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ZERO WASTE CAMPUS DINING

A Senior Project submitted

In Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Science in Industrial Engineering

The Faculty of California Polytechnic State University,

San Luis Obispo

by

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Checked by:_____________ Approved by:_____________________________

ABSTRACT

ZERO WASTE CAMPUS DINING

Jenny Caudillo, Sarah Dahel, Youlen Ghazalian

Cal Poly Campus Dining has a goal of becoming a zero waste entity by providing their customers with alternative methods of disposing their trash. Their current operations produce waste, specifically their methods of packaging the food. Campus dining plans to be more sustainable by providing their customers with reusable containers. The objective of this implementation is to reduce waste produced from one-time use, disposable food containers. The success criteria for the desired system is based around the ability to track and measure the reusable containers to prevent further waste, while providing the user an accommodating environment to ensure they will choose the sustainable option. Our experiment was designed using three objectives: usability, readability, and durability. In order to best accommodate the Cal Poly community, one of the supporting teams calculated the number, and approximate locations, of the return bins that will be collecting the reusable containers. Another supporting team worked on modifying the trash bins currently used at their operations to collect the reusable containers, in order to provide a seamless transition for the customers.

Based on the client's suggestions, we tested two methods of tagging in order to track and measure the reusable containers. The methods tested were barcode and radio frequency identification (RFID) tags. Tests were performed on the containers while containing both tags to measure readability. The tags were read using a direct scanner and an indirect scanner. The ultimate goal was to utilize an indirect scanner in order to avoid

an additional task for the current Campus Dining employees. The containers were also tested under different conditions, such as placing food inside the container, to test the readability of the tags. The results of the RFID tags ranked far superior when compared to the barcode tags. The measured readability with an indirect scanner of RFID and barcode tags was 100% and 4.16%, respectively. The tags were then tested for durability. The reusable containers would need to be washed after each use through Cal Poly Campus Dining's dishwasher, the Stereo Commercial Dishwasher model STPCW-ER. A sample of eleven RFID tagged containers was processed through fifty wash cycles. A quality check was performed to find ten of the eleven containers had no water infiltration on the RFID tag, providing a durability success rate of 91%. The tagged containers were tested again for readability after the fifty wash cycles and all of the tags were read, including the tag that was exposed to water.

In conclusion, it is our recommendation to move forward with the zero waste initiative in replacing the current dining disposable containers with RFID tagged reusable containers. The tags will be able to withstand the current cleaning methods, while providing accurate readings when returned into the designated bins. Campus dining will be able to avoid further waste by removing the need to purchase 177,200 disposable containers annually. A ten-year cost analysis calculated the cost of the implementation to be approximately $120,000, the utility costs to be $55,500, and a depreciated asset cost of $280,000. The total cost of the proposed implementation will result to approximately $450,000 by the end of ten years. In contrast, the current system, using the disposable containers, will result in a cumulative cost of $500,000. The savings after ten years of the proposed system is approximately $50,000.

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Supporting Teams:

Operations Research Support Team - Austin Lynch, Fredrik Stenson

Manufacturing Return Bin Design - Isaac Williams, Jonnathan Terry

Wash Cycle Time Study Analysis Team - Kyle Batman, Gage Garabedian, and Rafael Paroli

Technical Advisor:

Dr. Tali Freed

Sponsor:

Radio Frequency Identification (RFID) club

Key Stakeholders:

Greg Yeo (Operations Manager – Cal Poly Campus Dining)

Eric Veium (Energy & Sustainability Analyst – Facility Services)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. Introduction

California Polytechnic State University campus dining is the first of a handful of U.S. university campuses that is aiming to become a zero waste entity for the community. Campus Dining Operations Manager, Greg Veo, and Facility Services Energy & Sustainability Analyst, Eric Veium, approached our advisor Dr. Tali Freed in hopes of finding innovative solutions to remove as much waste from the system as possible, without disturbing the campus dining daily operations. They requested that we exchange all current disposable take-out containers for reusable plastic containers, as well as develop the ability to track these new containers in order to prevent further waste. Greg Veo suggested that we pilot Red Radish, one of the campus dining locations. Using industrial engineering tools, we tested two types of tags: barcode and radio frequency identification (RFID) tags. We tested these tags for usability, readability, and durability. Our supporting teams worked on gathering time studies for the wash cycles and the calculating the optimal locations of the return bins. Our goal was to create a self-managed product that will ultimately lead to a zero-waste campus dining experience.

II. Background (includes **Literature Review**)

Cal Poly is constantly innovating and creating solutions to promote sustainability. Cal Poly has taken to become a more sustainable campus through the following examples: water reduction competitions between on-campus housing facilities, the introduction of composite waste bins around campus, the addition of designated zero-waste locations during all campus-wide events, and more. Towards the beginning of Fall

2015, campus-dining representatives, Greg Yeo and Eric Veium, contacted Dr. Tali Freed in hopes of taking Cal Poly a step closer to a zero-waste campus.

Greg brought forward a study that was conducted at the University of California, Merced, The Ozzi System. The Ozzi System utilizes barcodes for takeout dining containers, and they wanted Cal Poly to integrate a similar system. The reason they are hesitant to use The Ozzi System is because it limits the information stored to the container; the return process limits the container position when inserted into the machine, and does not provide feedback to the customer. The Ozzi system is also costly with low return on investment. They provided specifics on what they envisioned the final product to be: a system that allows campus dining to track their containers and provide feedback and incentives to the customers. They wanted a self-managed product that will allow customers to simply drop the reusable containers in a return bin. The containers are set to have a 2-year lifespan, until further tests are conducted. In helping Greg's mission for campus dining, our team further researched RFID technology to consider it as a method for container tracking. This literature review will examine various topics pertaining to the success of RFID application and other tagging methods to promote zero-waste initiatives. Included in these topics are: types of RFID tags, pros and cons of RFID vs. barcode, disposable vs. reusable, RFID impact on return systems, university impacts, as well as impacts on RFID tags.

2.1 Literature Review

2.11 Types of RFID – quality, orientation, material, readability

Radio Frequency Identification (RFID) Performance: The Effect of Tag Orientation and Package Contents

There are many forms of Radio Frequency Identifications (RFID) that allow the user to optimize inventory collection and distribution. One must select the best type of RFID based on conditions such as: readability method, the material of the item being scanned, and the quality of the tag itself. In "Radio Frequency Identification (RFID) Performance: The Effect of Tag Orientation and Package Contents" (Clarke), a test was performed on the readability of the tags based on two main factors: the tag orientation, and the contents within the case. The hypothesis for the test was that the "orientation of tag affects the readability of the reader" and "substance within packaging also must have an affect on the tag's readability" (Clarke). Five orientations were tested, along with 5 different kinds of contents, resulting in 25 unique possibilities. The result of this experiment was that the tag orientation did not have a significant impact on the readability when the case was empty, however had a significant impact if that product contained any content, especially water. This is an important finding because for our project we will be using containers that have a very strong possibility of containing leftover food, which can directly affect the readability of the RFID as this experiment has revealed. Tags facing outwards have the best possibility of being read, especially when contents remain in the container, which we will be considered in our design stage.

A Conceptual Framework for Economic Analysis of RFID Reverse Logistics via Simulation

In “A Conceptual Framework for Economic Analysis of RFID Reverse Logistics via Simulation” (Ustundag) another experiment was performed to test the quality of 3 types of RFID tags: D-RFID, reusable EPC Gen 10+ dual-dipole RFID, and barcode integrated RFID tags. Each tag had a different cost with a positive correlation between the price and quality of the tag. The quality will determine the lifespan of the RFID tag and the amount of times it can be reused. A simulation tested the 3 types of tags to determine the most economically feasible solution. The result was that D-RFID, the most expensive tag, was the best option. The reason for this was that, “it showed that higher-quality tags lead to lower system costs” (Ustundag). An economic analysis was performed to show that higher initial costs would be worth the investment in the D-RFID tag. In this case, we will need to select a tag that is economically feasible, and also of high quality to withstand the washing conditions of the campus dining system.

Evaluation of an innovative system for improving readability of passive UHF RFID tags attached to reusable plastic containers

As discussed in “Evaluation of an innovative system for improving readability of passive UHF RFID tags attached to reusable plastic containers” (Singh), there are many advantages to using RFID technology. Some of these benefits include “reduced shrinkage, increased availability of containers, accelerated search processes for goods in supply chain, and cost savings” (Singh). In this case, a study was performed on reusable plastic containers (RPCs) with RFID tags and an energy transfer device (ETD). Authors Singh, Roy, Montero, and Rosener tested ETDs with RFID tags that were not directly under the antenna reader. In the study the authors found that “70.33% of tags were read with ETD attached, and 29.67% of tags were not read with ETD attached" (Singh). This concluded that the ETD had an impact to the readability of the tags. These results will be considered in our team's implementation to suggest whether or not we need to implement ETDs on the reusable containers.

The Internet of Things: From RFID to the Next Generation Pervasive Network Systems

"Network Systems" (Preuveneers) provided a background of RFID technology and its applications. As described by the author, there are three main components of a RFID system: the actual item a tag is placed on, the information stored in the tag, and the link between the tagged item and database. The four main types of tags are passive, active, semi-active, and semi passive. The definitions for the different types are based on the power source and microchips used. For example, a passive tag has "no battery or onboard power source and communicates through a backscatter", while active tags have "an onboard power source, usually a battery, and having a powered receiver and transmitter" (Preuveneers). The book continues to describe the technical aspects of how the communication between the tagged item and the database works. Each tag and reader has a different corresponding cost. This is beneficial for determining the optimal tag type as we complete our cost-analysis of our process. This literature will continue to be a reference for us when testing the tags in the washing cycle and designing the pilot return bin.

The art of UHF RFID antenna design: Impedance matching and size-reduction techniques

In the article by Gaetano, he studies the design of tag antenna size and its effect on the system efficiency. His study tested various forms of tag antennas including: the mender-line antenna, the planar inverted -F antenna, the nested-slot suspended – patch antenna. The inverted – F antenna was found to work poorly in the presence of metals. The main takeaway from this article is that the environment affects antennas performance. As a team when we are testing RFID signal strength our group will take into account the various different types of packaging and what kind will work best in receiving the signal. The team will also keep in mind to avoid metals, such as the utensils that may be left behind in the reusable food wear due to its effect on the readability of the tags.

2.12 Pros/cons of RFID tag and Barcode vs. RFID

A Framework for Developing Implementation Strategies For a Radio Frequency Identification (RFID) System in a Distribution Center Environment

The implementation of any new system comes with some difficulties and resistance, which is the same for the implementation of the RFID system. As mentioned in "A Framework for Developing Implementation Strategies For a Radio Frequency Identification System in a Distribution Center Environment", many major companies, such as Wal-Mart and Target, have already implemented RFID tags within their inventory. Some of the obtained benefits are "inventory management, passenger screening, product security, asset tracking and management, and other areas" (Ross). A study was performed to test RFID tags against the traditional barcode. Six scenarios were tested using different methods of deployment of RFID and barcodes. The result being that the scenario in which RFID was fully deployed had the lowest personnel activity costs, while the scenario with no deployed RFID had three times the personnel activity costs. As concluded by the authors, “there are clearly benefits to RFID deployment and these quantifiable benefits seem to vary based upon which functions are fully RFID capable” (Ross). As a team we discussed the benefits of RFID compared to the traditional barcode system and decided which system would be of most benefit to our client.

An assessment model for the implementation of RFID in tool management

In “An assessment model for the implementation of RFID in tool management”, Dovere, Cavalieri, and Lerace go into detail about the benefits of using RFID within four applications. These applications include: production-process, maintenance operations, instrumentation and equipment identification, and tool management in tool machinery. Within these applications, RFID technology increases efficiency and reduces human error. An experiment was performed where RFID was implemented across all machine tooling for a company. Data was collected for a before-and-after comparison, which showed a decrease in the number of accidental events, mean downtime, and scrap work. In their previous process, all units were accounted for by hand, which led to a greater risk for human error. As discussed in the conclusion, RFID technology results in higher accuracy than the manual process with significant potential in terms of reduced time for information sharing and less occurrence of human errors” (1011).

Return of Investment for RFID system

The author of “Reach for ROI in RFID”, highlights the benefits of RFID technology in stating that the system has “an enhanced ability to screen out counterfeit parts coming into the plant, the opportunity to improve decision-making, and the provision of better after-sales customer care” (Katz). As for cost, tags range from 55 cents to $55 each, reader's run about $2,000, and a local server is about $5,000, and a encoding printer runs about $5,000. Jeff Wacker, an EDS Fellow and futurist at Electronic Data Systems Corp. stated, "There are estimates that up to 30% of a capital budget are for items that are lost or stolen-not where they should be when people need to use them” (Katz). In Cal Poly’s campus dining current process, students are checking out reusable takeout containers, but are not being held accountable for the containers, resulting in a financial loss.

East West University, Bangladesh anticipating ethical challenges of RFID

An RFID tag can have a large amount of personal information associated with it. This is what brings up the ethical challenges in using RFID technology, as discussed in the article by Dewan and Shams. Privacy concerns in RFID fall into various categories such as: health risks, infrastructure threats, data corruption, and tracking and profiling individuals. In regards to health risks, this article discusses that there is, “no published research on electromagnetic energy impacts on human health and well-being” (Dewan and Shams). The ethical issue regarding infrastructure threats is that RFID is currently an “open” environment. This means that anyone with an RFID reader has access to all information associated with the RFID tag. This can lead to not only stolen information but even “malicious” RFID reading, one can simply carry an “RFID jammer” (Dewan and Shams), in their pocket and ruin the whole operation. This brings up a very important aspect in our study, our team must ensure that the information associated with the container (i.e. credit card numbers associated with deposit) is kept confidential and will not be hacked by an outsider. The first suggestion is that the vendors, in our case Cal Poly campus dining, should notify the consumer that RFID technology is being used and the risks associated with it. Secondly, the vendor should let the customer know how the data will be employed. Lastly, “security safeguards” (Dewan and Shams) should be used in order to protect against unauthorized access and stolen information.

2.13 Disposable vs. reusable – carbon foot impact/environmental evaluation

On the use of RFID in the management of reusable containers in closed-loop supply chains under stochastic container return quantities

As Cal Poly campus dining moves towards becoming a zero waste entity, certain measures need to take place in order for this to happen. The purpose behind using reusable containers is to reduce environmental impact. A sustainable supply chain will not only allow campus dining to retain the containers students’ use, but also serve to focus on the zero impact purpose by reducing the students’ impact to the environment. As explained by Kim and Glock, when reusable containers are not returned, it defeats the purpose of the zero waste cause because typically the packaging will be thrown away and there will be a need to purchase more containers. The biggest concern of using reusable packaging is the system of tracking. As stated by Kim and Glock, “tracking the position of packaging material in a supply chain is obviously an important measure to increase return flows and to improve their predictability". It is mentioned that there is a need to provide incentive for the customer to return the container, such as requiring a deposit or placing penalties for late returns. In our project, we will be implementing an incentive system using an initial deposit for the plastic container. The article continues to suggest that RFID is a "suitable tool to improve the visibility of assets in the supply chain and to prevent losses…"(Kim and Glock). As concluded by Kim and Glock, an RFID-tagged container system is preferred over a non-tagged classic system because of the economic and environmental benefits to the company.

Product Self-Management: Evolution in Recycling and Reuse

In "Product Self-Management: Evolution in Recycling and Reuse", author Valerie M. Thomas "explores the possibility of making product recycling and reuse easier by shifting responsibility for product management toward the product itself" (Thomas). She emphasizes that products should "self-manage" in order to increase the probability of being recycled or reused by the consumer. By adding bar codes and identification codes, consumers have access to detailed recycling information. RFID technology is considered a more efficient method for product self-management and allows for automatic tracking. She suggests that all manufactures should place permanent identifiers containing information in regards to the best disposal method. For our project, we plan to apply permanent RFID tags on the reusable plastic containers for campus dining. We will designate bins as the return points, in hopes of creating a self-managed product.

Impact on carbon footprint: a life cycle assessment of disposable versus reusable sharps containers in a large US hospital

Medical facilities tend to generate a lot of waste compared to other types of fields. “Annually, US hospitals use 35 million disposable (DSC) or reusable sharps containers (RSC) generating GHG in their manufacture, use, and disposal” (Grimmond). DSC results in tons of plastic in the landfills. The goal of US hospitals is to reduce the environmental impact, while reducing the sharps containers cost. The percentage reduction for using RSC is targeted to be 28% by 2020 and 80% by 2050. Hospitals are moving towards becoming more sustainable and environmentally conscious. Similar to the US Hospital industry, we will look into the environmental impact caused by both disposable food containers and reusable plastic containers.

Environmental evaluation of single-use and reusable cups

A study was performed to test the environmental impact of disposable and reusable cups. “The objective of the study was to find the minimum number of cycles the reusable cup has to do so that its environmental impact is smaller than that of the single-use cup” (Garrido). From the results, it was concluded that ten cycles of use of a reusable cup was needed to have a smaller environmental impact than a that of a single-use cup. This result is due to the materials used for the cups. The single-use cups are much lighter in weight and use much less raw material than reusable cups. This study is important to our project since we need to consider the environmental effects of the current single-use container versus our suggested reusable plastic containers. We plan to calculate the needed number of uses of a reusable plastic container to outweigh the single-use container benefits.

Eco campus: Applying the Eco city model to develop green university and college campuses

There is currently no single campus that has fully embraced every aspect of sustainability, but numerous institutions are strong leaders. Some successes have ranged from "installed water-saving technologies, such as dual-flush toilets, vegetated roofs to sustainable building design"(Finlay and Massey). Richard Register's Eco city model is believed to have the most strategic framework to help guide the entire institution into a sustainable option. Previous efforts to achieve sustainability have failed due to lack of consistency and lack of full implementation. One method that has been used to emphasize the growth on sustainability is incorporating interdisciplinary curriculums involving the "three pillars of sustainability" (Finlay and Massey), which are environment, economics, and society. This problem is relatable to our project because our client intends to implement the tracking system throughout all of campus dining. This goal may be a bit complicated due to different types of processes, resources, and people involved. In our case, we must focus on labor expectations from employees, administration, and consumers.

Waste Management RFID Impact

This study found in "Expert Systems with Applications", evaluated seven different waste management strategies for venue-based events and characterized the impacts based on waste audits and the Waste Reduction Model (WARM). The findings demonstrated correlations between carbon dioxide equivalent emissions, energy use, and landfill diversion rates. Of the seven waste management scenarios assessed, the recycling scenarios provided the greatest reductions in carbon dioxide because of the retention of high value materials, but are compounded by the difficulty in managing a two or three bin collection system. This source applies to our project because the findings from the audits conducted demonstrate the need of alternatives for universities. We plan to use this source as a guide for our design of experiment. For example, determine our baseline and determine the effect of RFID on waste management.

Economic and environmental assessment of reusable plastic containers: A food catering supply chain case study

In a study conducted by Riccardo and Accorsi, the multi-use food storage system was evaluated in order to see the economic return of reusable plastic containers. In addition, a sensitivity analysis was conducted to explore how different parameters, such as washing rate and container lifespan, change the economic impact. The finding of this study showed that there is an environmental impact caused by the application of single use packaging. The impact from the end-of -life depends on the way the packaged is disposed of (i.e. recycled vs. landfill). This is an important finding that can relate to the zero waste projects. The reusable containers that will be used in the Cal Poly campus dining will have a cost associated with benefits. These costs include the labor used to pick up the bins and bring them to the washes, and the cost of water used to clean the containers. This will be included in the economic analysis portion of the report.

2.14 RFID Impact on Return System

Supply Chain Management with Lean Production and RFID Application: A Case Study

In the case study “Supply Chain Management with Lean Production and RFID Application”, from Expert Systems with Applications, RFID technology is used to improve the efficiency of supply chain management. The study focuses on a three-tier supply chain process with inefficient transportation, storage, and retrieval operations. In the study, Value Stream Mapping was used to distinguish the changes that would occur after RFID technology is implemented into the system. Our team will be doing the same for our project. The case study mentions experiments’ “total operation time can be saved by 81% from current stage to future stage with the integration of RFID and lean”(Chen). From the case study, it was also determined that, “utilizing RFID technology, the cost of labors can be significantly reduced while maintaining current service capacity at the members in the studied supply chain”(Chen). The third factor taken into account in the case study was the return-on-investment (ROI) for the implementation of RFID technology. The results showed, “that the proposed method is both effective and feasible. “Overall, there were four common benefits: replacement of labor through automation, cycle time reduction, enabling self-service, and loss of prevention”(Chen).

2.15 University Impacts

Building a Smart University Using RFID Technology

RFID technology is obtaining a lot of visibility, "owing to its low cost, light weight, reduced size and inexpensive maintenance" (Proceedings). This article mentions the differences between RFID, barcodes, and smart cards. The main benefits that come with RFID are: the lack of need for the tag to be visible to the consumer, the various tag sizes available, the larger readability ranges compared to barcodes, the ability to be able to be reuse tags, and the ability to read multiple tags at once. Some measures taken during this study were that all employees and students received a tagged ID, along with tagged office materials that could be read upon entering a room. During the study, students and employees could be tracked based on the room they last entered, but there will be a lot of safety and privacy violations if we allow for this to happen in our process. This will be prevented by having the readers in only the return bin and tags on the item only which means the item will not be read until it is inserted inside the bin, thus not detecting the students previous and later locations.

2.16 Impacts on RFID Tags

Impact of Moisture & Washing on Performance of Embroidered UHF RFID Tags

One step in our dining takeout process is washing the returned containers to have them be cycled out again. We consider tag durability against water, pressure, heat, and chemicals when selecting a tag. This article considers, “wearable antennas exposed to various environmental conditions” (IEEE Antennas Propag. Mag.). The impact of moisture and washing on the performance of RFID tags was studied. It was found that, "the moisture absorbed in the tag structure can cause a temporary reduction in the tag read range" (IEEE Antennas Propag. Mag.). The final results for this study, "indicated that protective coating is needed for sustained operation" (IEEE Antennas Propag. Mag.). Some possible protective coatings are: "Flexible, durable, and hydrophobic polymers, such as polydimethylsiloxane (PDMS), and polymer-ceramic composites" (IEEE Antennas Propag. Mag.). This article is used as a guide for our research on protective coatings and adhesives able to withstand the washing cycle.

III. Design

The specifications proposed by Cal Poly Campus Dining and Facility Services was to create a design that will be able to seamlessly incorporate in the current system with little or no impact to the ongoing daily operations. The initial design was focused on one of the Cal Poly Campus Dining options: Red Radish. Red Radish is an on-campus dining destination, providing students with custom made salads. All their customers receive their salads in identical disposable, to-go containers. In their current operation, customers order their salad and all the ingredients are placed in the same disposable salad container. The containers are all identical size, shape, and design. Greg Yeo requested Red Radish as a pilot program due the commonality of these containers (see figure 1).

Figure 1. Red Radish's currently used disposable container

The requirements of the reusable containers were the need for accountability and usability. The overarching goal of implementing reusable containers in place of the current disposable containers was to minimize waste and promote sustainability within the Cal Poly community. In order to promote a sense of accountability, it was agreed to create an incentive program. Within the incentive program, the customer will be charged for the container through their Cal Poly account for checking out a reusable container. Once the customer finishes their meal, they will return the container to the designed return bin and will be refunded the charge on their account. Many published studies promoting recycling and reusing discussed the importance of usability for the customer. The results of these studies proved that if an accommodating environment was provided, the users would be more likely to utilize the sustainability programs implemented in their location. One of the supporting teams to the experiment, consisting of Austin Lynch and Fredrik Stenson, calculated the optimal locations for the reusable container return bins. The optimal locations are highlighted by the purple squares (see figure 2).

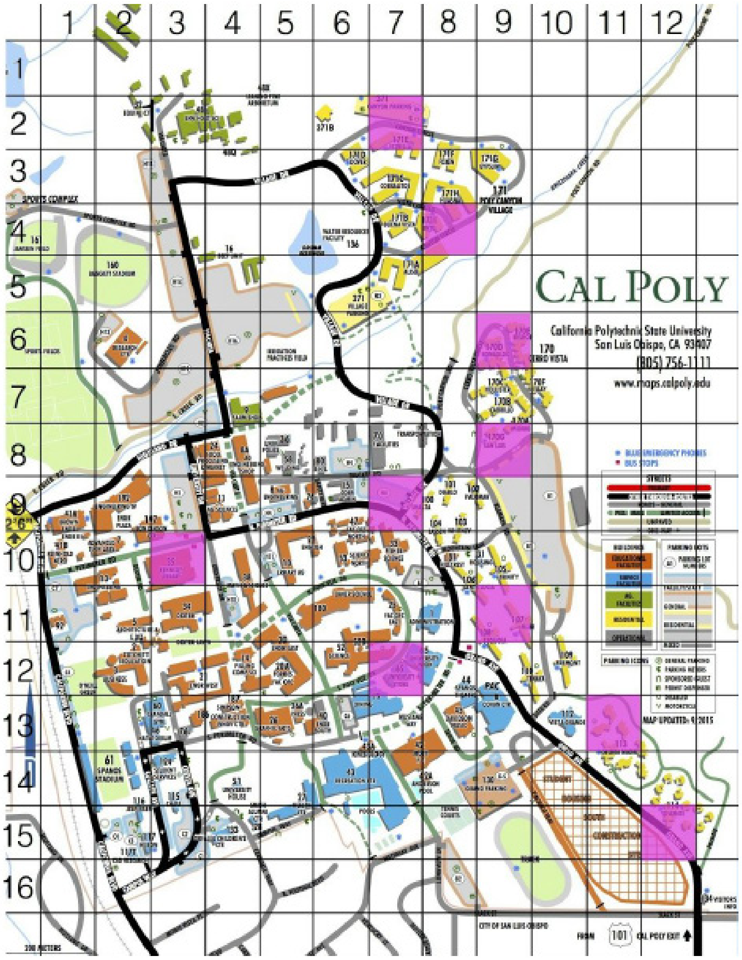

Figure 2. Solution for return bin distribution

The next step of the design was to create a system that would account for all the returned containers. Based on the technology available to Cal Poly's current operations, barcodes and RFID technology were both considered as methods to account for the returned containers. The experiment was based on the following success criteria: readability, durability, and usability (see Appendix 1).

Cal Poly is currently spending about $500,000 over a ten-year time period on the purchase of disposable containers. All costs are based on the campus operating for 9 months, a total of 270 days (Table 1), and the future costs presented over a ten-year period. Eric Veium, the Energy and Sustainability Analyst of Cal Poly, has said that a cost similar to the current cost for a new system would be suitable.

In order to begin testing for this project, initial investments were made costing the team a total of about $100 (Table 2). These costs include the purchase of twenty four reusable containers, which already had barcode tags included, and the RFID labels, in order to conduct various testing methods as seen in the Methods portion of this report. In the analysis of implementing a zero waste system, variable and fixed costs were considered including set up, maintenance, and material costs. As shown in the pie chart (Figure 3), one can see that the highest cost is due to the reusable container cost. The container lifespan is two years and with a return rate of 80%, providing the calculated need of 6,240 units to sustain the demand at the pilot location Red Radish. The next highest cost observed was that of the "Hardware". This includes the cost of the bin with a 10% tax rate.

The cost analysis was performed utilizing excel software. Twenty bins, two at each location was determined based off of the student demand from supporting team members Austin and Fredrik. The approximate, calculated costs of the reusable containers, the RFID tags, hardware, installation, maintenance, and labor is $40000, $1300, $27000, $3500, $2000, and $2700 respectively. Cal Poly can expect to pay about $120,000 (Table 3) for the first year zero waste implementation. These costs were based on current operating costs and figures provided by Eric Veium.

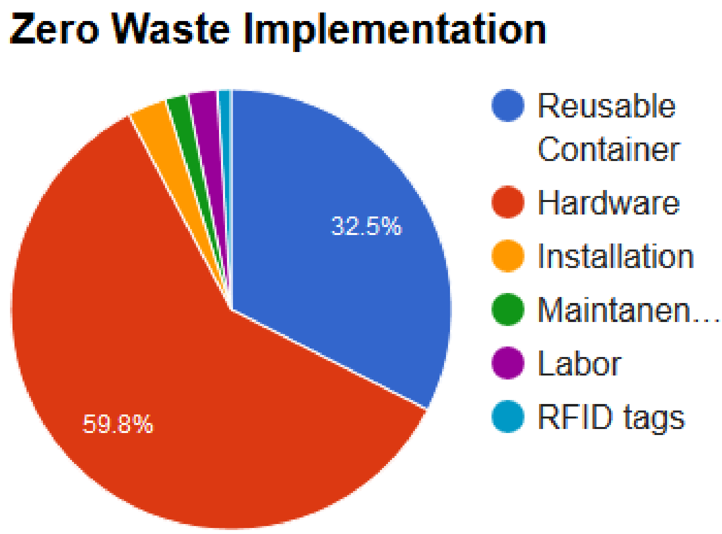

Figure 3. First year implementation costs

Campus Dining currently uses Stero Commercial Dishwasher model STPCW -ER to wash their dishes. If implemented, the tagged reusable containers will be placed in this dishwasher after they are returned. The dish room is stated to be working 7:30 to 22:30 each day, a total of 15 hours. In the cost analysis, the assumption was made that the dishwasher was utilized all of these 15 hours for 270 days/yr. with an 80% efficiency based on the kilowatt (kwh) usage. It has been taken into consideration a need for an extra dishwasher to accommodate the newly added reusable containers in the system. The dishwasher consumes 135,000 gallons of water per year, about 181 HCF (hundred cubic feet) per year; costing a total of about $2,200 annually in water costs (Table 4). The dishwasher also utilizes a great amount of electricity in order to power the motors, which pump water, heat water, and work the conveyer (Table 5). It is assumed the machine will be completing 694 washes in a day if running at 80% efficiency. The dishwashing machine will be consuming about 254 kwh/day, at an electricity rate of $0.12. The calculated annual electricity cost for the dishwashers is approximately $3,300 with a total utility cost of $5,600 (Figure 4).

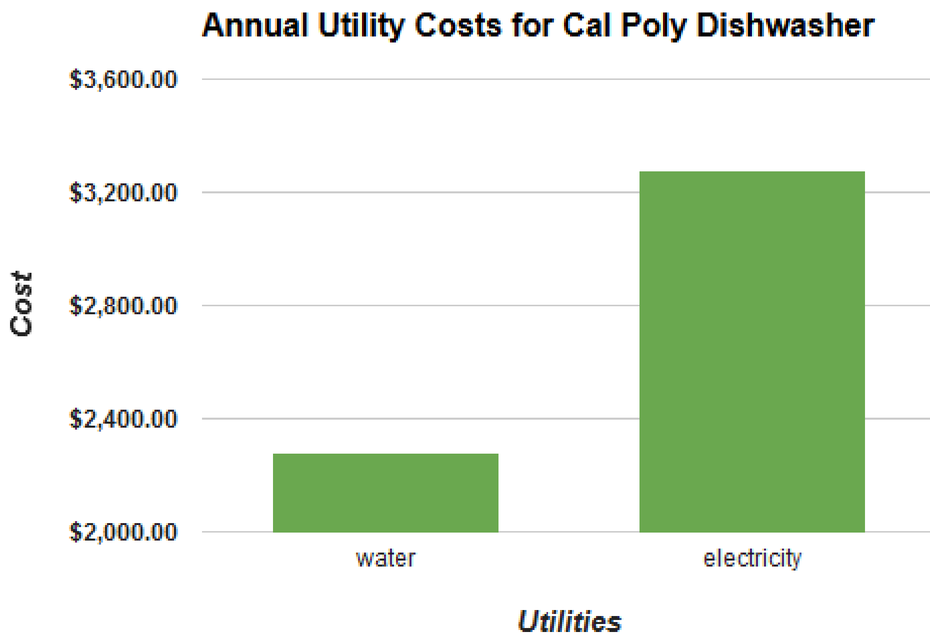

Figure 4. Cal Poly Annual Dishwasher Utility Cost

In the ten-year depreciation analysis (Table 6) it was assumed that life in years for the reusable containers, dishwashing machine, RFID labels, bins, and Ethernet cables are 2, 10, 20, 10, and 5 respectively. Assuming a 10% salvage value, an annual cost has been found to be about $28,000, and a ten-year cost of about $280,000. The cumulative ten year cost for the current system, using disposable containers, is equal to approximately $500,000. The cumulative ten year cost for the suggested system, using RFID tagged reusable containers, is approximately $450,000. This cost includes the depreciation of following assets: the reusable containers, the washing machine, the RFID labels, the return bins, and the Ethernet.

IV. Methodology

The two methods of container identification tested were barcode and RFID tags. A passive RFID tag was used in order to deliver high performance at a low-cost (see Figure 5). These tags were also chosen due to their ability to resist harsh environment, since the containers would be process through the Campus Dining's dishwashing machine. In order to ensure the identification tags would remain intact each tag was laminated using the Scotch Thermal Laminator. The tags were then attached to the containers using 9472LE Adhesive Transfer Tapes from 3M (see Appendix 2). This particular adhesive was the chosen option based on physical properties and performance characteristics. For example, submission in water has no measureable effect on the bond strength. The 9472LE Adhesive Transfer Tape also continues to hold securely when exposed to numerous chemicals and resists temperatures up to 200 degrees Fahrenheit. The tags were placed in various locations on the bins: the top, the bottom, and the side of the container (as seen in Figure 6).

Figure 5. Passive RFID Tag

Figure 6. Barcode Tag Locations

After the tags were placed, the containers were then scanned using two methods, the first method was using a hand-held scanner (as seen in Figure 7) and the other method was using an indirect scanner, meaning the scanner was placed inside a return bin. The hand-held scanner was model MC9090-GU0HJEQR7US from Motorola and the reader was model ALR-9650 from Alien. The barcode scanner and the RFID scanner were both placed inside the return bin. Each step of the experiment was performed on all twenty-four containers.

The return bin was a replicated version of the current disposable bins located in Red Radish. A breakdown of the steps of the experiment is seen in Appendix 3. Another independent variable considered was the food content within the container. It was assumed that there was a high possibility of leftover food content remaining in the containers when they were returned. Many articles discussed the possibility of readability error, especially for RFID tags, when water and food was incorporated within the test subject being read. A variety of foods were placed in the container, such as water, dry oatmeal, and pasta. One article also mentioned the effects of tag location on readability. The tags were placed in three different locations (top, bottom, and the side of the container) for both the barcode and RFID tags. Durability was measured by quality checks after the containers were placed inside of Campus Dining's washing cycle. Readability was measured in the PolyGAIT lab, where the containers were either scanned directly using a hand-held device or indirectly through the return bin scanner.

Figure 7. Handheld Scanning Barcode Tag

The return bin was designed by supporting team members Isaac Williams and Jonnathan Terry (see Figure 8). Isaac and Jonnathan have developed a return bin and system with the following functions:

- Containers are read when deposited in the bin
- A count of the containers is kept to control when it must be emptied
- The customer's name will be viewable upon returning the container
- A list of customers who have checked out the containers is kept
- The bin will read containers with no significant error

Figure 8. Return Bin Model

Figure 9 displays the functions of the system. These functions are labeled as check out, return, and information. The check out function allows the campus employee to register a tagged container to the customer as seen in Figure 10 and provides feedback to the employee as seen in Figure 11. Once the bin is full, the employee will then select the return function to update the available containers. The information function provides a status update of the containers currently circulating, providing details of the containers returned and the containers still checked out. The Campus Dining Administration has complete control and access over the master list providing information on students' accounts and the containers. Campus Dining is hoping to eventually develop a more sophisticated version of this program by providing students direct feedback when their containers are successfully returned.

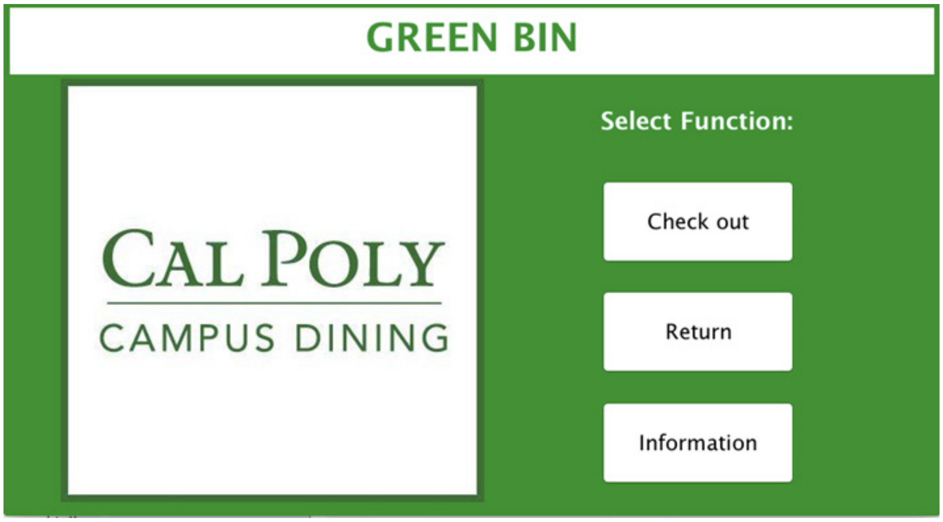

Figure 9. Campus Dining Green Bin Homepage

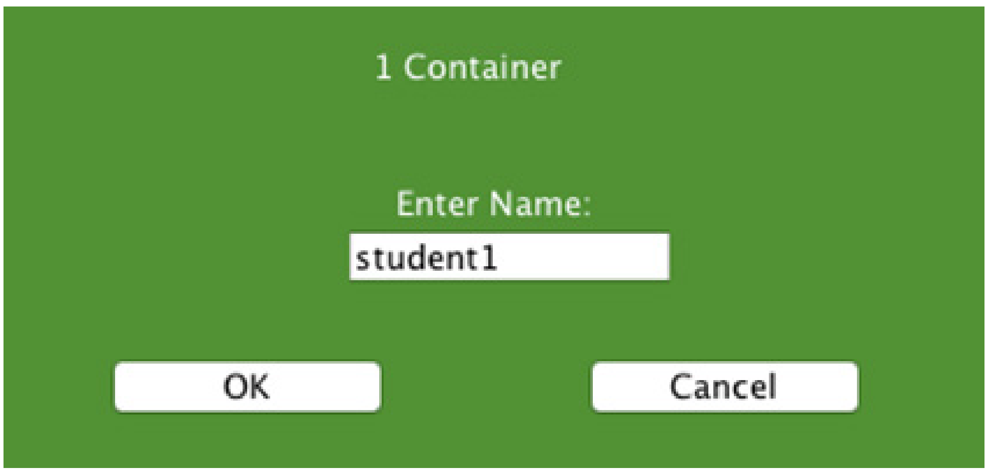

Figure 10. Check-out Form

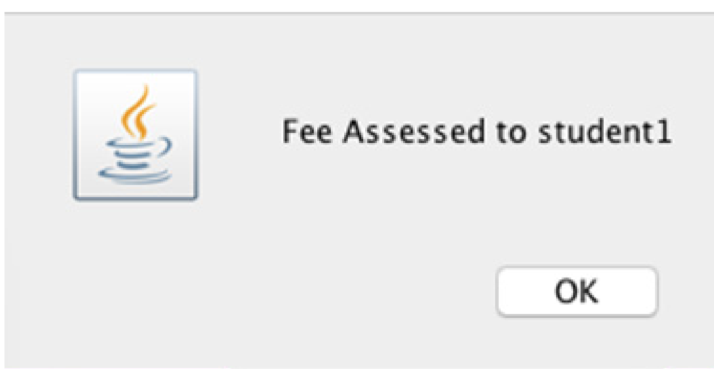

Figure 11. Successful Check-out Feedback

Simulation Model

Current State

After performing the time studies at Red Radish, the team wanted to ensure the rates of usage for the disposable containers were accurate by using Simio. Distribution rates were inputted for the customer arrival rates, salad preparation duration, and register check out duration. As shown below in Figure 12, after running the simulation from 11:30 AM to 9:00 PM, Red Radish operational hours, the throughput was 1,1106 containers used in one day of operation. This came to be very close to the number Greg provided of daily average units sold/purchased, which was 1,065 containers.

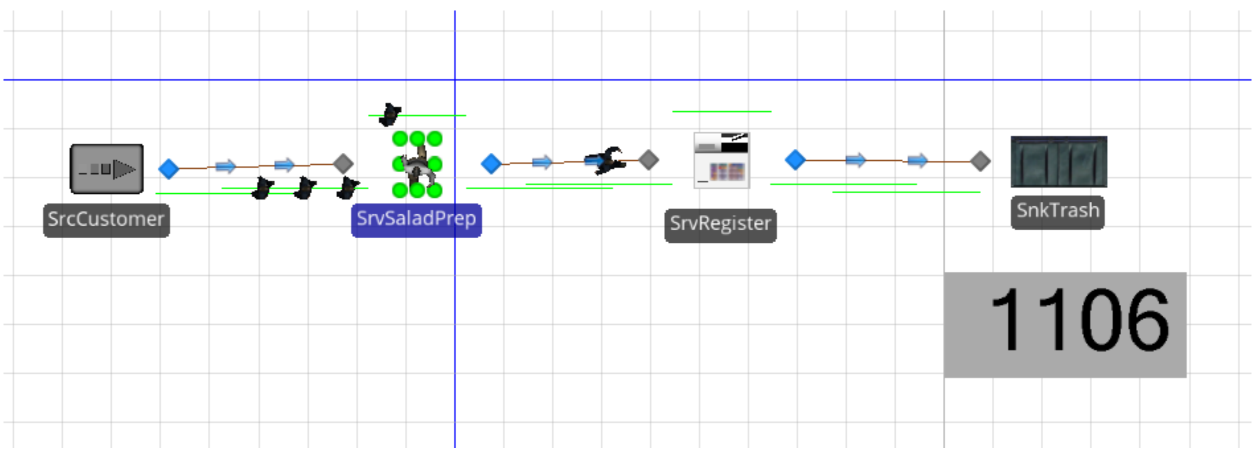

Figure 12. Simio Model for Current Process

The team went ahead and ran a small experiment to ensure that Red Radish was allocating its resources correctly. There are usually 2 or 3 employees working the front area. Following the current process simulation, 30 replications were ran for 3 different combinations of number of employees at each station. As seen in Figure 13 below, the combination of employees with the highest throughput of 2,169 containers is 2 employees at the salad preparation statin and 1 employee managing the register. We recommend for Red Radish to have this set up to provide the best service to its customers.

Scenario			Replications		Controls		Responses
☑	Name	Status	Required	Completed	SaladWorker	RegisterWorker	Throughput
☑	Scenario1	Compl...	30	30 of 30	1	1	1087.57
☑	Scenario2	Compl...	30	30 of 30	2	1	2169.37
☑	Scenario3	Compl...	30	30 of 30	1	2	1083.13

Figure 13. Employee Distribution Simio Experiment

Improved State

The simulation presented in the previous section, was modified to include the usage of the RFID tracking system. After each entity was processed at the register, they split 20% directly to the be disposed at the trash and 80% of the entities would be checked out to customers to be returned at a later time. The time path distribution between check out and return bin had an average of 5 hours, but with an exponential distribution took into consideration that some customers might return their container much faster or much slower. After the container reaches the return bin, an employee will pick up all containers and take them over to the wash cycle. The travel had an exponential distribution between 10 minutes to 30 minutes to consider different locations. After the containers were washed, they are ready to be reused! Two versions of this simulation were run differing with the time lapses between pick-ups at the return bins. Figure 14 displays the simulation with 1 hour between return bin pick-ups and Figure 15 displays the simulation with 2 hours between return bin pickups. Having lower times between pickups will have about 100 more containers ready for the next day. Taking this outcome into consideration and based on batch orders also supports the idea of purchasing 2,000 containers.

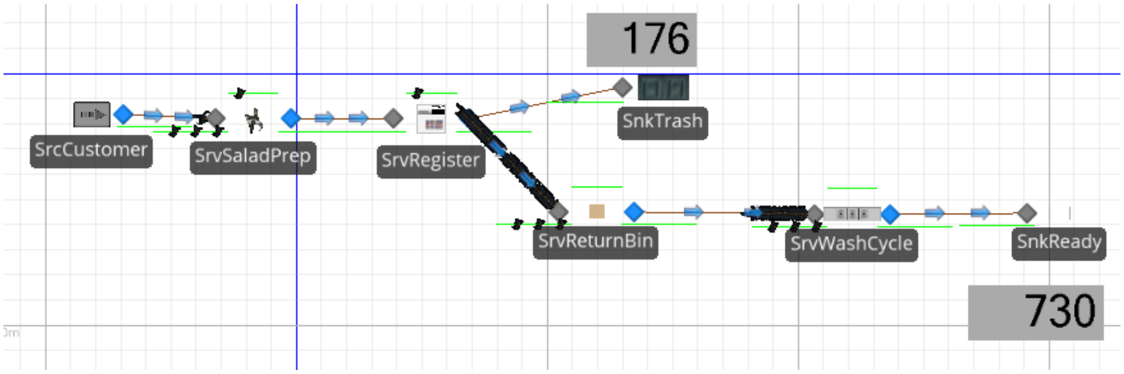

Figure 14. Simio Model for Proposed Method with pick-ups every hour

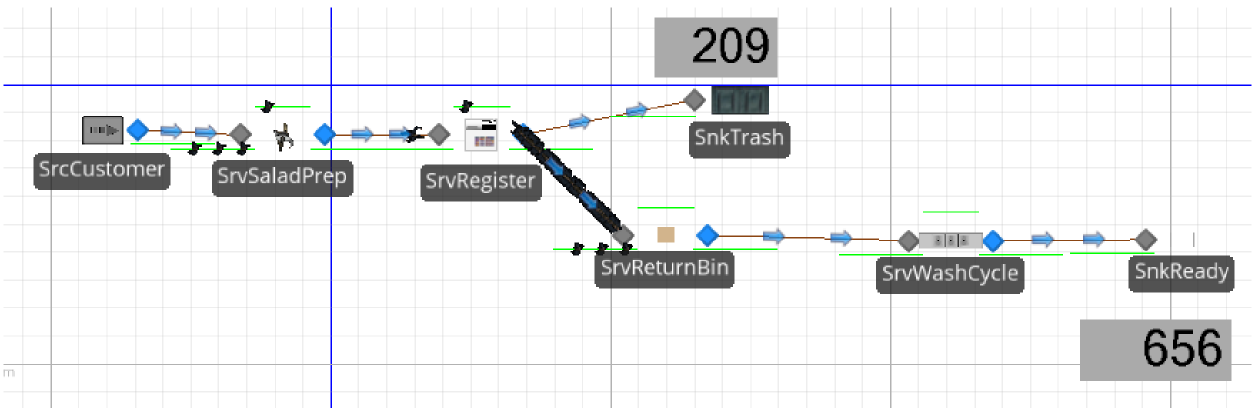

Figure 15. Simio Model for Proposed Method with pick-ups every two hours

V. Results and Discussion

The initial results collected were not as expected. After doing research on the adhesives available, the team was fairly confident that all the tags would stay placed on the container after being processed through the dishwasher cycle. From the twenty-four tested tags, four of the tags were damaged after being collected from the wash cycle. Through observation, it was determined the errors were the result of human error. Each tag was previously laminated and cut prior to being placed on the containers. It was found that water had infiltrated the tag and compromised the readability of the tag. A quality check provided the reason due to the infiltration as a gap in the lamination. The plastic was cut very close to the actual RFID tag, which lead to there being tiny holes in which water could enter during the wash cycle. The initial trial resulted in a 83% success rate, which the team agreed needed to be improved. For the second trial, it was agreed to leave 0.5” of plastic on all four sides of the tag (as seen in Figure 16) to ensure there are no holes for water to reach the tag. Another change that was also implemented was the location of the tag. The tags were tested in three locations on the bin: front, bottom, and side. Though literature supported the claim that location would affect the readability of the tags, all of our tests proved otherwise. The location of the tag did not in any way effect its performance regarding readability. A second trial was organized, but this time with the implemented change of 0.5” of space left between the tag and the lamination. For the second trial, a quality check was performed to check that the tag was located in the middle of the bottom to ensure that the edges of the tag would not lift up (as seen in figure 17). In this trial, eleven containers were tested going through the wash cycle fifty times. Only one tag of the eleven-tagged containers tested had water damage, resulting in a success rate of 91%. The eleven containers, including the container with water damage, were tested for readability and provided a success rate of 100%.

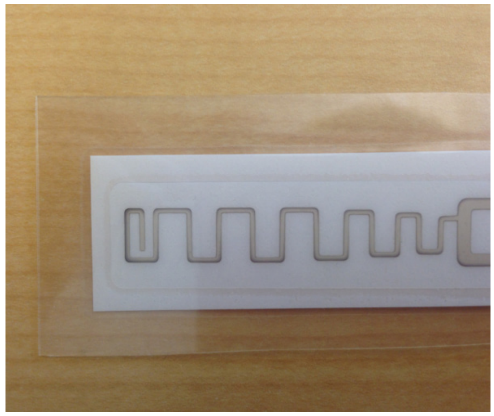

Figure 16. Revised RFID tag

Figure 17. Revised RFID location

The theory for our project was that RFID would have a better performance, based on the criteria of usability, readability, and durability, than barcodes. A test was conducted on the tags for each of the criteria categories. The theory of RFID being a better choice over barcode held. Both alternatives were able to be scanned directly, but containers with the RFID tags were able to be scanned indirectly when inserted to return bin at a 100% positive result rate while containers with barcodes only had a 4% success rate. The reason for this was that the barcode tagged containers needed to be held under the scanner in a very specific location in order to be read and this was not necessary for the RFID tags. Both alternatives were also tested with a variety of food (water, cooked pasta, and dry oatmeal) inside the containers. As predicted, the food did not affect the ability to be read for the RFID tags for either direct scan and the return bin scan for both alternatives. The food however did affect the scans of the containers with barcodes. The barcode containers had a 95% success scans for Pasta and 91% success scans for Oatmeal.

A RFID tag was positioned on the top, side, and bottom of the container. The position of the RFID tag also did not affect the ability of the container to be read. These results were just as predicted for this test. Another test performed to test the readability of multiple RFID tags, if the containers were stacked inside of the container return bin. This test was performed to consider the fact that some customers may have multiple containers. All twenty-four containers were read when placed inside the designated bin. As an additional task, the team tested the ability to read RFID tags enclosed within the container itself collected at the return bin. During one of the first meetings, Greg and Eric mentioned they would want to expand the tracking to silverware as well if implemented at other dining facilities. After thirty trials of enclosed tags, each additional RFID tag within the container acting as silverware was read. The design was well performed as it took all variables into consideration for both alternatives.

Overall, the cost estimates were as predicted. Using RFID tags was a more economical alternative and of higher quality compared to barcode over a 10-year analysis. As mentioned before, the laminated tags should be cut out of the original sheet with a 0.5” border. After seeing the defective tags, this procedure was taken and tested for 50 wash cycles with the result of 100% reads from the tags and 91% undamaged tags.

The primary unusual condition present during the testing was that some tags were being read even before they were inserted in the slot of the return bin. This condition would directly affect the accountability of the returned containers because the containers would be mistakenly accounted for prior to being placed in the return bin. This was taken care of by the design team, Issac Williams and Jonnathan Terry. They lined the return bin entry with aluminum to prevent readings to occur before desired.

Potential issues that may appear are tags not correctly laminated or placed on the container. A way to prevent this would be to double laminate the tags. This would ensure two coats protecting the RFID tag. Standard procedures should also be provided for the employees who will place the tag on the containers in order to decrease variability between containers.

VI. Summary and Conclusions

Cal Poly Dining is seeking to become a more sustainable entity for the community, but does not have a current system in place to replace their current operations using disposable take-out containers. The objective of our study was to create a traceable system that would allow the use of reusable takeout containers. Through research and test trials, it was determined RFID tags were the best option to track the containers. The RFID tags had the highest success rates in the criteria of readability, usability, and durability. All twenty-four containers were read when placed inside of the return bin, resulting in a 100% success rate in readability. In terms of usability, RFID tags involved the least amount of work for both the food provider, as well as the client. The RFID tags also were required to withstand the campus dining current washing methods.

The following conclusions were drawn:

- RFID tags provide a greater potential for sustainable practices by creating an accommodating environment for the users
- RFID tags have a 94% advantage of readability when compared to barcode tags
- RFID tags were durable enough to be able to withstand the current campus dining washing cycle with a 91% success rate and a read rate of 100%
- Multiple RFID tags were able to be introduced into the system and were accounted for by the return bin
- There is a potential to expand on the RFID tracking by adding RFID tags on the utensils within the container
- A ten year cost analysis showed a cumulative savings of approximately $50,000 if campus dining switches to the proposed system using RFID tagged reusable containers

The most important results of our experiment were the success of the RFID tag based on the criteria of usability, durability, and readability. This proved to our clients, Greg Veo and Eric Veium, that it was possible to switch from disposable containers to a maintainable system utilizing reusable containers. With the help of the supporting groups, the number of return bins necessary on campus was calculated and a usable RFID reading return bin was designed. Based on our experimental results, our theory of RFID tracking being more reliable and economical beneficial in comparison to barcodes as done by the Ozzi system held to be true.

After conducting the experiments, we were able to assist Eric and Greg's aim to guide Cal Poly's Campus Dining into becoming a zero waste entity. Based on the results, the team recommends to exchange the current disposable take-out containers for reusable plastic containers. We recommend implementing this change in a series based on the dining locations. This process would avoid too much change occurring all at once and will help students familiarize with the new sustainable option. It is our recommendation to start at Red Radish, since all their takeout containers are common in shape and size. The return bins will then expand to other parts of campus, as the change is implemented to other areas. A financial impact will be the initial investment for an additional washer due to the increased number of items to be washed. We expressed this to Greg and he mentioned that there is going to be an additional dish washing room over by the dining area in Vista Granada. We recommend to consider the capacity and properties of the new equipment purchased to make sure the purchase can meet the new demand and will not affect the adhesives or RFID tags if the tracking system is implemented. If this experiment was continued, we advise for different containers to be tested. During this experiment, we focused on one type of container that was suitable for our pilot location.

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APPENDICES

Appendix 1: Detailed Experiment Breakdown

Reusable Container

1. Independent Variables:
    1. **Barcode v. RFID tags v. none**
        1. Number of containers
    2. Food content within container
    3. Location of tag
2. Dependent Variables:
    1. Readability
    2. Durability
3. Process:
    1. Testing Readability
        1. Barcode v RFID v none
            1. Place identifier on container (barcode, RFID, or none)
            2. Submit container into bin
            3. Measure # of identifiers read
            4. Place multiple containers into bin
            5. Measure max # of containers read in bin
        2. Food content within container
            1. Place identifier on container
            2. Place amount of food in container
            3. Submit container into bin
            4. Measure # of identifiers read
        3. Location of tag
            1. Place identifier on container (barcode, RFID, or none)
            2. Place on top, side, or bottom of container
            3. Place multiple containers into bin
            4. Measure max # of containers read in bin
    2. Testing Durability
        1. Wash Cycle
            1. Place identifier on container (barcode, RFID, or none)
            2. Run container through wash cycle
            3. Examine visual status of identifier
            4. Place container into bin
            5. Measure # of containers read

Appendix 2: Adhesive Transfer Tape Properties and Characteristics

3M™ Adhesive Transfer Tapes with Adhesive 300LSE

8132LE • 8153LE • 9453LE • 9471LE • 9472LE • 9653LE • 9671LE • 9672LE

Storage	Store at room temperature conditions of 70°F (21°C) and 50% relative humidity.
Shelf Life	If stored properly, product retains its performance and properties for 18 months from date of shipment.
Recognition/ Certification	TSCA: These products are defined as articles under the Toxic Substances Control Act and therefore, are exempt from inventory listing requirements. MSDS: These products are not subject to the MSDS requirements of the Occupational Safety and Health Administration's Hazard Communication Standard, 29 C.F.R. 1910.1200(b)(6)(v). When used under reasonable conditions or in accordance with the 3M directions for use, the products should not present a health and safety hazard. However, use or processing of the products in a manner not in accordance with the directions for use may affect their performance and present potential health and safety hazards. **Note:** One of 3M's core values is to respect our social and physical environment. 3M is committed to comply with ever-changing, global, regulatory and consumer environmental, health, and safety (EHS) requirements. As a service to our customers, 3M is providing information on the regulatory status of many 3M products. Further regulation information including that for OSHA, USCPSI, FDA, California Proposition 65, READY and RoHS, can be found at 3M.com/regs.
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Appendix 3: Experiment Procedure

Objective: Create reliable, cost-efficient identification system to track reusable containers

Constraints: Container type, budget, storage, RFID system limitations, university restraints

Design Process:

Test various conditions - RFID types, RFID vs. barcode, adhesive, and wash cycle chemicals used for containers

Steps:

1. Confirm ideal pilot location
2. Perform time studies to determine the current process (i.e. number of times trash is removed from bin)
3. Find like-for-like reusable bin to replace current disposable container
4. Test various RFID tags, RFID vs. barcode, and possible adhesive
5. Test tag with adhesive in current container wash process
6. Select best adhesive and type of tag to be used for pilot
7. Create return bin and test tag with bin
8. Pilot test of bin and tagged containers
9. Perform time studies to compare previous process to revised process
10. Request feedback of customers and employees
11. Submit final recommendation to Campus dining

TABLES

Table 1. Current Container Cost

Current Purchases	Annual Quantity	Cost per Unit	Annual Total	Cost after 10 years
Disposable container lid	177,200	$0.11	$19,492.00	$194,920.00
Disposable container bottom	177,200	$0.17	$30,124.00	$301,240.00
			$49,616.00	**$496,160.00**

Table 2. Project Investments

Investments	Units	Unit Price	Total
Reusable containers	24	$4.00	$96.00
RFID labels	24	$0.10	$2.40
RFID lamination (donated)	24	$0.00	$0.00
Barcode labels (donated)	24	$0.00	$0.00
			$98.40

Table 3. First Year Costs for Zero Waste Implementation

Asset Name	Units	Purchase Price	Total Cost
Reusable container	12480	$4.00	$49,920.00
Washing Machine	1	$15,000.00	$15,000.00
RFID Labels	15600	$0.10	$1,560.00
Bin	20	$2,200.00	$44,000.00
Ethernet	10	$100.00	$1,000.00
			$111,480.00

Table 4. Dishwasher Annual Utility Costs

Gallons/wash	0.25
Gallons/day	500
Gallons/year	135,000.00
HCF in gallons	748
HCF per year	180.48
Cost per HCF (according to Eric)	$12.64
Cost per day	$8.45
Annual water cost	**$2,281.28**

Table 5. Electricity Annual Cost

Amount of containers	2,000.00
kW	56.4
Gallons/hour	98
Reusable container gal/wash	0.25
1 wash cycle [sec.]	93
Length of machine conveyer belt [ft.]	12
# of containers that fit in conveyer belt	24
Time to wash one container (sec.)	3.88
Total time to wash 2000 containers [sec.]	7,750
Time to wash 2000 containers [hrs.]	2.15
kW used based on 2000 containers	121.42
kW cost for Cal Poly	$0.10
Dishwasher kwh cost for Cal Poly daily	$12.14
Dishwasher kwh cost for Cal Poly annually	**$3,278.25**

Table 6. Ten-Year Depreciation Analysis

Asset Name	**Units**	**Purchase Price**	**Total Cost**	**Salvage Value**	**Life (yrs.)**	**Year 1**		**Year 10**	**Cost after 10 years**
Reusable container	12,480	$4.00	$49,920	$0.40	2	$22,464	**…**	$22,464	$224,640.00
Dishwasher	1	$15,000.00	$15,000	$1,500.00	10	$1,350	**…**	$1,350	$13,500.00
RFID Labels	15,600	$0.10	$1,560	$0.01	20	$70	**…**	$70	$702.00
Bin	20	$2,200.00	$44,000	$220.00	10	$3,960	**…**	$3,960	$39,600.00
Ethernet	10	$100.00	$1,000	$10.00	5	$180	**…**	$180	$1,800.00
Total			$111,480			$28,024	**…**	$28,024	**$280,240.00**

FIGURES

Figure 1. Red Radish's currently used disposable container

Figure 2. Solution for the return bin distribution problem

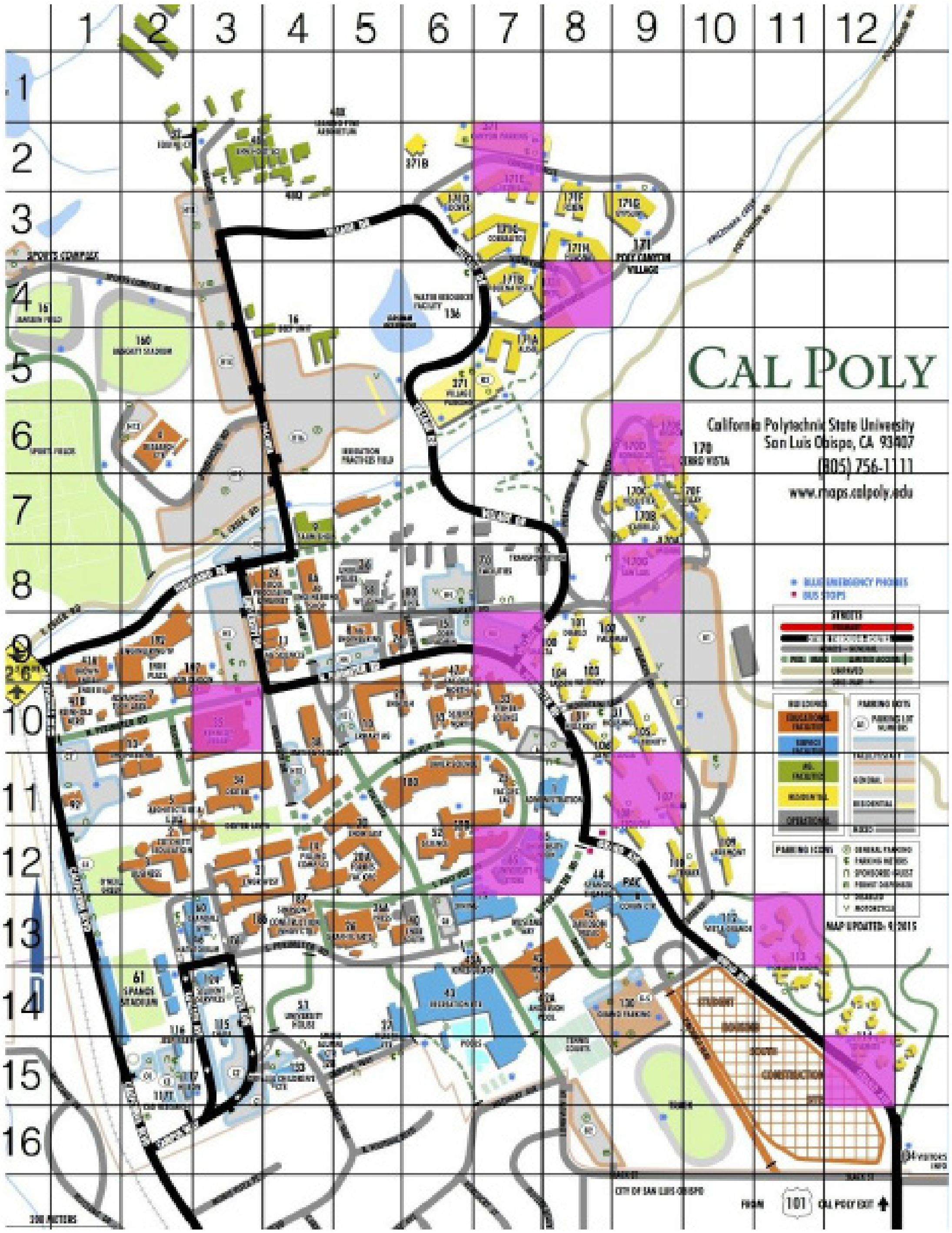

Figure 3. First year's costs breakdown

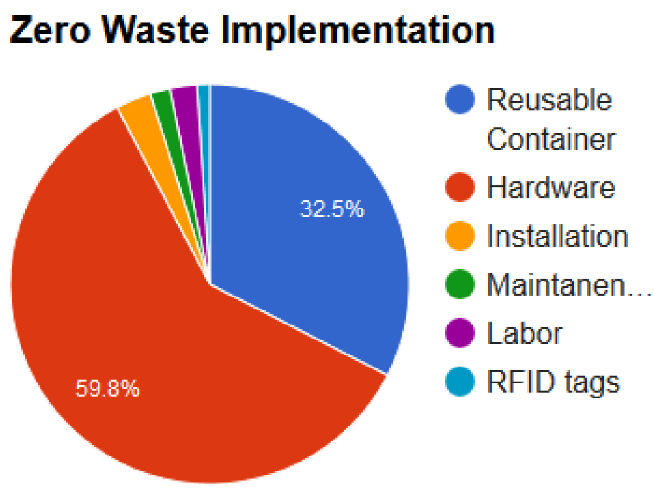

Figure 4. Cal Poly annual utility cost for dishwasher

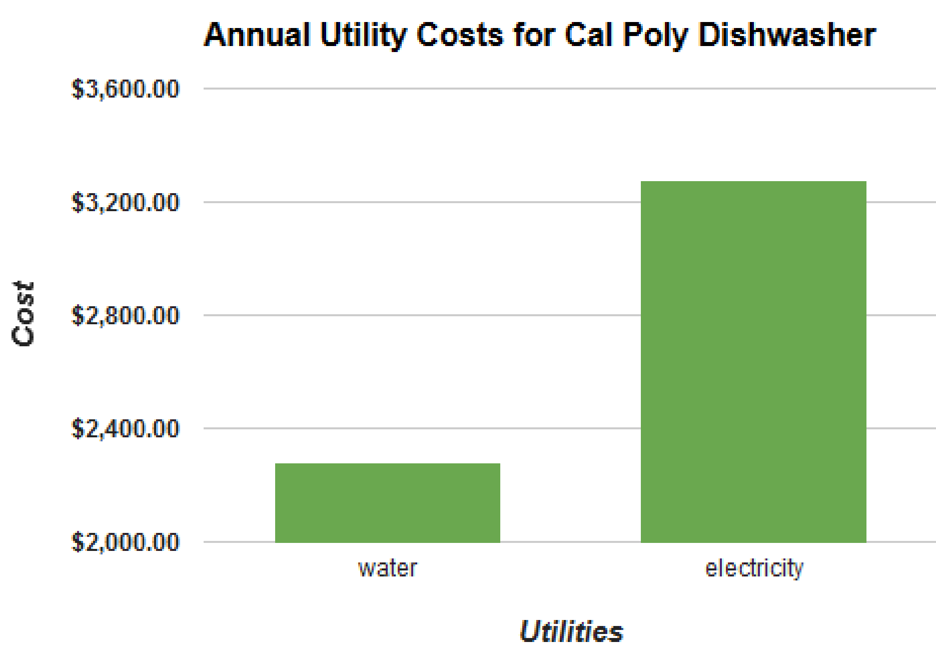

Figure 5. Passive RFID tag

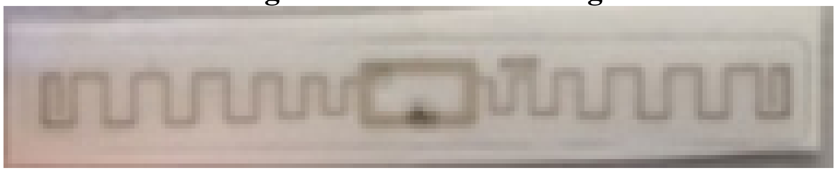

Figure 6. Barcode Tag Location

Figure 7. Handheld scanning of barcode tag

Figure 8. Return bin model

Figure 9. Campus Dining Green Bin Homepage

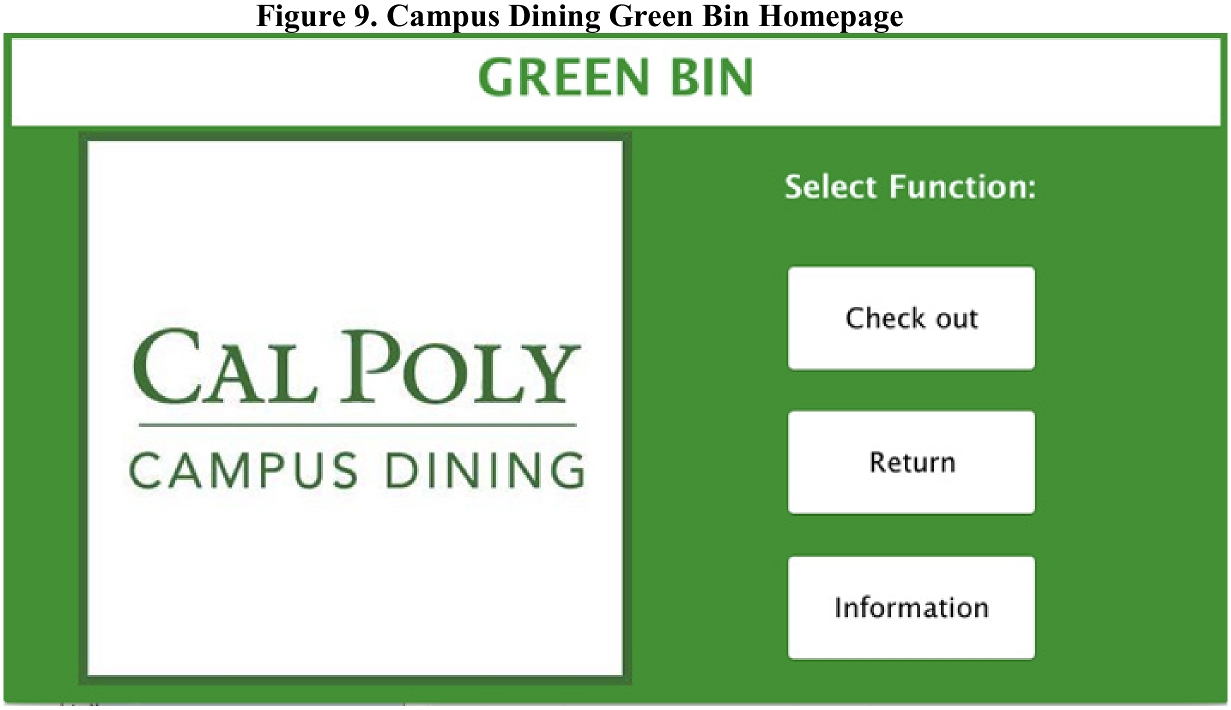

Figure 10. Checkout form

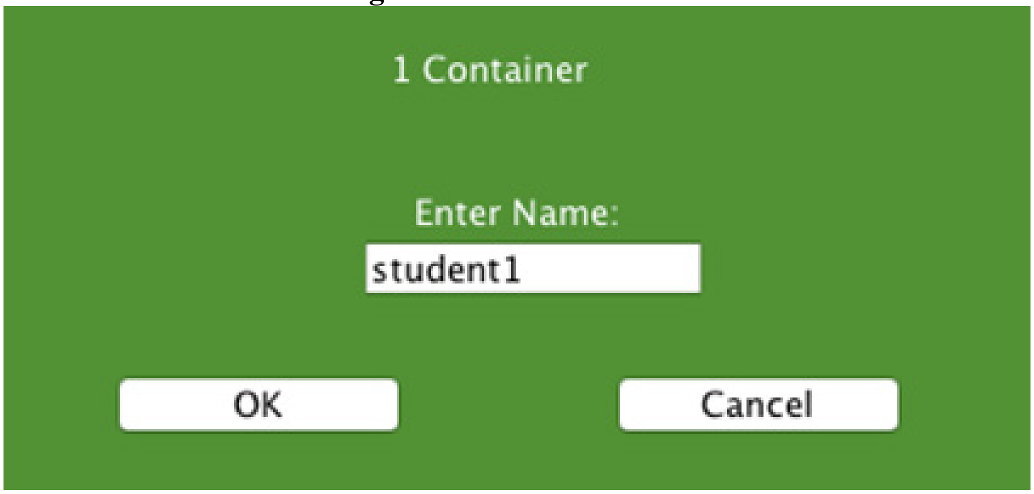

Figure 11. Successful checkout feedback

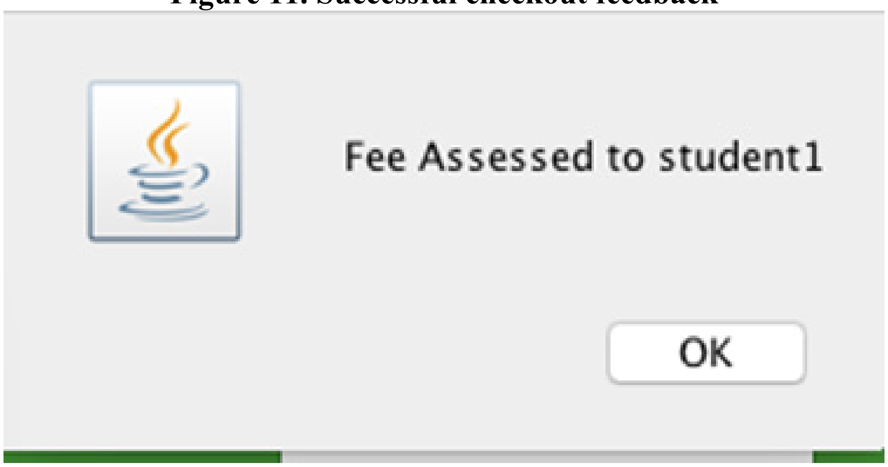

Figure 12. Simio model for current process

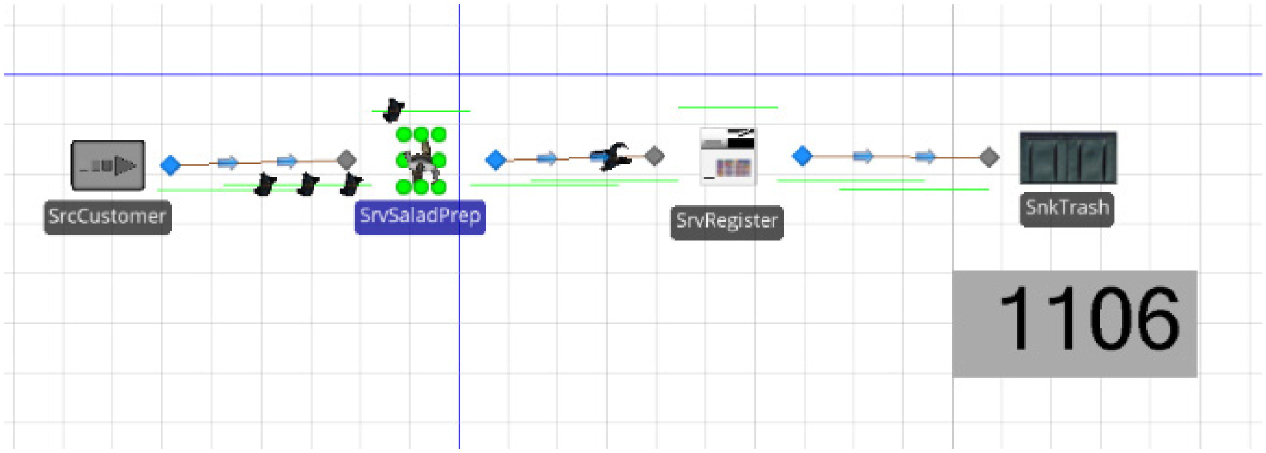

Figure 13. Employee distribution Simio experiment

Scenario			Replications		Controls		Responses
☑	Name	Status	Required	Completed	SaladWorker	RegisterWorker	Throughput
☑	Scenario1	Compl...	30	30 of 30	1	1	1087.57
☑	Scenario2	Compl...	30	30 of 30	2	1	2169.37
☑	Scenario3	Compl...	30	30 of 30	1	2	1083.13

Figure 14. Simio model of proposed method with pick-up every hour

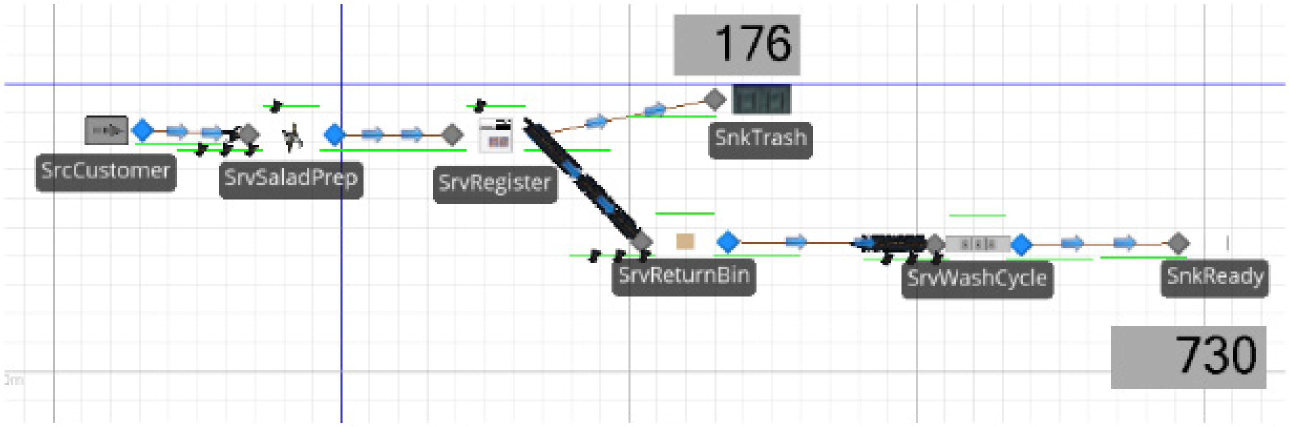

Figure 15. Simio model of proposed method with pick-up every 2 hours

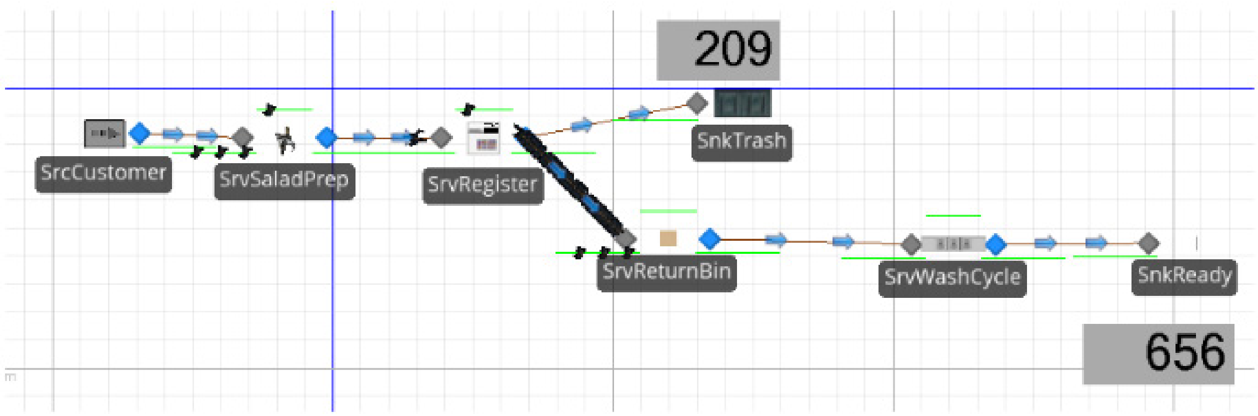

Figure 16 Revised laminated RFID tag

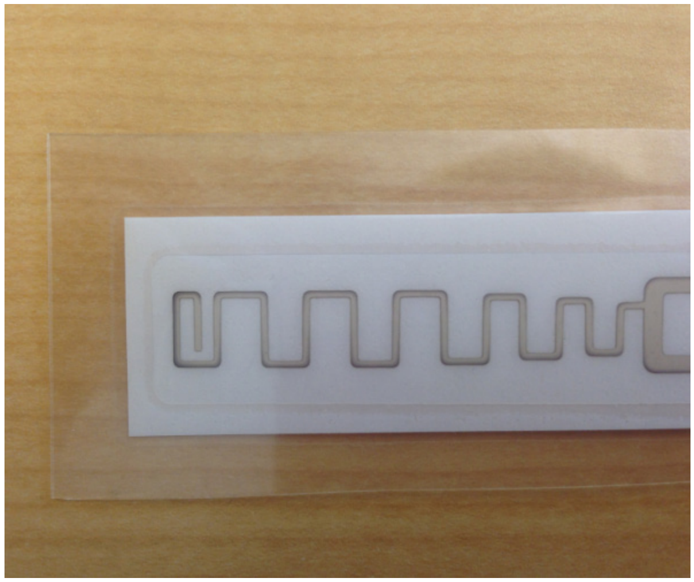

Figure 17. Revised RFID location