the tray will move on to a conveyor belt that will transport this tray from the open dishwasher to the designated drying station. Here the dishes will be stacked in proper piles by the robotic arm using the recognition system and left to cool down until desired for pick-up by an employee.

Limited Water Usage: After further consideration of the potential energy cost of the design it was decided the best way to achieve a lower water demand would be by increasing the capacity of the trays that are used in the dishwashing process. The Current trays are not specifically designed to handle the utensils and plates used by Pizza 900 and with some precision engineering the trays would be able to efficiently use the finite amount of space inside the dishwasher and in turn cut back on the number of uses necessary to maintain a sufficient amount of clean supplies for the customers.

3.3. Alternative Designs

When Pizza 900 approached our team, the Co-President of the company envisioned an automated dishwashing system to improve the current method by increasing efficiency and reliability, while decreasing the associated costs. The viable alternatives for the robotic mechanism, the gripping component, and the localization of the dishware were analyzed separately and then combined to produce our final engineering design.

3.3.1. Multi-Axis Robotic Mechanism

A multitude of robotic mechanisms with different numbers of robotic axes were considered for the design. An axis, in a robotics context, can be interpreted as a degree of freedom (DOF). If a robot has three degrees of freedom it can manoeuvre in the X-Y-Z axes (ASME, 2017).

Our team considered the utilization of a 3-axis, 4-axis, and 5-axis robot. The 3-axis robotic arm can be used for simple pick-and-place operations, where parts are placed with identical orientation and are dropped in the same exact place. A 4-axis robotic arm was considered, as it enables the system to rotate, while still traveling along the X-Y-Z axes. Selective Compliance Articulated Robot Arms (SCARA), Delta robots, and other traditional robots work with 4-axes. By adding another motor, 5-axis robotic arms are developed. These arms are able to move through the three spatial axes, while also rotating on two additional axes giving them almost total freedom of movement (Bélanger-Barrette, 2015).

3.3.2. Dishware Targeting System

Two main methodologies were investigated for the localization and targeting component of our system: a predetermined coordinate system in our programming code, and object detection through computer vision.

The first of the two avenues explored is the cheaper and less complex approach. By calculating the geometry of the trays and keeping the positioning of the dishware constant, our robot is able to perform pre-determined commands. This can be achieved through the development of a computer program code able to carry out the operations of our present mechanical system in question. This code may be written in combination of one or more programming languages providing us with some degree of flexibility depending on hardware used.

An alternative methodology, is to combine computer vision with the robotic arm and designing a smart robot arm system which can identify objects from images automatically and perform given tasks. In this case, the loaded trays are initially photographed through an internal camera, and all the objects in the image are identified using image processing methods. Once the image has been properly analyzed, all detected objects' coordinates are determined and transferred to the robotic arm. Afterwards, the arm joints' angles are calculated according to the received coordinates and the robotic arm targets the dishware and lifts it in the order it was detected (Yurtoğlu, 2018).\

3.3.3. Gripping System

An analysis of possible gripping mechanisms was conducted for this design as well. The gripping mechanism is used for the removal of the plates from the trays once the tray has been removed from the dishwasher and placed in the unloading zone. Gripping systems considered for the removal of the plates are the magnetic contact, jaw gripper and vacuum cup.

Magnetic contact systems have been already applied to dishware loading and unloading systems in recent years. These systems use magnetic end-effectors attached to a robotic arm to grip targeted articles. Using an input from a localization system, the gripper locates a targeted dish and "engages" the magnetic end-effector when it is within a specified proximity (around 1 cm). The system relies on the use of magnetic dishware, where the plates are either made of ferromagnetic materials or are fitted with permanent magnets. (Birkmeyer et al., 2017)

Jaw grippers are systems that create contact points around objects so that they can be moved. Jaw grippers can be pneumatic or electrical. Pneumatic systems use compressed air to move pistons that manipulate the position of their contact pieces onto the targeted object, whereas electrical systems use electrical components usually linear actuators and servomotors. Many different forms of these grippers exist. The parallel gripper has opposing jaws that move parallel to each other externally around a targeted object or push outwards on the internal walls of the object to create sufficient pressure for manipulation. Alternatively, there is the angular gripper which has rotating jaws around a central pivot. The length of each contact piece and angles of rotation can be adjusted to the geometry of the targeted object (Zhang, & Goldberg 2001). In addition to the motion trajectory, jaw grips can vary in design for the end-attachments or contact pieces. Encompassing grips create a frame around the entire object and lock. Alternatively, there are pure friction dependent grips. These usually can be smaller than encompassing grips however often require high grip force to secure the object depending on the coefficient of friction of the materials used for the contact piece (Guelker, 2014).

A vacuum cup system uses a soft flexible material in conjunction with an air hose to create a high friction vacuum contact with a surface. These can be attached to the ends of jaw grippers or used independently to grip objects. Primarily there are two types of vacuum cups, flat and bellows. Flat cups work well with horizontal loading shear and have quick response time. Bellows suction cups are good for textured or irregular surfaces and offer dampening which helps when working with sensitive objects or abrasive movements. Vacuum cups are primarily made of silicone, nitrile, polyurethane or Viton depending on the abrasion and temperatures of the application (Zhang, & Goldberg 2001).

3.4. Design Selection

3.4.1. Identifying the problem

The client, Alexandre Brunet, informed us that he wanted to eliminate the need to pay someone to be doing the dishes. Many ideas were discussed on how to do this, but an arm for stacking appeared to be a superior option.

3.4.2. Researching Criteria and Constraints

When attempting to research our topic it was hard to find topics similar to our design. The robotic arm to stack dishes was truly an innovative design that needed to be looked at in much more depth. The arm would need to fit into the small kitchen space available at the location and would need to be accessible for maintenance. Given the nature of a restaurant kitchen regular cleaning would need to be scheduled to adhere to standards as well as check-up routines to confirm the high humidity environment is not adversely affecting the arm itself. The arm would need to be able to run through a high traffic lunch or dinner rush and handle consistent daily use.

3.4.3. Brainstorming Possible Solutions

Many solutions were brainstormed, including a complete removal of the dishwashing system to increase capacity. Instead our team decided that would be too costly and we opted to design a tray that would both increase the capacity of plates that could be handled as well as enable our arm to work on a coordinate system instead of a visual sensor that would potentially fog in high humidity environments. Then do adhere to MAPAQ laws it was decided that the parts that would be handling the dishware would be stainless steel to account for sanitation (easy wipe down) as well as aesthetic. This in conjunction with a removable vacuum seal that can be replaced and washed will allow for operations to run smoothly and with limited resistance.

3.4.4. Picking the Best Solution

In picking the best solution, a numerical evaluation matrix was used. A scale of 1 to 10 was implemented, with 10 being the highest possible attribute score. Moreover, each consideration was weighted between 1 and 5. The best solution is the solution with the highest weighted average among categories.

Table 4: Pugh Chart method to determine path

Design Constraints and Objectives (Weight)	Baseline	Complete Redesign of Dishwashing Station	Integrated Tray Method
Aesthetics (2)	0	1	0.5
Cost to Remove (5)	0	-1	0
Ergonomics (5)	0	0.5	1
Time to Build (4)	0	-1	-0.5
Environmental Impacts (5)	0	0.5	1
Maintenance (2)	0	-1	0
Total→ Weighted Average	0	-4	9

For reasons of cost efficiency, time, and scale and from conclusions from the tabulation above, it was established that the best solution for our project was to design new trays and focus primarily on the stacking process of the dishwashing system. This design will also greatly reduce the environmental impact of removing and discarding parts of the dishwashing station as well improve the efficiency of the dishwasher with our tray design. There will be less maintenance in conjunction with less new, automatic parts and thus a lesser stress on employees to adapt.

3.4.5. Selection of Conveyor Belt

A conveyor belt system is needed to transport the stacked dishware and cutlery to be accessed by the operator. It was necessary to find a belt delivery system that could be used in a kitchen environment. The decision was made to use stainless steel covered system for the durability and cleanliness of the material. There were many other factors to consider such as moisture resistance from the water, size, cleanability and chemical resistance.

The decision to choose the right type of conveyor belt system to install is shown by the following Pugh chart in Table 1. In this Pugh chart, it was determined among the criteria discussed which of the models of conveyor belts would work best in a kitchen environment for the employees and appeal to the artistic nature of the customers.

Table 5: Pugh Chart Analysis of Various Conveyor Belt Options

Criteria for Success	Weight (1-10)	Base	Clean Move Standard	CleanMove Plus	CleanMove Ultra
Moisture Resistance	8	0	48	56	72
Size	5	0	40	40	40
Cleanability	9	0	45	56	90
Chemical Resitance/Durability	10	0	50	60	80
Apperance	3	0	12	21	27
Cleaver	2	0	2	2	4
Total			197	235	313

Based on Table 5, the Clean Move Ultra was chosen because it performed better using the Pugh chart and given the stress on cleanability, durability, the need for a high resistance to a moisture rich environment and the fact that this style of belt allowed for all the exposed parts to be stainless steel. The Ultra option was clearly the superior choice. Our client has stressed these parameters to be paramount, therefore other criteria such as material and installation costs were not included but will be further analyzed in the near future.

3.4.6. Arm Selection

The 3-axis robotic arm is limiting by only granting overhead access to the dishware. Since the dishes will be taken from a vertical position in the tray and placed horizontally in the stack, a rotating motor at the end effector is required. Additionally, since the the location of the two stacks will be 90° from each other in the horizontal plane, another rotating motor will be needed to manipulate the dishware in this limited area. Additional axes of rotation could increase efficiency and fluidity of motion of the arm but with their additional cost they are unnecessary for this application. The 5-axis robotic arm is sufficient for the process.

3.4.7. Targeting System Selection

The targeting system selection was based on their functionality in the given environment. Close proximity to a dishwasher with limited ventilation could pose a large risk of lens fogging from vapor if a camera were to be installed for computer vision. This would create considerable error to the overall accuracy of computer vision system. In addition, computer vision systems can add cost from the required hardware and complexity from the software needed. Therefore the option of using a pre-set coordinate system was selected. The plates are loaded into specific slots in the washing trays and those positions (once the tray is in the designated unloading zone) are constant. The arm will simply configure the end effector accordingly to these positions.

3.4.8. Gripping System Selection

The various options in gripping selection were thoroughly researched and discussed extensively with our client. The magnetic gripping system did not satisfy the project's constraints. The main reason was due to the fact that our client does not wish to replace nor modify his dishware to accommodate a magnetic system. Replacing dishware for magnetic dishware would an added cost and could have other repercussions by changing the dishware aesthetics.

The second dishware gripping system considered was a jaw gripper configuration. Although quite common in commercial and industrial automation systems, several potential issues arose upon further analysis. With a diameter of just over 30cm, the plates are much too large for an encompassing grip around them. The pure friction grip could require a sizeable amount of force and would have difficulty if the plates were still slightly wet, varying the coefficient of friction meaning variable force would be needed. Wet plates would affect most grip configurations therefore this reason was not the main deterrent. The principle issue found with the jaw gripper is the fact that they require access to both sides of the plate, which significantly increases the space given between plates in their tray configuration. Additionally, placing the plates will also be an issue with a grip underneath because they will be stacked and the lower lip of the grip will be caught between the plate and the stack.

For the above mentioned reasons, the vacuum grip system was selected. It is commonly used in industry for gripping various flat surfaced objects and requires access from only a single frontal plane, reducing space between plates. The single side gripping also facilitates the stacking of the plates with only requiring above clearance. As seen in Figure 5 in the Appendix, Eqn (1) and Eqn (2) show the theoretical diameter of the vacuum cup of around 5.1 cm that would be needed to manipulate our dishware.

4. Design Implementation

4.1. Constructing Model

We constructed the model using a Tinkerkit Braccio Robot (T05000) from Digi-Key Electronics. The original manufacturer is the Arduino Corporation which offers a range of software and hardware tools for use. Arduino boards are a popular tool for product development and an extremely successful tool for STEM/STEAM education. The arm was put together and the necessary movements were being implemented. Due to time constraints, unfamiliarity with Arduino, and an unforeseen intellectual property debate that greatly stalled the project further coding and precision alignment is necessary to develop a more complete model to showcase. The incomplete model can be seen in Figure 1 where the complete model can be seen in Figure 3.

Figure 1 The incomplete model arm from Arduino

4.2. System Overview

The design for an automated dishwashing system consists of various stages each with multiple functional components. Once the tray is loaded and the dishwasher begins its wash cycle, the autonomous system begins. The first stage is the linear actuated opening of the dishwasher followed by the tray retrieval component. This is then followed by the robotic arm unloading of the plates and cutlery to the stacking zone. Finally, the stacked plates and cutlery pod is transported to the final destination via the conveyor belt system for workers to access them.

4.3. Design Testing

4.3.1 Braccio Robotic Arm Testing

The design testing was focused on the robotic arm design concept. The acquiry of the Arduino Braccio Robotic Arm allowed for various coding and testing to be performed. The unit was assembled quickly and base test codes were ran. This testing phase became an iterative process as calculated angles were not showing expected results.

The first preliminary test conducted was a test file made to verify the correct assembly of the unit's various components. The six-servo-motor arm was configured to the "reach" position where each motor's angles were selected to configure the arm in a vertically erect straight position. From this test many individual servo motor adjustments were required as the angles imputed did not reflect the expected results. This involved repeated disassemblies and servo motor calibrations using a secondary Arduino Uno microcontroller board.

The secondary test involved the assessment of the arm's gripping ability. The first observation was made that the range of the gripping teeth was limited to a 63 degree window, from 10° to 73°. This restriction determined the parameters for the geometry of the target object. As the gripping width in the "open" position was 11 cm and the "closed" width was about 9.5 cm, our object's dimensions for initial load testing would need to be in that range. Several objects were tested such as 10 cm diameter cups of varying wall thickness but tests resulted in failures. This was due to the gripping mechanism's limited load range. The plastic cups were weighed at 33g, 19.5g, and 17g and the force applied on them from the gripping servo in combination with an apparent lack of friction (observed slipping) resulted in the arms inability to lift the objects. Therefore, a lightweight sphere of aluminum foil was used that met the dimensional and weight requirements of the gripping mechanism. The aluminum foil object was around 9.8 cm in diameter with a weight of 9 g.

The final test that was performed was the manipulation of the aluminum foil object. After many adjustments made the series of servo motor angles were created to effectively lift the object from a initial area and place it in the unloading area. This was a simple proof of concept of the predetermined coordinate system previously proposed and servo angle values for other object positions were made as well. Figure 2 is a snippet of the code used and displays the final angle values of the six servo motors along with their respective time delays to ensure smooth arm movement as to minimize risks of slipping or dropping of the object. We can see the various steps of the robotic arm as it operates and executes the test in Figure 3.

taketheplate

```
//Starting position
                    //(step delay  M1 , M2 , M3 , M4 , M5 , M6);
Braccio.ServoMovement(20,           0,  45, 180, 180,  90,  10);

//Wait 1 second
delay(1000);

//The braccio moves to the sponge. Only the M2 servo will moves
Braccio.ServoMovement(20,           0,  90, 180, 180,  90,   10);

//Close the gripper to take the sponge. Only the M6 servo will moves
Braccio.ServoMovement(10,           0,  90, 180, 180,  90,  60 );

//Brings the sponge upwards.
Braccio.ServoMovement(20,         0,   45, 180,  45,  0, 60);

//Show the sponge. Only the M1 servo will moves
Braccio.ServoMovement(20,         180,  45, 180,   45,   0,  60);

//Return to the start position.
Braccio.ServoMovement(20,         0,   90, 180,  180,  90, 60);

//Open the gripper
Braccio.ServoMovement(20,         0,   90, 180,  180,  90, 10 );

```

Figure 2: Snippet of code written in Arduino to show final angle values of the proof of concept movement test conducted.

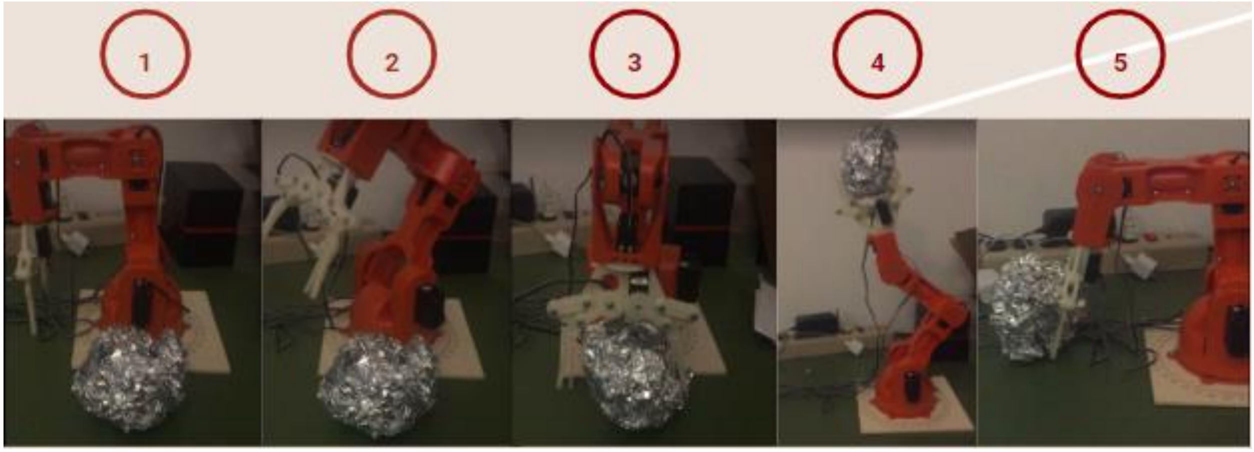


Figure 3: Snapshots of Braccio Robotic arm executing the test. Step 1 shows initial rest position, Step 3 is the acquiry of the object and Step 5 is the placement of the object.

Though our testing design uses a jaw gripper, our concept design still utilizes the vacuum cup system but due to the incompatible coding softwares it was not possible to code the use of a vacuum system on our Arduino based testing code.

4.3.2 Proximity Sensor Testing

Proximity Sensors were evaluated and we tested their effectiveness and best location. On the Braccio arm the proximity sensor affixed to various points to find optimum positioning to best identify plate presence. We selected an infrared proximity sensor for its availability and low cost.

We used the Sharp GP2Y0A02YK0F infrared proximity sensor. The product's specifications stated that the product has a range of measurement of 10 cm to 80 cm. This posed a few issues from a design perspective as the gripping teeth, to which the sensor is attached, are around 11 cm apart. Therefore the presence of a plate between the gripping teeth would be at a distance of only 5 cm, which is out of the sensor's supposed precision range. Objects placed closer than the minimum distance range return substantially higher analog outputs that are inconsistent with the expected in-range results.

```
arduino_code_for_proximity_sensor §

//collects data from an analog sensor

int sensorpin = 0;                 // The analog pin connected to the proximity sensor
int val = 0;                 // Setting initial variable to store the values from sensor(initially zero)

void setup()
{
  Serial.begin(9600);                 // Commences the serial monitor
}

void loop()
{
  val = analogRead(sensorpin);        // analogRead reads each value of the proximity sensor
  Serial.println(val);             // displays each value of the sensor to the serial monitor
  delay(3000);                     // Delay before printing next value
```

Figure 4: Display of code used for testing of Sharp sensor values.

A test was conducted to see what values are obtained when the object is set under 10 cm away from the sensor and at varying distances. The setup of the sensor involved connecting the proximity sensor to the Arduino Uno board and then affixing to a flat surface. A circular cardboard cut-out was used to replicate a dish and the sensor was used to identify the presence of the plate. The code used is displayed in Figure 4. It shows the analogRead method used to output values with a delay of 3 seconds to allow the object to be moved to the next position. The values obtained can be displayed on the following table.

Table 6: Values of proximity sensor distance test

Object Distance (cm)	analogRead() value
1	323
5	655
20	272
40	145
60	116
80	104

These values were then graphed to easily identify trends or anomalies.

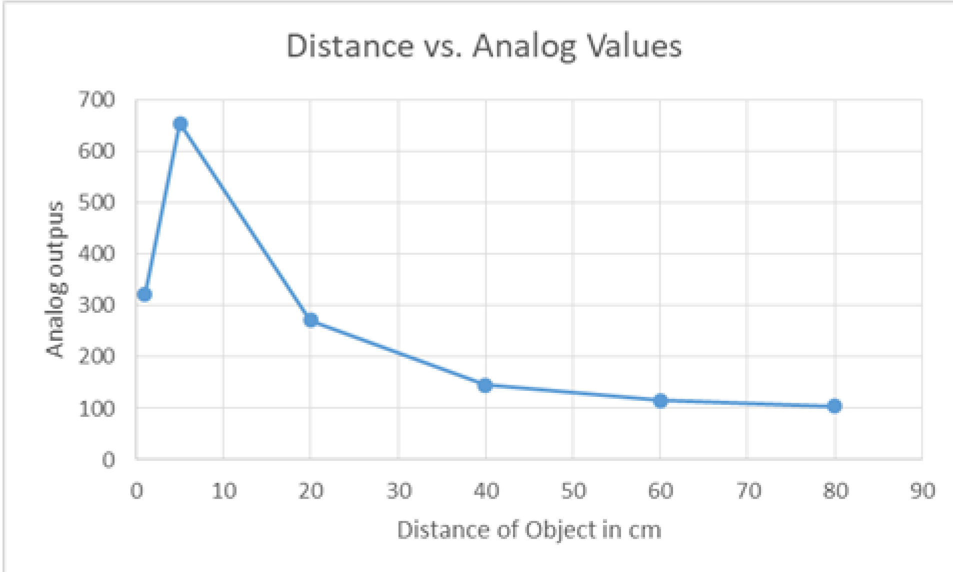


Figure 5: Graphical representation of values of proximity sensor distance test

Though the precision of the sensor was completely compromised at values under 20 cm, a key observation was made. As displayed in Figure 5 there is a significant peak when the object was placed at a distance of 5 cm. This peak is of significant interest to us as 5 cm (±0.5 cm) is the distance from the sensor to where a plate is found between the grippers. The use of the proximity sensor is only to simply identify the presence of a plate between the grippers. Therefore the analog value of 655 can be used as a switch for the system to continue with the recuperation, as in the closing of the grippers and the transportation to the stacking zone. With this result an if statement can be written within the robotic arm's commands to effectively identify the presence of a plate. We used 600 as safety factor for the analog output value, guaranteeing that it is not seeing the other tooth of the gripper which is around 11 cm away. The decision pathway for the plate identification is as follows in Figure 6:

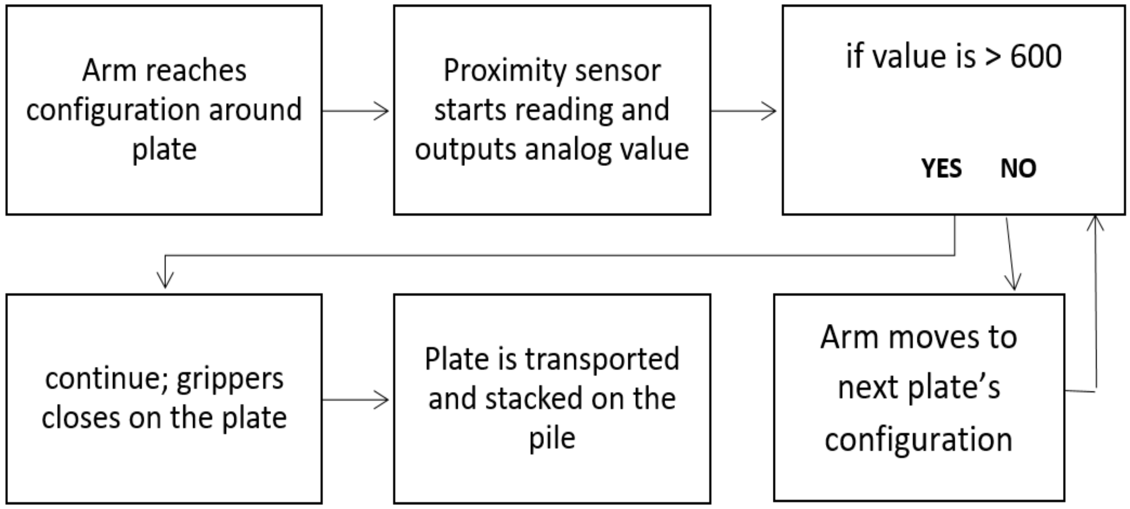


Figure 6: Flowchart representation of decision making pathway for plate identification and communication with arm

During the experiment we also noted certain limitations. The values of interest obtained were indeed anomalies and replications could prove to be difficult. Additionally when affixed on the gripper hand, the proximity sensor needs a constant background to successfully identify an object at the specified distance. The loops in the code above were written with 3 second delays but when it is attached to the arm, the commencement of the sensor readings must be enabled by the correct position of the arm which was difficult to code in the loop form of *Arduino*. Furthermore, when using infrared sensors, slight changes in light can be significant in sensor readings. The difference in light values from the testing area to that of its other implementation environments could be large enough to force the recalibration of the 5 cm window code.

4.3.3 Humidity Considerations

Once the dishwasher has finished cleaning the dishes there will be a release of water vapor into the air, thus creating a humid environment. This is potentially problematic to our design because it would begin to corrode the exposed wiring and joints and progress to leave our arm inoperable. Humidity is a significant problem when considering metallic moving parts and it is understood that corrosion progresses rapidly when relative humidity levels are raised. This relationship can be seen in Figure 7 below.

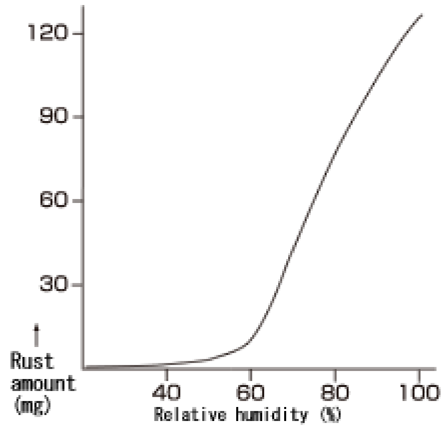


Figure 7: Rust vs. Relative Humidity (Apiste Corporation, 2018)

This graph was compiled by exposing a metal sheet to the air which includes humidity and inspecting the respective rusting quantity. This depicts the relationship between rust and humidity and serves to set a limit to the environment our model arm can withstand. Since we do not wish to test the limits of the single model arm obtained we decided to brainstorm potential recommendations to combat this foreseeable issue. The solution discussed was to enclose the structure and route all the cables internally to equip the arm to handle the most extreme cases as well as allow the water to flow vertically. An example of this can be seen in Figure 8 below.

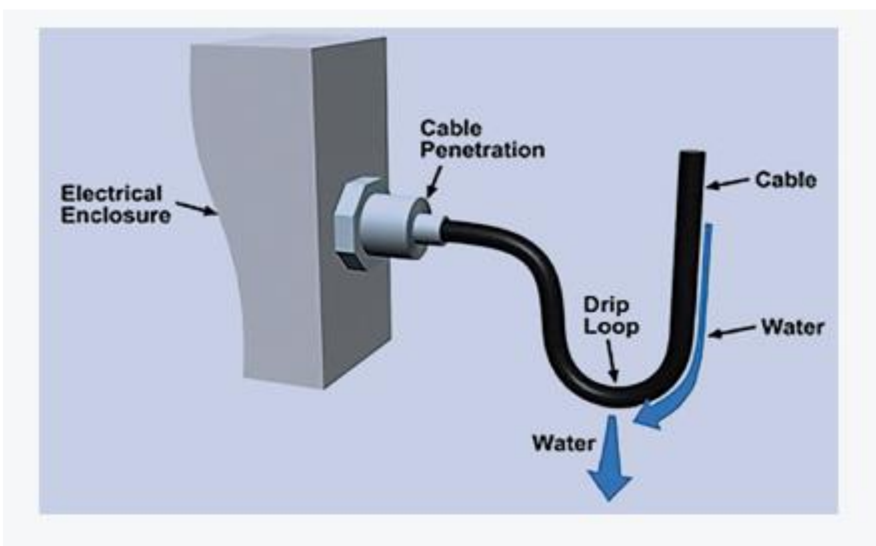
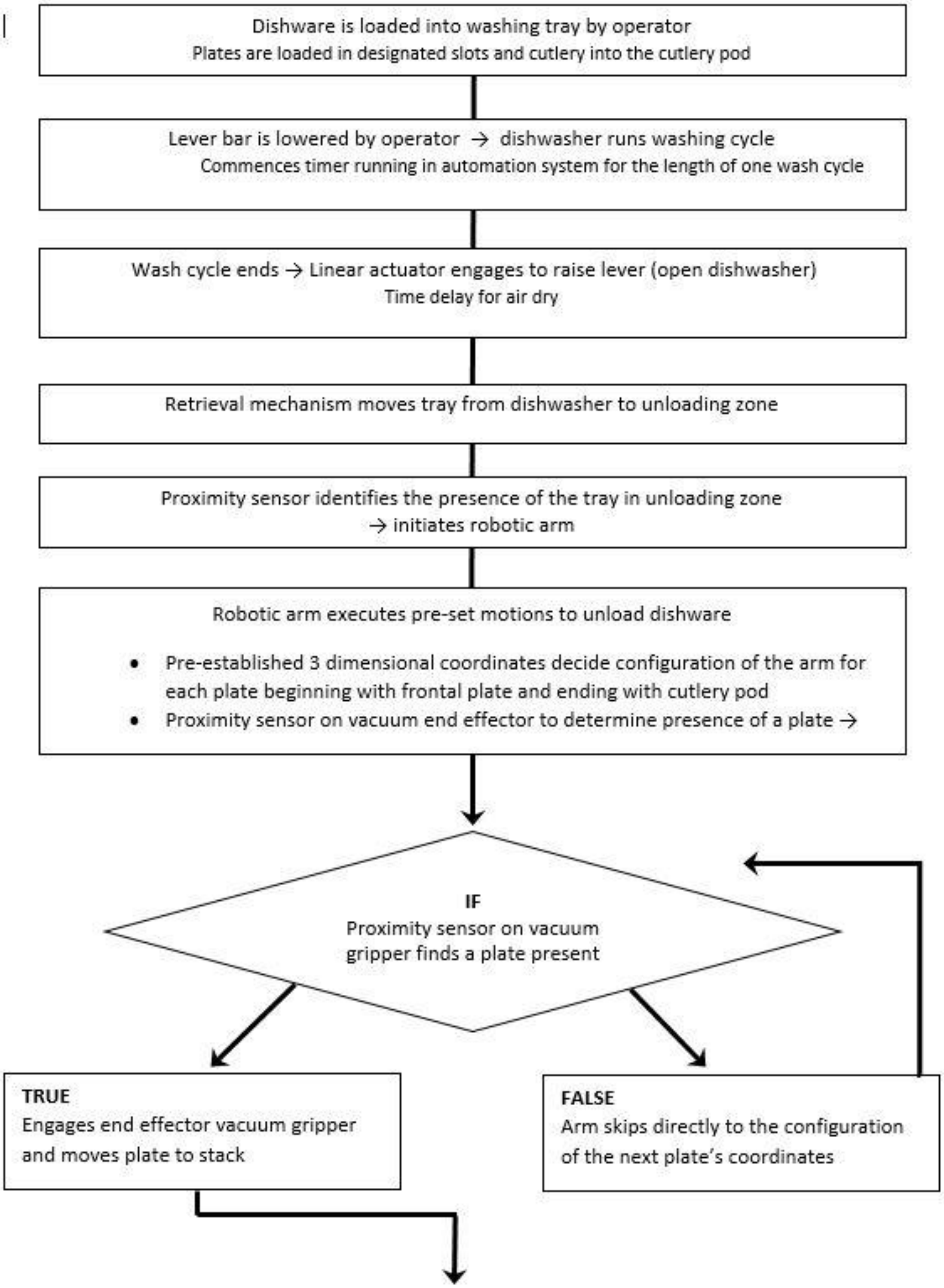


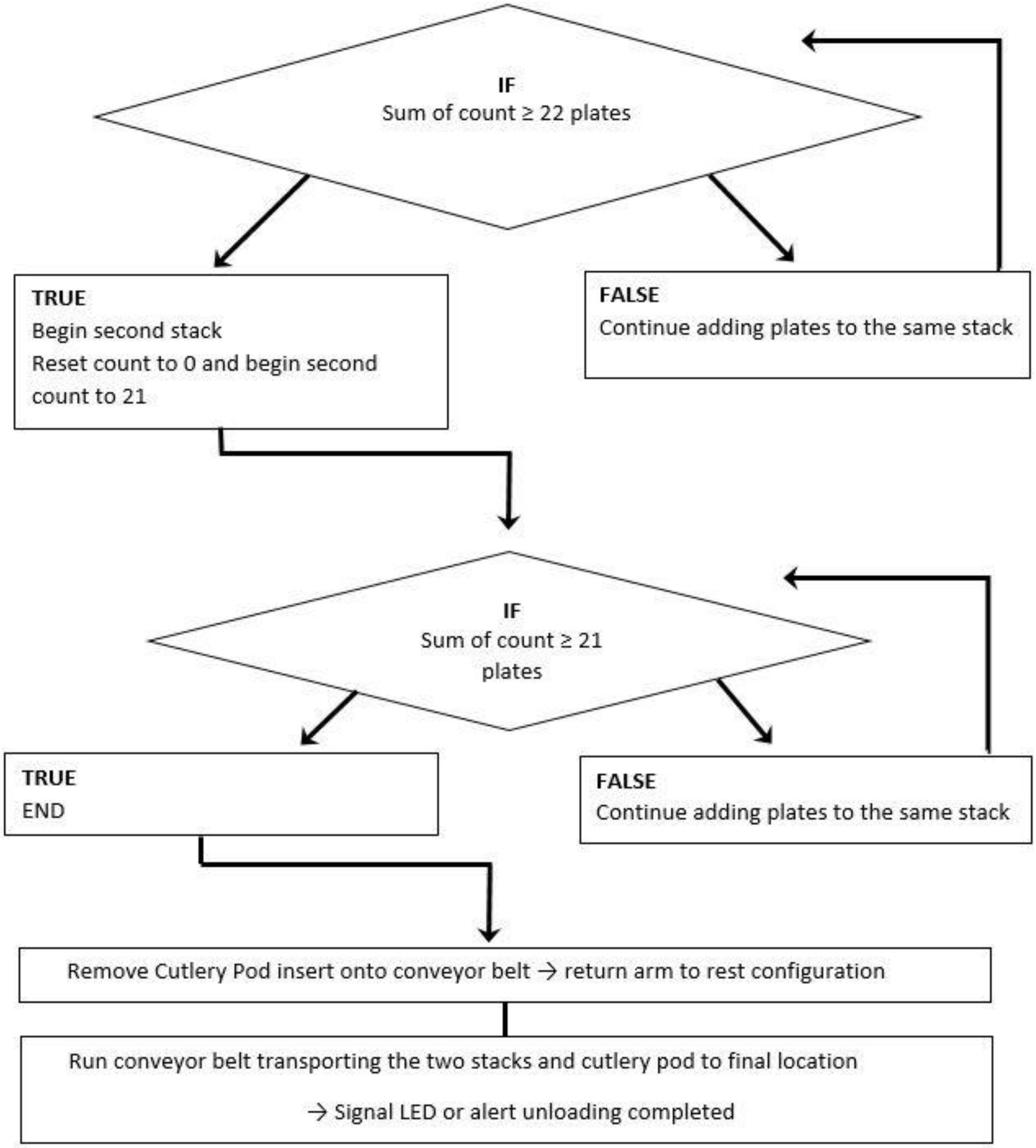
Figure 8: Advantage of Cable Orientation (Moisture Protection of Electronics - 2014)

This in conjunction with routine maintenance and an educated employee staff that would watch for potential breaks in the enclosure would help to keep the electrical components dry and working safely.

4.4 Process System Flowchart

This is a general overview of individual phases' communication and processing decisions in the system:


Dishware is loaded into washing tray by operator
Plates are loaded in designated slots and cutlery into the cutlery pod
Lever bar is lowered by operator → dishwasher runs washing cycle
Commences timer running in automation system for the length of one wash cycle
Wash cycle ends → Linear actuator engages to raise lever (open dishwasher)
Time delay for air dry
Retrieval mechanism moves tray from dishwasher to unloading zone
Proximity sensor identifies the presence of the tray in unloading zone
→ initiates robotic arm
Robotic arm executes pre-set motions to unload dishware
Pre-established 3 dimensional coordinates decide configuration of the arm for each plate beginning with frontal plate and ending with cutlery pod
Proximity sensor on vacuum end effector to determine presence of a plate →
IF
Proximity sensor on vacuum gripper finds a plate present
TRUE
Engages end effector vacuum gripper and moves plate to stack
FALSE
Arm skips directly to the configuration of the next plate's coordinates



The decision making process of the system is governed by timing and sensor indicators. The tray is designed in a way to limit variance in plate position to facilitate engagement with the vacuum cup of the robotic arm.

As soon as the operator lowers the panel of the dishwasher with the loaded tray inside, the automated process commences. Using a timer a linear actuator reopens the dishwasher door and an air drying stage occurs after the wash cycle. Afterwards, the tray is moved into the unloading zone using a second linear actuator and hook system. A proximity sensor identifies the tray and the above decision process is executed by the arm and vacuum end effector to unload and stack the dishware.

In the second stack, the proximity sensor on the end effector maintains a count of present dishes and empty positions if the dishwasher is under loaded which determines how many plates total will end up stacked avoiding and infinite false loop. The present dish count determines the height of placement of the robotic arm as illustrated in Figure 6 in the Appendix. The empty position count determines when to end the first and/or second stack. Stacks of under 25 plates were determined to avoid tipping yet limit number of total stacks.

Finally the dish stacks and cutlery pod are moved using a conveyor belt around to the final position across from the initial loading area. This facilitates the operators' trip where they can load the dishwasher tray and simply behind them they can access the cleaned dishware for immediate use in the restaurant. Alerting systems are available to communicate the completion of a washing cycle to the operators and will be implemented if deemed necessary by the client.

4.5 Design of Customized Commercial Dishware Rack

In addition to the development of the robotic arm, our team redesigned the current dishware racks utilized by Pizza 900 to improve the efficiency of the dishwashing process. Furthermore, by remodeling the trays we are able to ensure a consistent geometrical orientation of the dishware, enabling us to use a predetermined coordinate system in our programming code to target the tableware during the unloading stage of the process.

When our team first visited the kitchen facility of Pizza 900 in early September, we examined their current dishwashing process. The restaurant is equipped with square peg dishware racks with a side length of 49 cm, which at full capacity can fit 25 pizza plates or approximately 50 forks and 50 knives. Due to the size of the dishwasher, the development of larger trays was not feasible, however hefty improvements could be made as the dissimilar geometries of the current trays and the dishware left a lot of the tray area unused. Moreover, our team envisioned one single tray able to hold cutlery and pizza plates concurrently to eliminate the inevitable extra wash cycles the restaurant is running. Pizza 900 utilizes 0.5 cm thick plates with a diameter of 30.48 cm, therefore in our design it was decided to make the allotted space for each plate 1 cm wide and 31 cm long. As 49 cm is the limiting factor of the dishwasher for the tray design, and accounting for 0.5 cm thick borders around the exterior of the tray and an additional distance of 0.5 cm between each plate, our design fits 43 plates while leaving a total area of 307 cm^2 set aside for cutlery. To occupy the remaining surface area, we designed a removal cutlery pod which can hold 44 forks and 44 knives at once. The pod is 17.02 cm in length and 17.52 cm in width, with 0.5 cm thick, 10 cm tall borders and a 25 cm tall cylinder at its geometrical center of radius 6 cm. The cylindrical solid is essential for the unloading of the cutlery pod from the dishware rack onto the conveyor belt, as the 5 cm wide vacuum cup attached to the robotic arm must make contact with a high friction surface. For the development of the fork and knife allocated spots, the same optimization approach to the plates was taken. Figure 1 shows the overall geometric orientation of the newly designed trays and the detachable cutlery pod.

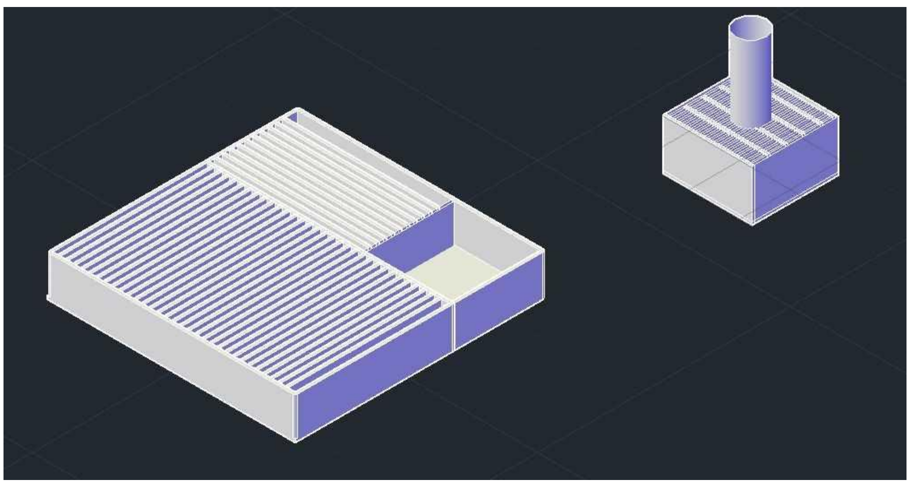


Figure 9: Conceptual view design of customized dishware rack and cutlery component using AutoCAD 2019. The 3-D Wireframe view and a more detailed view of the cutlery pod can be found in the Appendix as Figures 21 and 22.

To assist our design process, on one of our visits of Pizza 900, Mr. Alexandre Brunet gave us a brief overview of the daily operations of its Peel location. He shared with us that in one day Pizza 900 serves food to an average of 150 people, amassing to around 150 dirty pizza plates, and 150 dirty knives and forks. Glassware was not considered for this part of the design, as not enough opportunity for advances to the current utilized trays could be achieved.

Presently on an average day, the Pizza 900 employees must run their dishware 6 times to wash the plates, as well as an additional 3 times to wash the dirty cutlery for a total of 9 daily cycles. With the implementation of the new trays, Pizza 900 will see a 73 % increase in plates per rack and an addition of 88 cutlery spots per rack, therefore reducing the number of daily dishwashing cycles 23% from 9 to 6.9. This more efficient system will hence help Pizza 900 maximize returns, lower their environmental impact, and leave more time to its employees to focus on more productive tasks.

5. Design Considerations

5.1 Environmental Considerations

When Mr. Brunet approached us, he envisioned not only a profitable modification to his restaurant's daily operations, but also an opportunity to become more environmentally sustainable. The design made careful use of the facilities already available at the location and looked to eliminate variable use of water and energy due to human error and interaction.

5.1.1 Water Consumption

Commercial dishwashers vary in their water use from 2.5 to 8.0 gallons of water per minute, depending on the type of dishwasher (Buschatzke, 2014). When visiting the Peel location, our team ran a full cycle of the dishwasher and timed it to be precisely 2.1 minutes. Using these values, the daily water consumption of Pizza 900 at minimum and maximum conditions with and without the introduction of our newly designed trays can be found.

Present Water Usage:

$$\text{Maximum Consumption} = (8\ \frac{gallons}{min})(2.1\ \frac{min}{cycle})(9\ cycles)(4.546\frac{L}{gallon}) = 687.4\ \frac{L}{day}$$

$$\text{Minimum Consumption} = (2.5\ \frac{gallons}{min})(2.1\ \frac{min}{cycle})(9\ cycles)(4.546\frac{L}{gallon}) = 214.8\ \frac{L}{day}$$

Future Water Usage with Implementation of New Trays:

$$\text{Maximum Consumption} = (8\ \frac{gallons}{min})(2.1\ \frac{min}{cycle})(6.897\ cycles)(4.546\frac{L}{gallon}) = 526.7\ \frac{L}{day}$$

$$\text{Minimum Consumption} = (8\ \frac{gallons}{min})(2.1\ \frac{min}{cycle})(6.897\ cycles)(4.546\frac{L}{gallon}) = 164.6\ \frac{L}{day}$$

In conclusion, the implementation of these customized trays will result in a 23 % decrease of water usage by the dishwashing system, and Pizza 900 could save more than 60,000 L of water in a year.

Further water savings can be achieved by modifying the current pre-rinsing process of Pizza 900. A low-flow, high-performance pre-rinse spray valve is in fact the single most cost-effective piece of equipment for water savings in commercial kitchens and our team has made numerous recommendations to our client, stressing the benefits of the installation of this apparatus (Delagah, 2015).

5.1.2 Energy Consumption

In 2003, the U.S. Department of Energy (DOE) established that a minimally compliant dishwasher would use 2.17 kWh per load of dishes (Hoak and Parker, 2008). Using this value, the daily energy consumption of Pizza 900 due to the dishwashing equipment with and without the introduction of our newly designed trays can be calculated.

Present Energy Usage:

$$\text{Energy Used} = \left(2.17\ \frac{KWh}{cycle}\right)(9\ cycles) = 19.53\ \frac{KWh}{day}$$

Future Energy Usage with Implementation of New Trays:

$$\text{Energy Used} = \left(2.17\ \frac{KWh}{cycle}\right)(6.897\ cycles) = 14.97\ \frac{KWh}{day}$$

Once again we notice a 23 % decrease in the KWh consumed by the dishwashing equipment, amounting to a reduction in energy usage of 1664 KWh in one calendar year. As we move forward with the project a more thorough energy analysis will be completed, taking into account the overall energy the whole automated system will consume.

5.2 Social Considerations

There are two perspectives to consider when discussing the project. The first perspective is the users. The user must have a simple, but effective time with the new design and feel safe when in proximity of the operation. The user must also be left ample space to walk around and input dirty dishes or take clean ones away. The other social perspective to consider is that of the customer of Pizza 900. The performance of the system must be smooth and not disturb the dining environment of a customer whether that be noise, smell, malfunction, or even being an eyesore.

5.2.1 Occupational Health and Safety

It is important when considering any process in the workforce that the project considers the impact to the employees who are directly affected. According to the government of Canada, "A health and safety program is a definite plan of action designed to prevent accidents and occupational diseases. Some form of a program is required under occupational health and safety legislation in most Canadian jurisdictions. A health and safety program must include the elements required by the health and safety legislation as a minimum" (CCOH, 2018). The basics of the plan outlined are laid out below:

- Individual responsibility.
- Joint occupational health and safety committee.
- Health and safety rules.
- Correct work procedures.
- Employee orientation.
- Training.
- Workplace inspections.
- Reporting and investigating accidents/incidents.
- Emergency procedures.
- Medical and first aid.
- Health and safety promotion.
- Workplace specific items.

The safety and health of the employees and customers comes first in any design process. The supervisor will ensure they are familiar with the equipment present and the employees are properly trained on how to use it. There will be guidelines and warnings posted on the correct use of the facilities being used as well as procedures on what to do when a malfunction or mishap occurs. All personal will be held responsible to maintain the high standard set by the supervisor and enforcing it amongst other employees. All other relevant laws and regulations will be incorporated in the program as a minimum.

Further social considerations involve suitable noise level in the workplace. This is to be monitored in the selection process of vacuum gripping systems primarily in the pump selection. As the required force to lift a single plate is not enormous, the required mini-pump associated with the system can easily fit within the bounds of safe noise levels. The Vuototecnica boasts a small level of less than 50 dB in all their mini pump products (around -.04 bar pressure) (Vuototecnica, 2018). This value is well below the 90 dB regulatory standard of Quebec (CCOH, 2018). A second aspect considered in the product selection for the gripping system is maintenance. There are a wide variety of pumps available with sufficient specifications for the task that require no lubrication, which significantly reduces maintenance requirements of the entire system (Vuototecnica, 2018).

It should also be noted that the gripping system being used by the robotic arm will be detachable and therefore fall under standard sanitization practices once a full use of one day has concluded. This is within the guidelines set by the MAPAQ and will also help promote a healthy and enjoyable dining experience for the customers.

5.2.2 Technophobia

Technophobia is the fear or dislike of advanced technologies. With rates of innovation and technological improvements continuing to rise, technophobia is a rising social issue particularly in the workforce. Furthermore, technophobes have a higher probability to report experiencing anxiety-related mental health issues and to fear unemployment and financial insecurity (McClure, 2017). Therefore, this section assesses the threat of technological unemployment and the impact our system will have on Pizza 900’s current employees.

One of the main concerns for many is that the job market is diminishing due to increases in automation. Additionally, many believe not only that work prospects are decreasing but also that this rapid development of the robotics industry is increasing demand for educated workers and threatening the survival of the less educated (Acemoglu, 2003). Even those who have completed a college education may encounter fear of unemployment and financial insecurity as software and robots can do human work with higher reliability, higher efficiencies, and lower costs.

Throughout our design we continuously considered the direct and indirect effects of introducing our system into Pizza 900's value chain, taking into account its possible replacement of the current dishwashing system. When we presented our concerns about a possible rise in technophobia in his restaurant as a result of this automation, Mr. Brunet explained us that he didn't plan on letting go any of his current employees. Rather, he envisions they could be moved to more productive and less mundane tasks. By taking advantage of the increase in manpower, Pizza 900 will maximize its profits by increasing the value delivered to customers. Furthermore, by removing workers from dull responsibilities you can greatly limit workforce depression, increase collaboration and teamwork, and ultimately maximize profits.

5.3 Risk Factor Matrix

Table 7: Risk Factor Matrix

Keeping the safety of those involved in mind it was important once the design path had been finalized to consider the possible risks that finished product might entail. The risk factor matrix in Table 7 was made based on the template used by The United States Department of Energy. In their system, a risk is ranked from 1-3. The number one is considered the lowest risk, colored green, and least likely. The number two is moderate risk, colored orange, and moderate likelihood. The number three is considered the highest risk, colored red, and most likely to occur (Department of Energy, 2018).

Risk Factor	Risk Rank (1-3)	Risk Contributor	Solution
Contamination of Arm and Belts	3	Low Maintenance of parts in contact with dishes	Parts in contact are clean fromt start and will be cleaned daily
Wiring in a Kitchen Environment Becomes Saturated	2	Wires are in a damp environment	Proper encasing of electrical equipment
Stacks Should Not Exceed 25 Plates	1	43 plates are being sent through a wash	Stacks will be cut into 21 and 22 piles by a count
Gripping Potentially Will Become Saturated	2	The damp plates will wet the rim of the suction cup	Rim is removable and will be washed and replaced daily
Physical Entrapment Hazard	1	Employees will become tangled in moving parts	Proper training to explain equipment in use
Dishes Are Dropped by Arm	1	A wet rim of the suction cup or clogged flow	Suction will be stronger than the minimum needed to lift plates

5.4 Economic Considerations

To accurately determine the economic viability of this design, a thorough financial analysis must be completed. The following economic analysis is split into two sections: a break even analysis of the investment in new dishware racks, and a cost-benefit analysis of the whole envisioned system. Lavotica will experience first mover advantages entering a new market hence primary market research data is unavailable, therefore several simplifying assumptions were made.

5.4.1 Break- Even Analysis

Break-even analysis is a financial analysis technique widely used by management and accountants to determine the break-even point of an investment as shown in Figure 10.

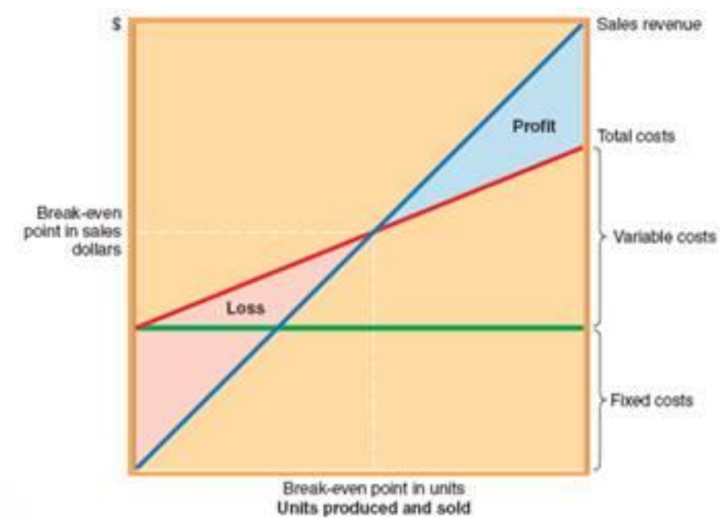


Figure 10: General Break Even Graph (Tutor2u Business, 2018)

To put it simply, total variable and fixed costs with and without the utilization of the customized trays are compared, to determine the time at which Pizza 900's investment in the new trays becomes profitable.

To complete the analysis we must first compute the fixed relevant costs, which are simply equal to the cost of the customized trays. Polypropylene was chosen to construct our trays, as its thermal properties enable it to withstand high temperatures and it is a widely used and affordable plastic (Grebowicz et al., 2007). Using the measure function on AutoCAD 2019, our team found the total volume of our customized trays and cutlery pod to be 9604 .. ^{3}.

Using the density of our material, its cost per weight, and the overall volume of our design we can calculate the total cost of one dishware rack:

$$Initial\ Capital\ Expenditure = (Volume)(Density)(Cost\ of\ Material)$$

$$Volume = 9604\ cm^3$$

$$Density = 0.92\ \frac{g}{cm^3}\ \text{(Lenntech, 2018)}$$

$$Cost\ of\ Material = 0.58\ \frac{\$}{kg}\ \text{(Statista, 2018)}$$

$$Initial\ Capital\ Expenditure = (9604\ \frac{cm^3}{tray})(0.92\ \frac{g}{cm^3})(10^{-3})(0.58\ \frac{\$}{kg}) = 5.10\ \frac{\$}{tray}$$

Now that the fixed costs involved with the production of new trays have been calculated, the variable costs must be found to finish the economic analysis. To calculate the variable costs associated with the dishwashing process, both before and after the implementation of the trays, the water and energy costs must be found and summed. The Ville de Montreal website specifies the price of water to be *0.22* $\frac{\$}{\square^3}$ (Ville de Montreal, 2018), while Hydro-Quebec's Electricity Rates effective April 1, 2018, for medium power usage, in Montreal are 9.81 cents per KWh (Hydro Quebec, 2018). The following formulas were used to calculate the total maximum variable costs, hence at maximum water consumption:

Utilization of Current Dishware Racks:

Total Maximum Variable Costs =

$$(0.22\ \frac{\$}{m^3})(0.57\ \frac{m^3}{cycle})(9\ \frac{cycles}{days})(\#\ of\ days) + (0.0981\frac{\$}{KWh})(2.17\frac{KWh}{cycle})(9\frac{cycles}{days})(\#\ of\ days)$$

Utilization of New Dishware Racks:

Total Maximum Variable Costs =

$$(0.22\ \frac{\$}{m^3})(0.44\ \frac{m^3}{cycle})(6.897\ \frac{cycles}{days})(\#\ of\ days) + (0.0981\frac{\$}{KWh})(2.17\frac{KWh}{cycle})(6.897\ \frac{cycles}{days})(\#\ of\ days)$$

Using these equations data for total costs for a full calendar year was found and plotted against time.

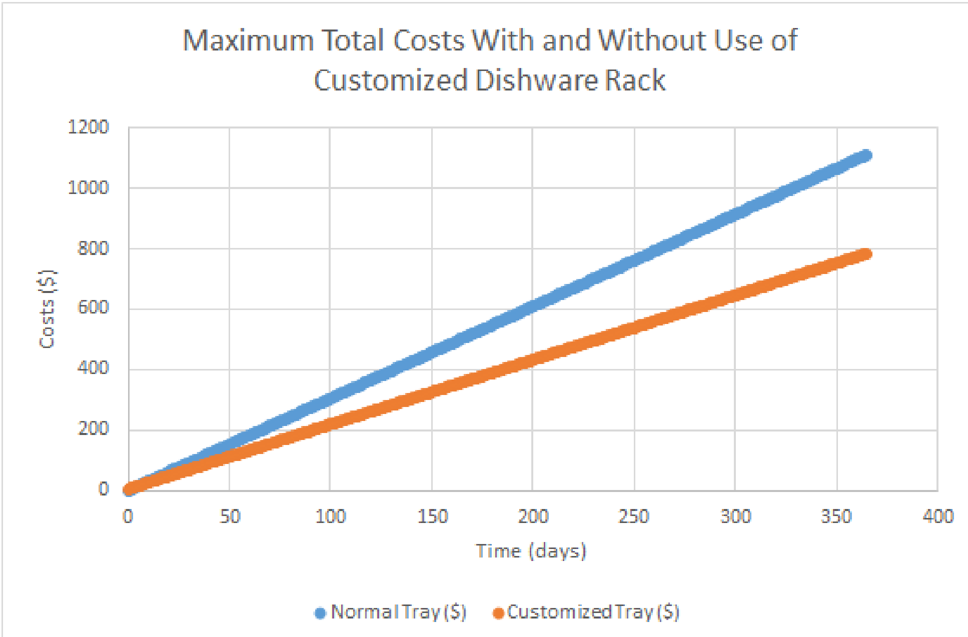


Figure 11: Total costs with and without use of customized dishware rack at maximum water usage.

Figure 11 follows the principles outlined in Figure 10. The fixed costs for the system presently in motion are $ 0 as no initial investments must be made, while the fixed costs once the new trays are introduced jump up to $5.10 which is the initial capital expenditure for the production of the trays. The variable costs then grow at a constant rate proportional to time and the moment the two curves intersect represents the break-even point. To find the break-even point we simply equate the total variable plus fixed costs of the current system to the total variable plus fixed costs of the newly incorporated system and find time. The capital investment in one tray therefore becomes profitable for Pizza 900 after just 5.6 days. The net savings from the introduction of the trays at any point in time can be seen in Figure 4, which clearly illustrates how there is potential to save around $326 in a period of 1 year, a 64 % return on investment.

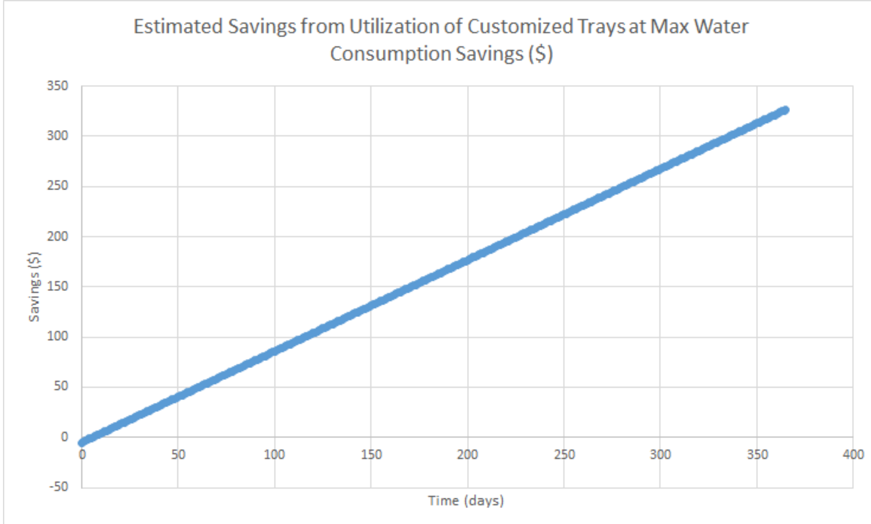


Figure 12: Estimated savings at any point in time over a period of 1 year with the utilization of customized trays.

5.4.2 Cost-Benefit Analysis

Robot utilization has risen exponentially since the 1960s, and the significant advances in computing technology, artificial intelligence and electronics have contributed to them becoming safer to use, easier to program, and more affordable. In fact, the price of industrial robots has fallen more than 25% since 2014 and is expected to continue following this downward trend. The main factors in determining robot costs are reach, number of axes, application, end of arm tooling and safety components. Implementing a robotic arm system which could effectively operate in Pizza 900's limited kitchen space, considering the costs of conversion, has a cost structure like the one depicted in Table 8.

Table 8: Cost Analysis of Implementation of Automated Dishwashing System

Components	Costs ($)
Robotic Arm	22,000
Pedestal	3,000
Vacuum Suction Cup	500
Manual Labor	1,000
Total Cost	26,500

This breakdown was gathered using appropriate assumptions and data collected from the costs of similar products in the robotics industry, as Lavotica will experience first mover advantages entering a new market and primary market research data is therefore unavailable.

Furthermore, manual labor costs were calculated assuming a total of 40 hours will be needed for installing the system at a rate of 15 $/hr.

However, to determine the economic viability of this robotic-arm design a detailed financial analysis must be completed. As the driving reason for Mr. Brunet to implement this automated dishwashing system is cost reduction, the design must be simultaneously innovative, reliable, and cost efficient hence enticing restaurant owners to alter their current work organizational structure. To calculate the true cost of operating the robotic arm, labor cost savings must be considered. By replacing manual labor with robots, the average global labor-cost savings could reach 16% worldwide by 2025, and as high as 24% in countries with higher wages such as Canada (Boston Consulting Group, 2015).

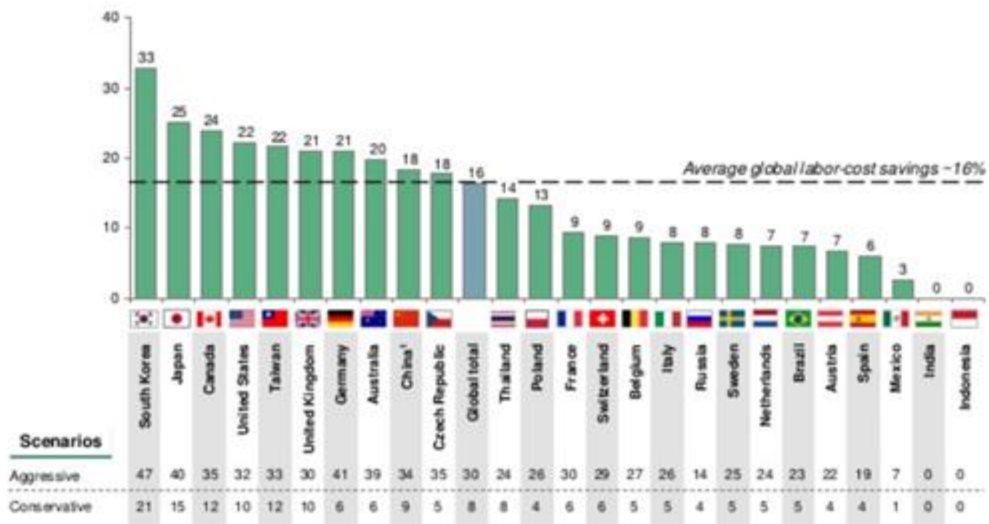


Figure 13 : Labor-cost savings from adoption of advanced industrial robots (%, 2025)

To put these labor cost savings into perspective we can calculate and compare the operating costs of the current dishwashing system utilized at Pizza 900, vs. the possible state once Lavotica's technology is introduced. Assuming 40-hour work weeks, 52 weeks a year, and considering that after accounting for health care, insurance, income and time off Mr. Brunet spends $100,000 on dishwasher salaries:

$$Current\ System\ Operating\ Costs = \frac{(100{,}000\ \frac{\$}{year})(5\ years)}{(40\frac{hour}{week})(52\ \frac{week}{year})(5\ years)} = 48.08\ \frac{\$}{hour}$$

$$Lavotica's\ System\ Operating\ Costs = \frac{(\$26{,}500)}{(40\frac{hour}{week})(52\ \frac{week}{year})(5\ years)} = 2.55\ \frac{\$}{hour}$$

As the calculations above clearly show, by introducing the robotic arm into Pizza 900's value chain, the restaurant will notice a drastic drop in their operating costs showing an almost 2000% decrease. The following cash flow diagrams further illustrate the cost benefits of Lavotica's system over a five-year span.

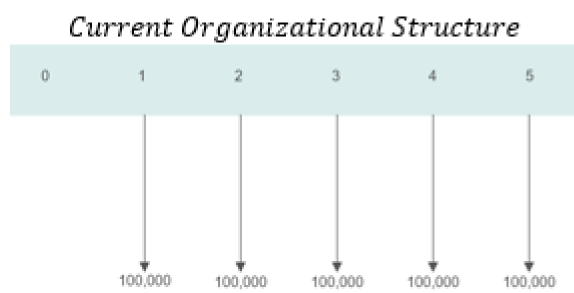


Figure 14: Current dishwashing costs cash flow.

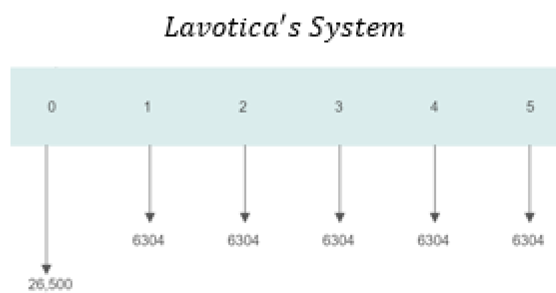


Figure 15: Dishwashing costs cash flow, after introduction of robotic arm.

In the current system, the yearly operating costs were provided to our team by Mr. Brunet, while for Lavotica's system they were found by spreading the 2.55 \$/hour , over 52 40-hour weeks and adding a \$1,000 maintenance charge per year. To facilitate comparison of the two diagrams, the present value of each was calculated assuming a 5% interest rate and using the following formula:

$$P\left[\frac{1-(1+r)^{-n}}{r}\right]$$

$$P = Periodic\ Payment$$
$$r = rate\ per\ period$$
$$n = number\ of\ periods$$

Therefore, under conventional operational methods in 5 years, Pizza 900 will spend $432,947.67 on dishwashing services, while with the introduction of Lavotica's automated dishwashing system it will only spend $53,793.02. This means that in just five years the introduction of this new system will directly save $379,154.65 to the Pizza 900 owners. Additionally, further intangible economic benefits come from the installation of Lavotica's automated dishwashing system through increased cleanliness reliability, as well as continuous operation with minimal human intervention.

5.5 Life Cycle Assessment

Life-cycle assessment (LCA), also known as life-cycle analysis, is a powerful tool to determine the holistic environmental impacts associated with every stage of a products life, from material extraction to disposal or recycling (International Organization for Standardization, 2006). After all phases are properly investigated and assessed, the results are then compared and analyzed among various factors. For the purpose of this design report, the life cycle analysis aims to determine the energy demand of the washing system operated by Pizza 900. Furthermore, this LCA investigates the environmental impact, measured as net carbon dioxide ($CO2$) emissions because of raw material extraction, production, distribution, consumer use, and disposal or recycling.

5.5.1 Functional Unit of Analysis, Impact Categories, and System Boundary

For the purpose of this examination, we will use one dirty pizza plate as our functional unit of analysis. The impact categories that are investigated are $CO2$ emissions, and total energy use. These values are calculated over the dishwasher's lifespan, which Pizza 900 replaces every decade. Furthermore, the system boundary for this study entails raw material extraction, manufacturing, and use phase for a dishwasher. Phases such as transportation and end-of-life are not considered for this section, but rather are discussed further along in the paper.

5.5.2 Life Cycle Energy Analysis

To begin our analysis, we established through secondary research the total energy associated with acquiring and processing all the raw materials that comprise an average dishwasher from 2008. Boustani et al., in their appliance remanufacturing and life cycle energy and economic savings paper outline this process. First, they gathered raw materials energy intensity in dishwashers by using the data on the energy cost of common materials. Next, knowing the raw materials' energy requirements, the energy demand of raw material acquisition and processing phase was quantified. Likewise, to quantify the energy used during the manufacturing and assembly phase we can base our calculations on literary values and multiply the manufacturing energy intensity by unit mass (Boustani et al., 2010). Their research produced the following figure illustrating the life cycle energy demands of new appliances:

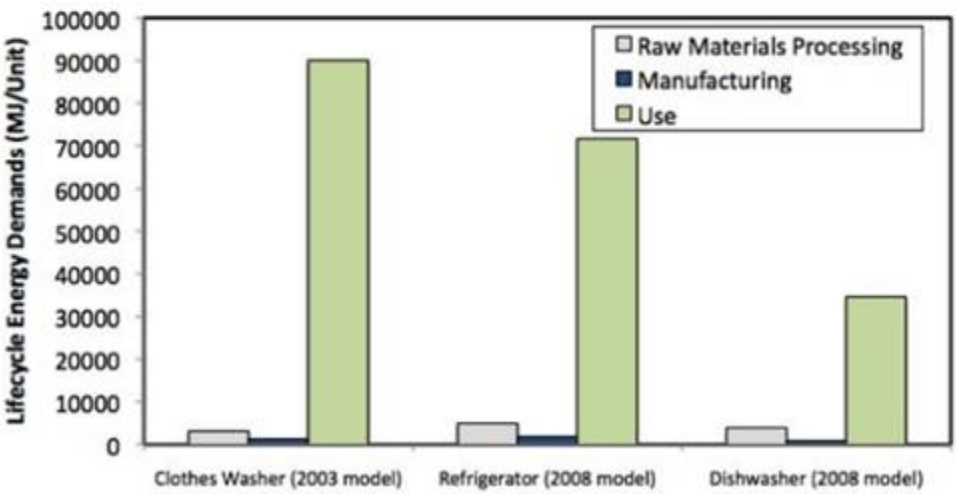


Figure 16: Life Cycle Energy Assessment of New Appliances (Boustani et al,2010)

The use phase is clearly dominating energy consumption, as it represents around 90% of the life cycle energy for all three appliances examined. Assuming Pizza 900's dishwasher has a similar energy usage structure as the one investigated by Boustani et al., by quantifying energy consumption during one phase we can find proportionally the energy usage of the remaining stages.

The direct energy use of Pizza 900's dishwasher over its lifecycle was calculated using the energy consumption equations (with the implementation of the customized trays) outlined in the environmental considerations section of the paper, and is depicted in Figure 17:

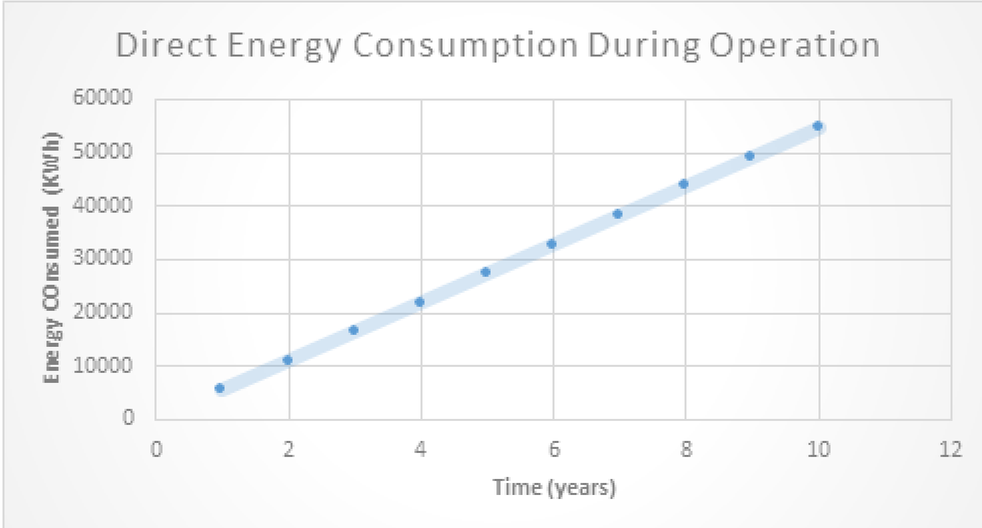


Figure 17: Energy Consumption of Pizza 900's dishwasher over its 10-year lifespan.

As Figure 17 clearly shows, Pizza 900's dishwasher will consume around 54640 KWh because of operation over ten years.

Furthermore, to produce a more comprehensive life cycle analysis, we can calculate the energy required to heat the water used by Pizza 900's dishwasher to the desired temperatures. Assuming the water comes in at 15 °C, and must reach a temperature of 35 °C, the total energy used to heat water can be calculated as follows:

$$Q = mc\Delta T = (density\ of\ water)(volume\ of\ water)(specific\ heat\ of\ water)\Delta T$$

If we assume maximum water consumption (526.7 L/day), and use values under standard atmospheric conditions for both the density and specific heat of water, then the daily energy needed to heat the water is:

$$Q = mc\Delta T = (997\ \frac{kg}{m^3})(526.7\ L)(0.001\ \frac{m^3}{L})(4200\ \frac{J}{kg})(35°C - 15°C) = 44110\ kJ \text{ or about } 12\ kWh/day$$

If we then multiply this usage of energy times the lifespan of the dishwasher we can quantify the total energy consumption due to water heating for Pizza 900's dishwasher:

$$Water\ Heating\ Energy\ Usage = \left(12\frac{KWh}{day}\right)(365\ days)(10\ years) = 43800\ kWh$$

Therefore, the total energy consumption during operation of the dishwasher over 10 years is 98440 kWh.

Now using proportional analysis gathered through secondary research, we can calculate the energy consumed during raw materials processing and manufacturing:

$$Raw\ Material\ Processing\ Energy\ Usage = (98440\ kWh)(0.1) = 9844\ \text{kWh}$$
$$Manufacturing\ Energy\ Usage = (98440\ kWh)(0.03) = 2953.2\ \text{kWh}$$

Now that we successfully quantified the holistic energy consumption of a dishwasher, we can assess its impact to climate change in terms of kg of carbon dioxide emitted. Holistic Energy Consumption=98840+9844+2953.2=111637.2 kWh which is equivalent to 78.9 metric tons of Carbon Dioxide Equivalent (EPA, 2018)**.** To put this number into perspective the following figure was developed:

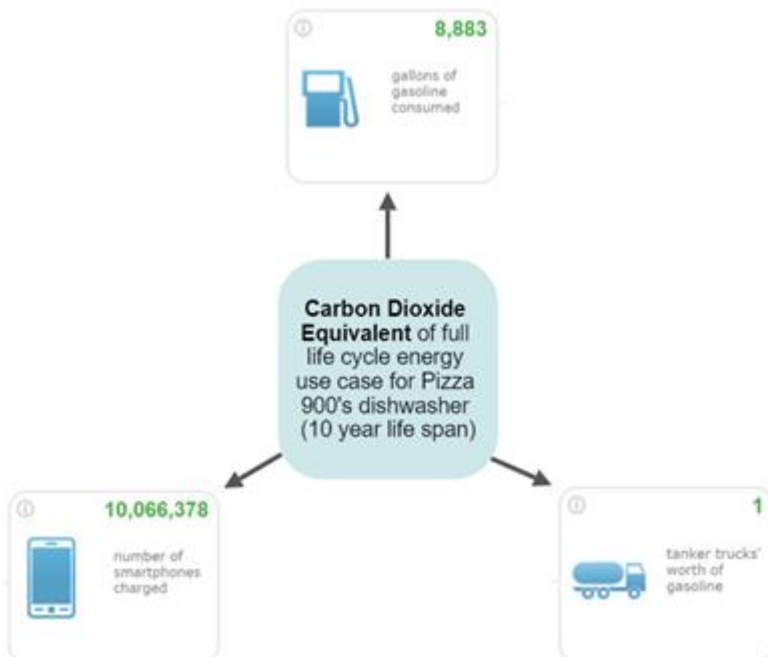


Figure 18: Carbon Dioxide Equivalences to life cycle energy use of Pizza 900 dishwasher

5.5.3 End of Life Strategies

In this section, the energy impacts associated with disposing or recycling of the dishwashing system were investigated. First, we looked at the impact transportation to a local landfill or recycling facility has after conducting a detailed literature review on the topic, we assumed a traveling distance of around 50 miles. From Keoleian study, we gathered the typical transportation energy of a diesel-operated tractor-trailer is about 2.05 MJ per ton-miles of transport, shifting our focus to the energy consumed during the actual disposal or recycling process (Keoleian et al., 1997). In the case of system disposal, we made the simplifying assumption that the energy consumption of this end-of-life process is negligible. This enabled us to better investigate the energy impacts of disposal as an end game strategy, which turn out to be less than 0.02% of the total life cycle energy (Boustani et al., 2010).

As an alternative to disposal, our system could be recycled for parts, remanufactured to increase its lifespan, or donated to an educational institute to be used for research rather than industrial purposes. All three of these are likely to be net energy-expending, as a result of energy consumption during transportation and end life treatments. Nevertheless, remanufacturing of appliances can increase their energy ratings and efficiency, making these options viable if the right conditions apply.

In conclusion, the dishwashing system does have significant negative effects on the environment, further stressing the added sustainability value from the introduction of our customized dishware racks. Furthermore, our robotic arm system will have a longer lifespan than the dishwashers currently operated, decreasing its net carbon footprint.

6. Conclusion

The automatic stacking unit design for Pizza 900 will fulfill the desired parameters set in the scope of this project. The system will eliminate the necessity for someone to reorganize the dishware once the wash cycle has concluded. Additionally, with the design of the newly customized trays Pizza 900 will reduce the amount of daily water consumed by increasing the capacity of the trays. This innovation will minimize Pizza 900’s environmental impact by not only decreasing water usage, but also energy consumption.

The trend of increasing automation has been facilitated in part by the newest technological advancements in fields such as sensor research and robotics in combination with the decreasing price of automation in general. A great reduction in initial capital investment in the past decade have allowed for projects such as Lavotica to be viable alternatives to traditionally labor intensive aspects of businesses.

This projects aimed to propose an overall system concept with economic, environmental and social justifications to solve a common issue of cost of labor in industry. We proposed a system that would be able to be integrated into the existing environment of operation of our client. We concentrated on critical components of this overall design to conduct testing and see that our concepts could indeed be applied at the fundamental levels.

Lavotica is excited to see the future of the project as our client contacts us with invested interest in our system overview and plans to use our research in the next phase of his plan to implement a full-scale operational semi-autonomous dish unloading system at Pizza 900 with the plan to expand even further afterwards.

6.1. Recommendations

This system that was envisioned by this design still has much room to grow and improve. It should be noted that optimizing the movement of the arm, a recapture system for the water used, a heat exchanger to optimize the drying cycle of the dishwasher, further optimization of the dishwasher, and alternative powering would all increase the efficiencies of the project. Also, a system to deal with food waste generated by the scraping of leftovers would be beneficial form an environmental standpoint.

If the client allows it, we would recommend further work to be taken on this project. In, fact, this project could be divided into several aspects that each could be investigates as stand-alone research design concepts. The unloading phase, using a robotic arm was chosen to be the focus of this testing phase the tray retrieval system from the dishwasher as well as the conveyor belt and possible cleanliness quality checkpoints using computer vision are all areas that are of great interest for the project.

We recommend using a more precise robotic arm system which the final budget permits. This arm should have waterproofing and corrosion resistant components to cover the metal moving parts of the system as well as the exposed wires. This aspect is of great importance as humidity not only limits the operational lifespan of the system but the oxidation of metals threatens the risk of rust contamination in dishes which could be a health concern to clients as well as the fact that unprotected wires in the presence of moisture pose a risk of electrical fires.

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8. Appendix

8.1 Calculations of Vacuum Cup Size

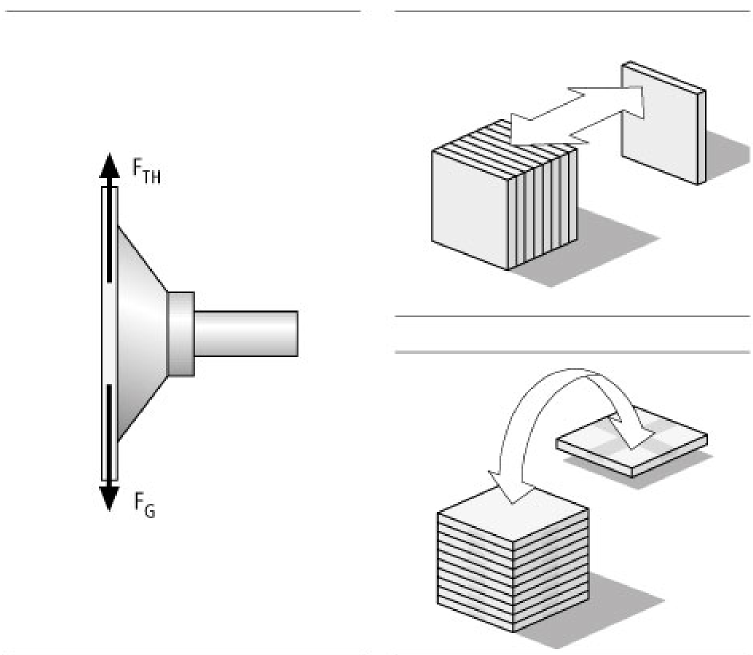

Figure 19: Free body diagram of forces involved in vertical vacuum cup configuration (SCHMALZ, 2018)

Theoretical Holding Force Calculation of a Vertically Set Plate:

$$F_{theoretical} = (m/\mu) \times (g + a) \times S \qquad (1)$$

m – *mass of plate* (DUDSON, 2018)

μ – *coefficient of friction of surface of plate*

g – *force of gravity*

a – *acceleration of object in system* (SCHMALZ, 2018)

S – *safety factor*

$$F_{th} = (1.1365\ kg/\ 0.4) \times (9.81\ \ m/s^{2}\ + 5\ m/s^{2}) \times 2 \qquad (2)$$

$$F_{th}=84.16N$$

Determining diameter required:

d – *diameter*

F_{th} – *Theoretical Holding Force*

ΔP – *Difference between Ambient and System Pressure*

$$d = 2\sqrt{(F_{th}) / (\Delta P \times \pi)}$$

$$d = 2\sqrt{(84.16N) / (40000\ Pa \times \pi)} = 0.05176 \text{ m or } 5.176 \text{ cm}$$

Note: Value of coefficient of friction based on damp ceramic surface (minimum). ΔP value is taken as standard for mini pump vacuum systems (SCHMALZ, 2018)

8.2 Stacking Count System Diagram

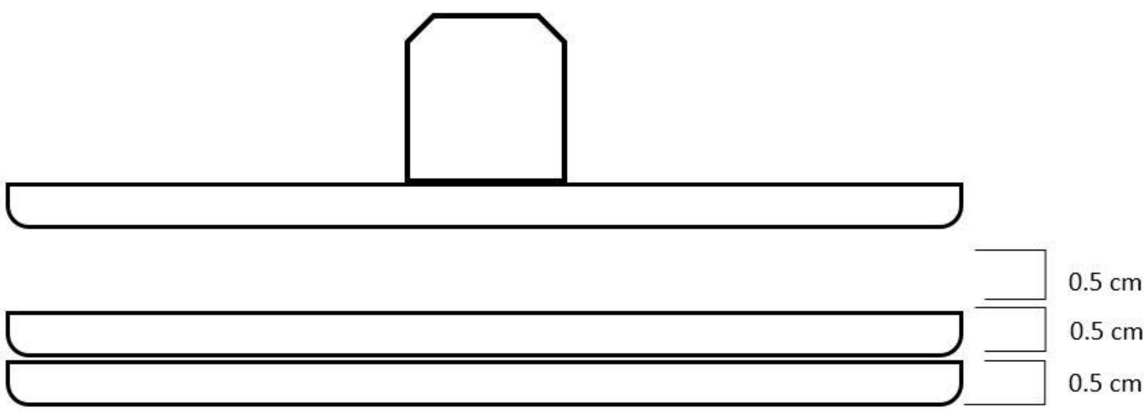

Figure 20: Schematic representation of stacking system that uses present plate count to sum the height of the next plate's placement. Each present plate adds to a total height starting at 0 cm adding plate thickness, 0.5 cm, to each placement position.

8.3 AutoCAD Design of Customized Dishwasher Trays

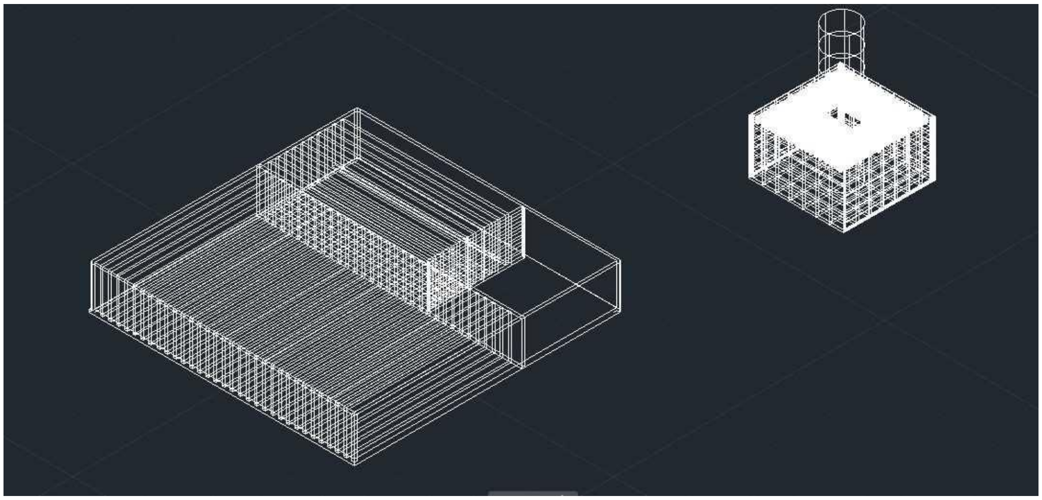

Figure 21: 3D Wireframe view design of customized dishware rack and cutlery component using AutoCad 2019.

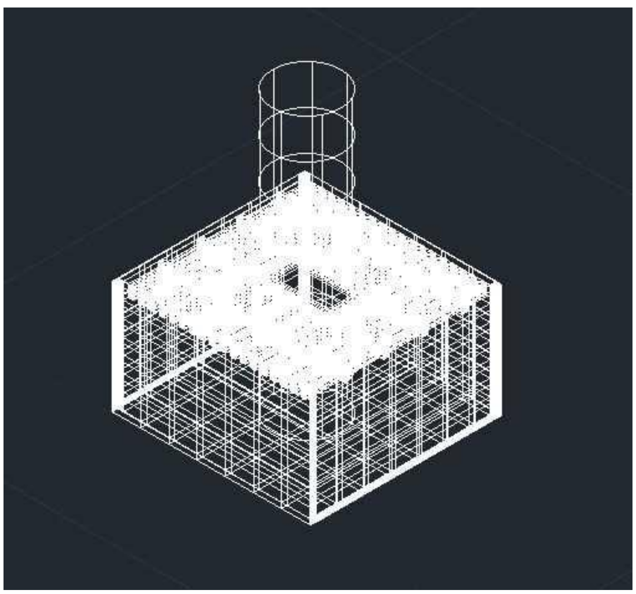

Figure 22: 3D Wireframe detailed view design of customized cutlery pod using AutoCad 2019.

Note: Dimensions and proportions are discussed in detail in the design implementation section.