REUSABLE CONTAINER SYSTEM OPTIMIZATION FOR SMART CITIES

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Abstract

Federal and local governments are investing in methods to discourage use of disposable containers in order to reduce waste generation and protect the environment. In this project we propose the use of reusable takeout food containers as a replacement for disposable takeout food containers. Reusable takeout container systems may use barcode or RFID (radio frequency identification) technology to track and manage the distribution, collection, cleaning, and end-of-life recycling of reusable takeout food containers. Such systems will require the use of container collection bins. The design and optimization of a network of container collection bins is the topic of this project.

We propose a method to optimize the location network of collection bins at a Smart City. As a case study we use data collected in the city of San Luis Obispo, CA. The reusable container use cycle can be described as follows. A company provides the reusable takeout food containers to restaurants. The restaurants distribute these containers to their customers. After the container is used a customer drops it off in a convenient location for the company to pick it up and wash it. Since convenience of container drop off is crucial to customer participation, strategically placing the drop off bins around the city such that they are highly visible and easily accessible will maximize user satisfaction and benefit to the city.

Determining the optimal set of container collection bin locations was performed using a linear programming model that optimized the bin network visibility and accessibility. Visibility and accessibility were measured by traffic volume, pedestrian volume, and population density. The optimization model included varying the quantities of drop-off bins, as well as varying bin sizes and costs. An economic analysis was used to determine the optimal combination of quantity of bins, bin size, and bin cost that maximized the benefit to the city.

We simulated the potential container collection routes in order to estimate collection and transportation times and determine the optimal set of collection routes. Similar to the linear programming model, the simulation model also had variable input capabilities. The flexibility of our models may prove useful for future efforts to plan reusable container systems for Smart Cities.

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I. Introduction

San Luis Obispo is a progressive town and a leader in waste reduction striving to become a zero waste community. According to the EPA, the amount of plastic plates, cups, and containers that are recycled is negligible [17]. Furthermore, in 1970, 25.9% of food was eaten out and in 2012 that percentage had grown to 43.1% [12]. The combination of people increasingly eating out and low recycling rates initiated a movement to implement reusable containers.

California Polytechnic State University has a newly developed reusable container program, headed by Dr. Tali Freed of the Industrial and Manufacturing Engineering department. The program is in the developmental stage and aims to secure an educational loan of up to $2 million dollars from the U.S. Department of Education. The program revolves around take-out or to-go containers from restaurants all over San Luis Obispo, Cal Poly included. The constant flow of students, travelers, and permanent residents creates a huge amount of container waste and these one-time use containers can be eliminated. Currently, several prototype reusable containers have been created and restaurants will serve food in a standardized container once the proper infrastructure is installed. Proper infrastructure includes container delivery, a convenient system of drop-off bins for the customers, and container sanitization that follows FDA standards.

Tali Freed plans on applying for the grant through a two-step program. The first step, which was completed in 2016, created a system of drop-off bins for the Cal Poly campus. This project proved that a reusable container system would be beneficial at Cal Poly and showed enough positive benefits from a reusable container system to initiate step two.

This project will focus on the second step of the project, which targets to substitute one-time use take-out containers with reusable containers for restaurants in the City of San Luis Obispo. **To receive the grant, San Luis Obispo must determine the logistics behind the reusable container system. The logistics include the number, placement, type of drop-off bin and pickup routes between drop-off bins**.

To solve the problem the following deliverables need to be completed:

1. Investigate background and study similar projects

2. Obtain accurate data

3. Find optimal drop-off bin locations for each number of allowable drop-off bins

4. Analyze best number of bin and type of bin combination

5. Simulate most acceptable solutions to create pick-up route

6. Analyze financials for city

The solution approach that was used followed six steps based on the above deliverables. Step one was researching background information on recycling, data collection, garbage collection data and costs, RFID tracking, similar formulations, simulations, and financial information along with studying similar projects that have been done at Cal Poly and on other campuses. Our customer requested the solution be found through the formulation of an operations research problem, so accurate data of the highest traffic areas in San Luis Obispo had to be obtained. Data was found through observations, surveys, and the analysis of online databases. Step three consisted of the precise formulation of the problem considering vehicle volume, pedestrian volume, number of bins, population density, price and capacity of drop-off bins. Step four analyzed each combination of number of bins and type of bins to show the most optimal solution. Step five created a Simio model which provided the most effective pick up route between bins. The final step was to compute an economic analysis of the bins to ensure the final solution will have financial sustainability for the users and the city.

II. Background and Literature Review

Background

The city of San Luis Obispo is a quaint town that revolves around the college and thrives from the 21,000 students [5]. Students are the reason why San Luis Obispo was named "The Happiest Town in America", however, the young population comes with a serious problem, wastefulness. On average, college students eat out 4.4 times per week, which leaves a large footprint on waste due to to-go food containers [12]. The city of San Luis Obispo needs to reduce takeout food container waste by implementing a citywide reusable container program.

The project team has been asked to create a system that fully and successfully implements a reusable container program in the city of San Luis Obispo. This program must be user friendly in order to be successful. The first part of the project will plan a system of drop off bins that is convenient, accessible, and sustainable to the user. The second part of the project will be to assist the container cleaning company in a plan to effectively clean and track reusable containers.

Literature Review

The literature review is broken into five main topics to help logically organize the research of our problem. The topics that were studied were sampling techniques, container tracking, operations research formulations, existing recycling programs, and economic costs associated with implementation.

Sampling Techniques

Data had to be collected on high volume roads and pedestrians in different locations around San Luis Obispo. A report titled "'State-of-the-Art' Report on Non-Traditional Traffic Counting Methods" (2) regards volume estimation of traffic. It discusses many different ways, traditional and non-traditional ways to count traffic. It describes traditional ways as bending plate, pneumatic road tube, inductive loops and piezo-electric sensors and non-traditional devices as video image detection and passive magnets, acoustics, infrared and ultrasound. This report discusses the positives and negatives of both methods of traffic measurement. Understanding the benefits and drawbacks of these methods is important to the project because to accurately place the bins, an accurate volume of high traffic areas has to be known.

Along with the volume of roads, an accurate depiction of pedestrian traffic in many areas around San Luis Obispo had to be understood. A report titled "Pedestrian Counting Methods at Intersections: A Comparative Study"(3) discusses the three main methods for counting pedestrians at intersections: manual counts with sheets, manual counts with clickers, and manual counts with video cameras. This report does not only discuss the ways to execute these methods, but the accuracy of each one. The results that were found from this experiment were that manual counts with sheets and clickers underestimate pedestrian volumes with error rates from 8% to 25% with higher error rates at the end or beginning of the period. This report helps with data accuracy by mentioning things to avoid while collecting data along with determining the error rates of each method.

Data was originally taken manually with hand counters in hour intervals, but after doing several counting sessions, existing traffic counts in San Luis Obispo were researched. Traffic data was found on a website called "slocity.org" published by the city of San Luis Obispo that contained traffic data for all of San Luis Obispo. The data showed every major road and every stoplight in the city. All of the stoplight data was put in excel (Table 1) then analyzed. This data contains daily car traffic volumes as well as daily pedestrian volumes for 113 stoplights in SLO. This data will be used to target high volume area to decide the location of drop off container bins.

Additional research into the needed sample size for this population was done along with analysis of previous researchers sample sizes. An article that addresses what sample sizes should be used with varying populations in the medical field called "Sample size used to validate a scale: a review of publications on newly developed patient reported outcomes measures" was investigated. This article looks at how the sample size for most studies (in the medical field) is rarely justified with theoretical data and that sample size needs to be researched, meaning that the sample size should never be assumed to be large enough.

Container Tracking

One issue brought up was tracking the reusable containers. The containers cost around $3 each and allowing people to check out on an honor system was not economically feasible. One paper titled, "Information quality attributes associated with RFID-derived benefits in the retail supply chain" by Carmine Sellitto, Stephen Burgess, and Paul Hawking provided insightful RFID tracking information. In summary their finding showed RFID-derived benefits in timeliness, accuracy, and tracking resulted in increase profit for certain companies. Now knowing that RFID tracking was beneficial, specific RFID devices were researched. A paper titled, "Antenna design for UHF RFID tags: a review and a practical application" by K.V.S Rao, P.V. Nikitin, and S.F. Lam discuss antenna designs for box tracking in warehouses. The paper goes over detailed design, modeling, and simulation for tracking boxes in warehouses but due to the lack of financial discussion in this paper, it was ruled out due to the infeasibility of extrapolating this is an entire city. Cheaper ways to track people checking out containers were researched to avoid manually tagging each one, and the idea of credit card tracking evolved. A charge would occur when checking out the container and a reimbursed when returned to the bins. One patent, "tracking and credit method and apparatus" by James Doouglas Shultz describes a system for automatically recording a participant's actions in an activity. This particular system uses a custom-tracking card that each participant has, but it could be improved upon by using a PolyCard or even a credit card. These identifiers connect to a computer network where vendors can identify if a person needs to be charged or reimbursed. A tracking system is needed is to ensure the bins are not being used once then thrown away or kept indefinitely, but due to the complexity of this problem, tracking was decided to be out of the scope of this project.

Operations Research Solving Methods

Armed with appropriate data and continually collecting more every day, literature reviews of operation research routing methods were completed. A book titled "Hybrid Algorithms for Service, Computing, and Manufacturing System" by Nathalie Perrier provided helping computations for data analysis. Specifically, the chapter titled "Vehicle Routing Model and Algorithms for Winter Road Spreading Operations" went over efficient routing for maintenance operations using operations research techniques. While maintenance operations is not the same subject as recycling, the solving technique can be used by adjusting the constraints to help get drop off bin locations. Understand many methods of operations research was crucial to find the correct one to base our system on, so a paper titled, "International Journal Operations & Production Management" by J. Will M. Bertrand and Jan C. Fransoo which gives an overview of quantitative model-based research for operations management was very insightful. The authors went over operations research techniques from the past 20 years from a wide number of disciplines.

A different option that was researched to determine high volume places in San Luis Obispo was population density. An article titled "Strategic planning of recycling options by multi-objective programming in a GIS environment" created a model that uses a mapping system with population density incorporated. Instead of splitting the city up into quadrants, it uses different income groups, population densities, and all possible roads where the service could be located. The income groups are split into high income, medium income, low income, and slum. The population was found from a population density map and was put into term of persons per meter square. The roads that were selected had to be compliant with the needs of the service aka proximity to a powerline, bi-directional traffic. This method of mapping could be incorporated into the placement of the recycling bins because it gives a more accurate depiction of the volume of people in different places and creates a stronger relationship between denser populations and placement of services.

To find the information needed to use population density in the formulation, a website called "Statistical Atlas" gives maps of San Luis Obispo broken down by population, population density and income. It gives this data with an exact number along with a scale to determine how that area relates to other places in San Luis Obispo. Because the scope of the project just focuses on the city of San Luis Obispo, this website is more helpful than others like it because it breaks down the information by city, not just county. This information allows the formulation to be based on a more intricate and accurate mapping system.

To best generate a solution to maximize the bin location based on population density, the city of San Luis Obispo will be broken down into a grid, similar to a past senior project titled: "Modeling the Location of Return Bins for a Reusable Container Program at Cal Poly." This project describes formulation for the pedestrian paths that will be focused on along with a systematic method to break the city into a grid to formulate an optimization of the model.

After pedestrian volume, vehicle volume and population density were obtained, the formulation of the system had to be created. Many formulations with similar problems were investigated. An article titled "Optimal Location of Fast Charging Station on Residential Distribution Grid" discusses how to optimize charging stations in a residential neighborhood. It describes the method that was used, the formulation of the solution, and the final selection of the best solution. This article is related to our project because although it is focused on fast charging stations and not recycling, the method behind it is very similar to this project's solution method. Looking at the article and how the formulation was set up really highlights the places in our project where problems could occur with our formulations and what to be aware of. A paper titled "Distance decay and coverage in facility location planning" covers material supporting the idea that as distance between recycling bins increase, the likelihood to recycle decreases along while showing the method and formulation that was used to solve this problem. This paper focuses on park-and-ride and recycling in Columbus, Ohio. The method they used is similar to the steps that so many others take, by first identifying possible places for recycling places, placing constraints on the bins, then solving using operations research for the most efficient solution. Although this method is often used, this article discusses placing a constraint on the allowable distance between locations. Placing a constraint on the allowable distance between bins was discussed, but was not included because of the small area that the bins were being placed in.

An article examining bus routes titled: "Locating Stops Along Bus or Railway Lines--A Bicriteria Problem" was examined because the bins will be treated our as if they are bus stops to weigh the difference between the amount of people who can go to a bus stop and the amount of people who are missed by a certain stop. This is applicable to the drop off bins because of the need to ensure that not only the maximum number of people are reached, but also minimum number of people are missed.

A bin pick up schedule was identified as an efficient solution to the way the cleaning company for the bins could most effectively pick up the containers. A study was looked at that optimized a pick-up and delivery route system under certain time constraints titled: "Optimizing Single Vehicle Many-to-Many Operations with Desired Delivery Times: I. Scheduling." The problem that was looked at is solved using an optimization model similar to the design of our system of bin locations. Pick-up times for each bin location, desired pick up intervals, and container delivery will all be constraints when planning the pick-up and drop off routes for the cleaning company.

When looking at "An interactive optimization system for the location of supplementary recycling depots" an optimization model for the placement of bins was developed that can help to ensure that new bin placement does not effective current bin placement and shows when additional bins are needed in certain areas depending on things such as population density and number of pick-ups of bins. This optimization model can be used for the placement of take-out container wash bins in order to see where multiple bins need to be placed in certain areas if at all.

After the formulation is created and solved, the solutions need to be analyzed to check for uncertainties. According to an article titled "Using Simulation to Facilitate Analysis of Manufacturing Strategy", simulation models can help get the best possible solutions in manufacturing environments. It discusses that simulation is most helpful when there are limited amount of good solutions to help identify the best solution amongst them. Simulation modeling is good for this because it eliminates solutions that are very uncertain, meaning they are reliant on high demand or other highly uncertain situations. This can be related to our project because even though it is not a manufacturing environment, the operations research problem will give us a few different solutions. The multiple solutions should be reviewed with simulation modeling to take uncertainties into account to ensure the most reliable solution is found.

Existing Recycling Programs

When beginning the research for this project, an assessment of the reusable to-go containers needed to be done to ensure it was a proper solution for the city of San Luis Obispo. A research paper titled "A Comparative Life Cycle Assessment of Compostable and Reusable Takeout Clamshells at the University of California, Berkeley" explains why using reusable clamshells is a relevant solution. This study showed that although reusable to go containers take more water than disposable containers, a reusable to-go container after 15 uses equals the greenhouse gas contribution, energy consumption, and material waste impact of a single throw away container. Although this study occurred on a college campus, the effects of the reusable containers vs. the throw away containers remains about the same.

Once reusable to-go containers were proven to be an environmentally friendly solution for the city of San Luis Obispo, a system of pick up bins had to be created, but many questioned whether the location of the bins was important to the validity of the program. According to a report titled "Influence of distance on the motivation and frequency of household recycling", there is a high correlation between the proximity of recycling bins and the likelihood that people will recycle. The results of this report were that as distance to the recycling bin increased, the likelihood of people recycling decreased. This report is important to the collection bin project because it revealed that convenience is crucial when it comes to recycling programs. This knowledge led to the investigation into the highest volume places in San Luis Obispo to with the goal of setting up the most convenient system of drop-off bins.

While helpful data for specific problems were found, sources supporting the validity of the overall system were also researched. A similar system to reusable containers is the California recycling policy on reusable bags. An article titled "Will Banning Plastic Bags Help The Environment" by Enrico Dorigo proves that the ban on plastic bags are a very helpful to the environment due to their slow rate of decomposition, their high source of micro plastic particles. Plastic bags are also the most cheaply produced plastic item, so financially; industry would not suffer without them. The website, "calrecycle.gov", goes through the calculations of how much plastic is saved by switching to a reusable bag instead of a one time use bag and discusses the specific policy points for this program in California. The redistribution and sanitation of reusable items was a potential issue that was researched through specific examples in the food industry. An article titled, "What if all packaging was reusable" by Julia goes over standardization of containers in the food industry. The idea involved using standardized containers for every food item you buy, then returning the containers to a middleman. The middleman cleans the containers then sells them back to manufacturing companies to be filled back up. Another paper titled, "Reducing Wasted Food & Packaging: A Guide for Food Services and Restaurants" by the EPA goes over the benefits of reducing wasted food and packaging. The benefits include saving money, reducing environmental impact, reducing hunger, and supporting the community in general. This article by the EPA helps justify the financial and environmental benefits of this reusable container program.

The article "Comparison of recycling outcomes in three types of recycling collection units" analyzes the different types of bins and the effect they have on recycling. The article states that recycled bin structure may affect the recycling rate, but signage does not affect it as much. This information helped the project by endorsing our solution to make bins convenient to users instead of creating an increase in pro-recycling signage.

A study entitled "Perceived barriers to food packaging recycling: Evidence from a choice experiment of US consumers" looked directly at US consumers. It analyzed the reasons why people recycle along with likelihood of recycling between different groups of people. The results from this article found that customers do not want to clean their own packages. This justifies the need for a sanitation system so the customers do not have to clean their own containers. This program will only be sustainable if the users feel it is convenient to them, so creating a program that washes the containers for the users will encourage participation.

Economic Costs

The final step that needs to be taken to prove the validity of the project is an economic analysis of the reusable to-go container as it relates to the users and the city. A senior project titled “Reason-To-Reuse: A Sustainable to-go food storage container system for restaurants” written in 2013 is very helpful to the current project. It gives many helpful statistics, tables, visuals, and comes to the conclusion that a reusable to go container is very feasible for San Luis Obispo. Along with having another source justify that the reusable container solution is good for the environment, it proves the solution fiscally viable.

The costs of transporting the containers to the facilities will be high, but to help lower this cost, a study called “Calculating the costs of waste collection: A methodological proposal” was researched. This study provided a process in which one can calculate the cost of different waste collection services and can provide the time and value for waste collection. This methodology is what economically justifies the proposed alternatives by providing different costs based on many factors including location of wash station, location of bins, collection times, collection crew size and many other factors.

III. Design

Designing the system of collection bins was broken into three steps: data collection, linear programming, and simulation. The following section will explain how the data was obtained, then inputted into Microsoft Excel Solver and Simio.

<u>Obtaining Data</u>

A large amount of data was needed to determine the locations of the bins around the city of San Luis Obispo. This data needed to describe the most populated places in the city to ensure the most convenient placement for the users. This data was collected in three ways: Observations, Surveys, and Online Databases.

Observations

The initial data collection options for manual observations were laser counters, tally counters, or written notes. Literature reviews and research found laser counters to be the most accurate, but the cost for the required equipment was out of budget. Next, manual notes and tally counters were compared and tally counters were found to be superior. Tally counters, which cost around $10 each, closely resemble the tool that Costco employees use to count customers entering the store (Figure 1). This counter was used to count the number of vehicles or pedestrians traveling around different places in San Luis Obispo. Customers were counted in one-hour time blocks from various high traffic places across the city.

The specifications for tally counter observations were:

Each target area (Table 2) will have data collected at four times:

a) 12PM-1PM, Weekday

b) 12PM-1PM, Weekend

c) 5-6PM, Weekday

d) 5-6PM, Weekend

Weekdays are defined as Monday to Thursday and Weekends as Friday to Sunday. The above categories were determined to account for data variation. For instance, certain areas may have different data for lunchtime and dinnertime or Weekday and Weekend. The data collection procedure aimed to minimize these standard deviations.

The constraints for the observations were:

1. Inside the city of San Luis Obispo. (Figure 2)

2. Not including Cal Poly campus. (Figure 2)

The collected data can be found in Table 3 (Pedestrian volume) and Table 4 (Vehicle volume). The collection of data was never completed because a more reliable source of information was found.

Survey

A survey was created on SurveyMonkey (Figure 3) to understand how often Cal Poly students ate out, where they were most likely to go, and how likely they were to bring their reusable container.

The specifications for the survey were:

1. The survey would be open for 1 month.

2. The survey would consist of three questions.

The constraints for the survey were:

1. Only Cal Poly students and faculty would have access to it.

San Luis Obispo Traffic Data

The third and most reliable source was data from the City of San Luis Obispo. Stated on the Transportation Planning and Engineering section, "The City counts selected intersections and segments every two years, and performs speed surveys as required by state law. This data is used for signal timing and other engineering studies" [8]. Since manpower on this project was minimal and funding to accurately count volume was not present, data from the city proved to be the largest resource. The public website provides data from all 113 traffic light crossings across the city of San Luis Obispo (Figure 4). When seeking more detailed information, the total two-day traffic volume average was accessible. Every traffic light's vehicle and pedestrian volume was imported into an excel sheet (Table 1) for future analysis.

San Luis Obispo Population Density

Population densities in different parts of San Luis Obispo were researched to ensure optimal placement of drop-off bins. Traffic data alone targets highly traveled areas around the city, but does not consider high density living areas. The fundamental goal of the solution aims to target customer satisfaction so placing drop-off bins near users' homes will ensure convenience. A detailed population density map [6] (Figure 5) of the city of San Luis Obispo was found and converted into usable data by dividing the map into grids and assigning each grid with a number (Figure 6). Each grid was then ranked on a scale of 1-5 based on population density (Figure 7) with 5 marking highly populated areas. Assigning numbers to the population density map allows the scale of 1-5 to be incorporated when formulating the linear programming model.

Linear Programming Model

The formulation was created to optimally place drop off bins around the city of San Luis Obispo. The amount of observations that were taken were not enough to assume accuracy and the feedback that was received from the surveys was too minimal to use. The traffic data and population density data showed a large enough sample size and depicted an accurate representation of volumes around San Luis Obispo, so the optimal linear programming model was to be developed from these two sources of data. Below is the formulation and constraints for our model:

Stoplights

$$i \in \{1,2,3, \ldots ,113\}$$

Grid positions

$$j \in \{1,2,3, \ldots ,83\}$$

Decision Variables

$$X_{ij} = 1 \; if \; stoplight \; (i) \; inside \; grid(j) \; is \; chosen \; for \; drop \\ - off \; bin \; location, otherwise = 0$$

Data

$$Max \; Z = \left(\left(\left(T_{ij} \right) * 1.5 \right) + \; P_{ij} \right) * \; B_j$$

Note: Vehicle volume multiplied by 1.5 to represent an average of 1.5 people in each car.

$$Z = estimated \; amount \; of \; bin \; accessibility$$

$$T_{ij} = vehicle \; colume \; at \; corresponding \; traffic \; light \; (i) \; inside \; grid \; (j)$$

$$P_{ij} = pedestrian \; volume \; at \; corresponding \; traffic \; light \; (i) \; inside \; gridf \; (j)$$

$$B_j = population \; density \; scalar \; in \; each \; grid \; 1,2,3,4,5$$

$$D_j = population \; density \; by \; groups \; (1-2), (3-4), (5)$$

$$N = \max number \; of \; total \; drop - off \; bins$$

Constraints

$$M_j \leq 2 * max\ group\ D_j$$

$$N \leq 50,40,30,20,10$$

Simulation

Once the optimal number and placement of the drop off bins was determined, a pick up route for the washing faculty was devised. The pick-up route was modeled in Simio where the pickup truck was set as the model entity, each bin was replaced with a basic node and the path between each node was set by following the streets in San Luis Obispo (Figure 8). In order to set the delay at each basic node, garbage collections routes and times were researched. It was discovered that each stop on a garbage route takes 4.25 minutes on average [4]. Based on this data the delay at each basic node was set at a triangular distribution with a minimum of 5 minutes, mode of 7 minutes and a maximum of 12 minutes to accurately model the time required to load the contents of a drop off bin into the vehicle. The time for the collection bin was increased, as the unloading of a container drop off bin cannot be physically lifted as easily as a residential trash bin and will require the employee to physically step out of the collection vehicle. The assumption was made that the act of leaving the vehicle would on average add two minutes. The time to unload the container drop off bins would not be faster than that of garbage collection and could in fact take almost up to 3 times as long. The most desirable route (Figure 9) takes approximately 3.1504 hours to complete.

IV. Methodology

The methodology section will explain how each potential solution was tested using our linear programing model. Five linear programming models were run, one for each allowable number of bins: 10, 20, 30, 40, or 50 bins (Table 5). The models solved for the optimal intersections to place the drop-off bins in the city of San Luis Obispo (Table 6-Table 10) which were then plotted on maps of the city (Figure 10-Figure 14). The customer requested an optimal combination number of bins (Table 5) and type of bin A, B or C (Table 11). Each bin has a different return rate, capacity, and initial cost. These numbers were defined by our customer. The bin with the higher initial cost was said to have a higher return rate because of better ergonomics along with a larger capacity because of a larger bin. There are three types of bins for each possible solution, creating a possibility of 15 solutions. Since our customer requested certain number of bins and bin types, other options were not in our scope.

Physical testing and ranking of these 15 different solutions was not an option because of the large scale of the system. Determining the optimal solution was done by analyzing the most profitable bin type and bin number combination for the city of San Luis Obispo. The economic analysis was performed in an excel spreadsheet where all the cells are linked. This was to ensure ease of use in the future if any of the assumptions change. The assumption list was large and had many variables estimated from a variety of literature review sources. When data becomes more accurate or another city wants to use the model assumptions can easily be changed. The assumptions were broken into three categories; researched, calculated, or given.

All costs and incomes (Table 12) and assumptions (Table 13) are listed and described:

- **"Cost Saved to City per Reusable Container Use to Avoid Landfill"** was given from the client as 0.05 for 5 cents saved for each time a reusable to go container was used instead of a disposal container.
- **"How Many Users/Year"** was calculated off the recycling rates of San Luis Obispo residents, San Luis Obispo's population, and the number of times people eat out in a week.
- **"Percentage of Food Eaten Out"** was researched and found to be roughly 30% [2].
- **"Number of Meals Eaten a Week"** was based on the national average of 3 meals per day and 7 days in a week.
- **"Number of Meals Eaten Out in a Week"** was the 21 meals in a week multiplied by the percentage eaten out in a week.
- **"Number of Meals Eaten Out in a Year"** was the number of meals eaten out in

a week multiplied by the number of weeks in a year.

- **"Number of Containers Used to Full Life Cycle/Year/User"** was the number of meals eaten out in a year divided by the number of uses/container.
- **"Number of Uses/Container"** was given as 50 uses per container from the client.
- **"San Luis Obispo Population"** was researched and found as 47,339.
- **"% San Luis Obispo Likely to Recycle"** was researched and based off both the California recycling rate and the recycling rates of college students as college students recycling rates are higher.
- **"% San Luis Obispo Not Likely to Recycle"** was the remaining percentage after the percent likely to recycled is calculated.
- **"Initial cost for container"** was the cost to purchase the containers that would be used in the program. This was defined by the customer.
- **"Charge of Disposables"** was the tax that our client told us that would be implemented if the program would be put into place. This was defined by the customer.
- **"Cost of average trip"** was researched off the average cost of a garbage trip.
- **"Cost/Bin"** was defined by the customer and is described as the initial cost of each bin.
- **"Initial Cost of Washing Facility"** was defined by the customer as zero due to the use of Cal Poly's washing facility for this program.
- **"Total Cost of Bins"** was the number of bins multiplied by the Cost/Bin.
- **"Return Rate_Bin"** was the return rate of the containers to the bins based on the ergonomics of the bins.
- **"Return Rate_Locations"** was the return rate of the containers to the bins based on the fact that not all checked out containers will be recycled.
- **"Containers Returned/Year"** was the number of containers used/year multiplied by the overall return rate of the containers.
- **"Income from Initial Container Purchase/Year"** was the number of containers used/year multiplied by the initial cost of container.
- **"Income from Returns/Year"** was the cost saved to city per reusable container use to avoid landfill multiplied by the containers returned per year.
- "**Tax from Disposable Use/Year"** was to incorporate the residents use disposable containers every time they eat out. It was defined as the charge of disposable multiplied by the number of times eaten out per year multiplied by the % not likely to recycle multiplied by population of San Luis Obispo.
- **"Tax from Non-Return User Who Disposable/Year"** was to incorporate the residents who forget their reusable containers or buy one and do not consistently use it. It was defined as the charge of disposables multiplied by the number of times eaten out per year multiplied by the total return rate of the containers.
- **"Capacity"** was defined by the customer and determines how many containers

each bin can hold.

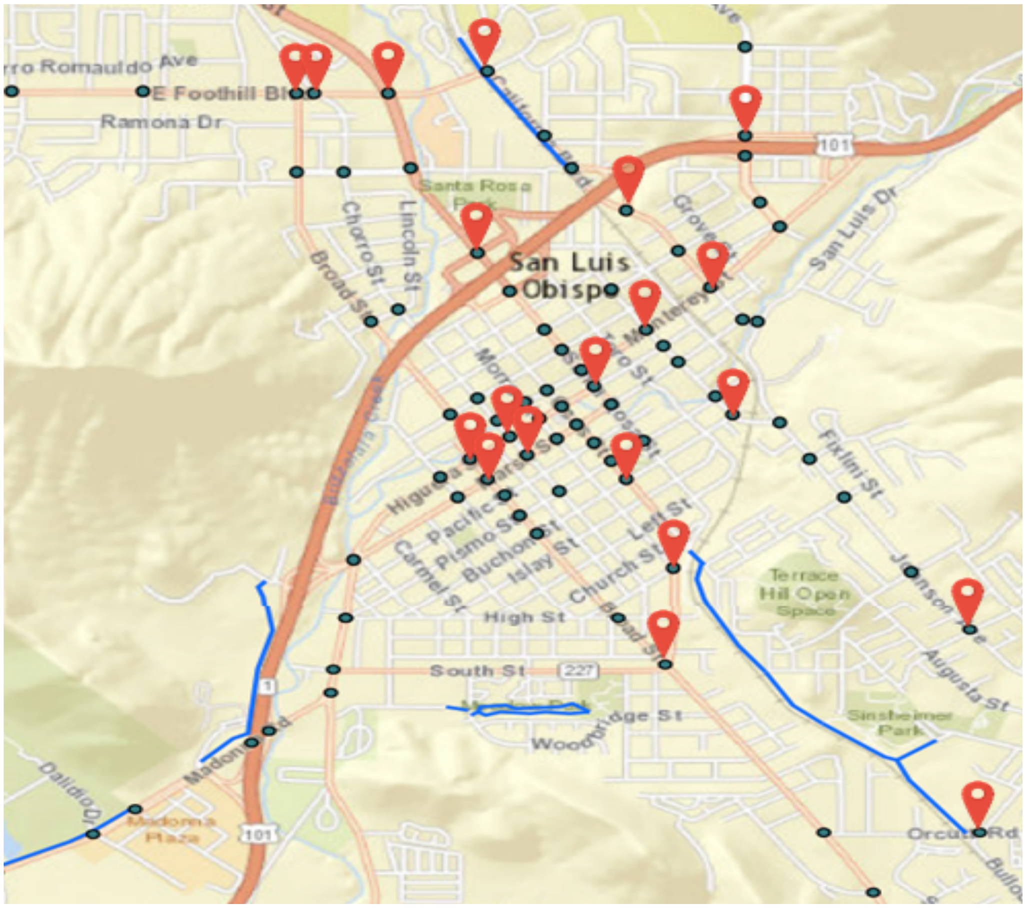
- **"Expected Containers/Day"** was defined as the expected number of containers that would be placed in all the bins per day. It was calculated by dividing the containers returned per year by the number of days per year, 365.
- **"Collection Trips/Day"** was defined as how full the drop-off bins would be each day. It was calculated by dividing the expected containers per day by the number of bins multiplied by the total number of bins.
- **"Collection Trips/Week"** was the collection trips per day multiplied by the number of days in a week, 7.
- **"Minimum Trips/Week"** was defined as the minimum number of times that the drop-off bins must be collected from to follow FDA sanitation rules and to never reach full capacity. FDA sanitation rules forces the bins to be collected a minimum of 2 times a week, but if capacity is met, it must be collected more. If the collection trips/week is greater than 2, the calculated number is rounded up and determined to be the minimum number of trips per week. If the collection trips/week is less than 2, the minimum number of trips/week is 2.
- **"Cost of Trips/Week"** was defined as the cost of collecting the bins per week. This was calculated by multiplying the cost per trip and the minimum number of trips per week.
- **"Cost of Trips/Year"** was the cost of collection trips per week multiplied by the number of weeks in a year, 52.
- **"Cost to Run Washing Facility/Year"** was based on the costs to run and maintain a water treatment plant.
- **"Income/Year"** adds together the income from initial purchase per year and the income from return per year. The tax from disposables are not included in the income per year because they are assumed to be donated to programs that help reduce the waste in landfills. This is assumed because programs such as the reusable bag program do this with their taxes on disposable bags.
- **"Cost/Year"** adds together the cost to run the washing facility per year and the cost of trips per year.

These assumptions were then used to analyze each combination of number of allowable bins and type of bin. The above metrics were related in an excel sheet to incorporate costs and incomes. The output of the excel sheet was each of the 15 options ranked from best to worst based off profitability (Table 14).

V. Results and Discussion

This section will present the top five solutions given from our linear programming model and economic analysis together. The top results will be given first, and other options will be shown in the appendix. The next paragraphs will discuss potential secondary impacts from the system and areas of improvement/future work.

The linear programming model gave 5 different location placements of bins. The location placement solutions depend on the number of allowable number of bins, but these solutions did not incorporate the different types of bins. Through the testing of the design with a profitability analysis of each combination, the solutions were tanked. The top five solutions based on break-even point (Table 15) and based on financial status in 10 years (Table 16) were inspected. The number one solution was the same in both case, 20 type A bins. This solution had a break-even point before 2 years and a profit of approximately $158,00 in 10 years. The location of 20 bins can be seen on the map below (Figure 11) and the exact name of the stoplight intersections can been found in Table 7.



The results that were achieved from our top solution were not completely what was expected, but not unreasonable. When initially looking at the different types of bins, one may expect that the higher return rate of the more expensive bin compensates for the higher initial cost, but this solution proved that the initial cost of the bin is much more of a priority than the return rate of it. The other aspect of this solution is the number of allowable bins in the system. This formulation included population density along with pedestrian and vehicle volumes. On the above map (Figure 11), it can be seen that most of the locations are placed in downtown San Luis Obispo. The number of bins was not needed to be as higher as initially expected because the downtown is a highly populated small area, so not many bins are needed to cover the area. When more drop-off bins get added to the system, not enough user convenience is created, making 20 bins the optimal solutions.

When implementing this solution, multiple things should be considered. This solution presents a great solution for the placement of drop-off containers at traffic lights, but it is limited to traffic lights. High volume pedestrian walkways are not included in this formulation because of the lack of data on those locations.

The profitability analysis also needs to be considered as an estimate because of the assumptions that were made. Although all assumptions have evidence to support them, they are estimates. This means that these numbers may be subject to change if the assumptions prove to be incorrect. If these assumptions are change, the analysis tool is very easy to change because all the numbers are linked to one another. This provides an easy tool to the user if more accurate assumptions are determined.

When testing the design, an economic analysis was created to choose the best solution between the possible 15. This analysis provided the solution of 20 type A bins, but an analysis of not implementing a system needed to be considered. Based on population growth, a graph of how many containers will be thrown out over the next 10 years (Figure 15) estimates that if no system is installed, nearly 100 million containers will be thrown out in San Luis Obispo over the next 10 to 12 years. This means that San Luis Obispo is missing out on $150,000 by the end of year 10 of no reusable container system being implemented.

The financial profitability of the program is not the only reason why the program should be implemented. The major impact this program will have is environmental, but it is not the only one. If San Luis Obispo receives this grant, it would be great publicity for the city and shows that San Luis Obispo is serious about its zero waste directive. This program will also create jobs for the city by creating a company to pick up the containers from the drop-off bins. Although these are all positive impacts from this system, the possibility for a negative reaction from the residents of San Luis Obispo is always possible, but based on how widely the reusable bag system was accepted after the implementation in 2012, the fear of the system failing due to negative cultural reactions seems improbable. Changing people's behaviors is always difficult, but San Luis Obispo’s go green mentality gives this system the best chance to thrive.

VI. Conclusions

A multidisciplinary group of faculty from Cal Poly San Luis Obispo is applying for a grant from **The Federal Board Of Education** to implement a reusable take out container system at Cal Poly and in the city of San Luis Obispo. In order for San Luis Obispo to receive the grant, the logistics behind the drop-off bins has to be determined. The logistics consist of how many drop off bins, the type of drop-off bin, the locations of the bins, and a pick-up route between the drop-off bins to collect the reusable containers. The deliverables that were completed were:

1. Background of reusable container programs, formulations, tracking, and previous senior project thoroughly studied and applied to this project.

2. Accurate vehicle and pedestrian volume in San Luis Obispo obtained through San Luis Obispo's online database.

3. Drop-off bins locations for each allowable number of drop-off bins found through linear programing problem formulated to maximize user convenience.

4. Combination of optimal number of bins and type of bin found through profitability analysis: 20 Type A Bins.

5. Most desirable pick-up route between drop-off bins found through simulation.

6. Solution of 20 Type A bins found to be most profitable compared to all other solutions and the option to do nothing

In this project, the locations that the solution found placed them at traffic light intersections, but to determine the exact locations, further analysis should be conducted. A future project should be to analyze the exact placement of the drop-off bins at the lights, incorporating ways to limit effect on traffic conditions.

Future projects should also attempt to not only include traffic lights, but high volume pedestrian walkways, bike paths, stores, and schools. This would require years of accurate data collection in order to ensure that the volume of the places was accurately depicted along with meeting the required sample size. Funding for the required equipment, man-hours, and other necessary resources.

One idea that could be incorporated into future designs would be allowing different types of bins in the system. The system we created choose one type of drop-off bin that was universal to all the locations that were found. In the future, if one location had much more accessibility than others, it could be permitted to have a bin type with a higher capacity and better ergonomics to ensure the maximum user satisfaction while more isolated locations would have a smaller, lower quality drop-off bin.

To create a system of drop-off bins for reusable to go containers, the recommendation is to place 20 Type A bins in the locations defined in Table 7. This will create the most convenient system for the user based on population density, vehicle volume and pedestrian volume. The most desirable route between drop-off bins is defined in Figure 9 and takes on average, 3.1504 hours to complete the pick-ups.

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Appendix

Table 1

Location	Number	Car Volume	Pedestrian
HIGHLAND & CHORRO	1	2853	82
HIGHLAND & SANTA ROSA	2	16405	259
PATRICIA & FOOTHILL	3	4247	156
TASSAJARA & FOOTHILL	4	4791	92
FOOTHILL & BROAD	5	8292	361
CHORRO & FOOTHILL	6	9295	414
SANTA ROSA & FOOTHILL	7	21705	511
FOOTHILL & CALIFORNIA	8	10204	1678
HATHWAY & CALIFORNIA	9	7966	159
CALIFORNIA & TAFT	10	8600	106

HWY 101 NB & CALIFORNIA	11	7412	51
MILL & CALIFORNIA	12	5162	170
GRAND & SLACK	13	5121	439
GRAND & FREDERICKS	14	5181	76
GRAND &101SB	15	5725	174
GRAND &101 NB	16	4305	233
GRAND & MILL	17	3030	144
MONTEREY & GRAND	18	5961	170
BROAD & MURRAY	19	1292	99
CHORRO & MURRAY	20	2999	112
SANTA ROSA & MURRAY	21	16273	225
LINCOLN & BROAD	22	1922	43
LINCOLN & CHORRO	23	4365	147
OLIVE & SANTA ROSA	24	17292	201
WALNUT & SANTA ROSA	25	13882	156
MILL & JOHNSON	26	2295	184
MONTEREY & CALIFORNIA	27	9646	313
CALIFORNIA & MARSH	28	5455	388
SAN LUIS & CALIFORNIA	29	5031	593
MILL & SANTA ROSA	30	10272	370
PALM & SANTA ROSA	31	9446	630
MONTEREY & JOHNSON	32	7464	518
HIGUERA & JOHNSON	33	4992	314
MARSH & JOHNSON	34	6694	311
MONTEREY & SANTA ROSA	35	11082	1227
PALM & BROAD	36	2457	1538
PALM & CHORRO	37	4360	1058
MONTEREY & CHORRO	38	3227	2135
MONTEREY & MORRO	39	2647	4058
MONTEREY & OSOS	40	3511	2134
HIGUERA & NIPOMO	41	5840	1251
HIGUERA & BROAD	42	5687	3779

HIGUERA & CHORRO	43	6186	5183
HIGUERA & MORRO	44	4555	5229
HIGUERA & OSOS	45	5644	2453
MARSH & HIGUERA	46	11254	155
MARSH & NIPOMO	47	6010	504
MARSH & BROAD	48	7263	1257
MARSH & CHORRO	49	6911	3041
MARSH & MORRO	50	4872	2284
MARSH & OSOS	51	6869	1166
HIGUERA & SANTA ROSA	52	8959	860
MARSH & SANTA ROSA	53	8338	595
PACIFIC & BROAD	54	4702	432
PISMO & BROAD	55	4808	280
PISMO & CHORRO	56	1999	281
PACIFIC & OSOS	57	4053	568
PISMO & OSOS	58	5111	520
PISMO & SANTA ROSA	59	4419	378
PISMO & JOHNSON	60	6229	129
BUCHON & BROAD	61	4467	197
BUCHON & OSOS	62	6066	288
BUCHON & JOHNSON	63	6517	115
SAN LUIS & JOHNSON	64	9868	81
LIZZIE & JOHNSON	65	9820	152
ELLA & JOHNSON	66	8801	112
SANTA BARBARA & MORRO	67	6688	195
BROAD & HIGH	68	5462	109
SANTA BARBARA & MORRO	69	6688	195
BISHOP & JOHNSON	70	8594	116
SYDNEY & JOHNSON	71	6975	72
JOHNSON & LAUREL	72	6940	75
JOHNSON & SOUTHWOOD	73	4286	43
JOHNSON & ORCUTT	74	3263	29

LAUREL & ORCUTT	75	7133	179
BROAD & ORCUTT	76	17447	202
SOUTH & BROAD	77	15972	176
HIGUERA & SOUTH	78	12415	161
HIGUERA & MADONNA	79	14677	89
MADONNA &101 nb	80	14218	55
MADONNA & 101sb	81	16633	74
MADONNA & EL MERCADO	82	11973	87
MADONNA & DALIDIO	83	12262	58
LAGUNA & LOS OSOS VALLEY	84	10942	163
LOS OSOS VALLEY & PREFUMO	85	9979	25
DESCANSO & LOS OSOS VALLEY	86	8994	45
OCEANAIRE & LOS OSOS VALLEY	87	10876	78
ROYAL & LOS OSOS VALLEY	88	11763	261
MADONNA & LOS OSOS VALLEY	89	16387	221
MADONNA & PEREIRA	90	9397	37
MADONNA & OCEANAIRE	91	11149	131
GARCIA & LOS OSOS VALLEY	92	11986	26
FROOM RCH & LOS OSOS VALLEY	93	15980	116
AUTO & LOS OSOS VALLEY	94	13681	82
JOAQUIN & LOS OSOS VALLEY	95	14611	28
& LOS OSOS VALLEY	96	15493	19
LOS OSOS VALLEY &	97	11939	32
HIGUERA & LOS OSOS VALLEY	98	10750	42
HIGUERA & VACHELL	99	11440	30
HIGUERA & SUBURBAN	100	11100	108
HIGUERA & TANK FARM	101	13617	118
HIGUERA & GRANADA	102	9844	126
HIGUERA & PRADO	103	10593	141
HIGUERA & MARGARITA	104	8396	130
BROAD & ROCKVIEW	105	13567	52
CAPITOLIO & BROAD	106	13722	59

INDUSTRIAL & BROAD	107	14954	54
TANK FARM & BROAD	108	19802	328
TANK FARM & POINSETTIA	109	4844	146
BROAD & AERO	110	6861	8
BROAD & AIRPORT	111	6448	2

Table 2

Location	**Walking/Driving**
Firestone	Walking
Santa Cruz Taqueria	Walking
Splash Cafe	Walking
Movie Theater Ally	Walking
Madonna Costco	Driving
Madonna Mcdonald's	Driving
Madonna Trader Joe’s	Walking

Downtown Parking Structure (3)	Driving
SLO High School	Driving
Starbucks	Driving
Tiki Hut	Driving
Santa Rosa Park	Driving
Mustang Village	Walking
Food for less/Trader Joe's	Walking
Down Broad Street	Driving

Table 3

Location	Time (Lunch or Dinner)	People Walked By (Number)
Santa Cruz Taqueria	Lunch	69
Movie Path	Lunch	705
Madonna Chipotle	Lunch	127
Firestone	Lunch	165
Santa Cruz Taqueria	Dinner	74
Madonna Chipotle	Dinner	194
Jamba/Starbucks	Lunch	101

Weekday

Weekend

Table 4

Location	Time (Lunch or Dinner)	Cars Drive By (Number)
Costco Parking	Lunch	743
Costco Parking	Dinner	852

Weekday
Weekend

Table 5

Number of Allowable Bins
10
20
30
40
50

Table 6

Intersection Name	Grid #

SANTA ROSA & FOOTHILL	10
BROAD & SANTA BARBARA	31
FOOTHILL & CALIFORNIA	11
MARSH & SANTA ROSA	31
MONTEREY & CALIFORNIA	23
HIGUERA & CHORRO	30
CHORRO & FOOTHILL	10
HIGUERA & SANTA ROSA	23
HWY 101 NB & CALIFORNIA	18
LAUREL & ORCUTT	56

Table 7

Intersection Name	**Grid #**
FOOTHILL & BROAD	10
CHORRO & FOOTHILL	10
SANTA ROSA & FOOTHILL	10
FOOTHILL & CALIFORNIA	11
HWY 101 NB & CALIFORNIA	18
GRAND &101SB	18
OLIVE & SANTA ROSA	17
MONTEREY & CALIFORNIA	23

MONTEREY & JOHNSON	23
HIGUERA & BROAD	30
HIGUERA & CHORRO	30
MARSH & BROAD	30
MARSH & CHORRO	30
HIGUERA & SANTA ROSA	23
MARSH & SANTA ROSA	31
BUCHON & OSOS	31
SANTA BARBARA & MORRO	31
SYDNEY & JOHNSON	44
LAUREL & ORCUTT	56
BROAD & SANTA BARBARA	31

Table 8

Intersection Name	**Grid #**
FOOTHILL & BROAD	10
CHORRO & FOOTHILL	10
SANTA ROSA & FOOTHILL	10
FOOTHILL & CALIFORNIA	11
HWY 101 NB & CALIFORNIA	18
MILL & CALIFORNIA	18
GRAND & SLACK	12
GRAND & FREDERICKS	12

GRAND &101SB	18
OLIVE & SANTA ROSA	17
WALNUT & SANTA ROSA	22
MONTEREY & CALIFORNIA	23
MONTEREY & JOHNSON	23
MARSH & JOHNSON	23
HIGUERA & NIPOMO	30
HIGUERA & BROAD	30
HIGUERA & CHORRO	30
MARSH & BROAD	30
MARSH & CHORRO	30
HIGUERA & SANTA ROSA	23
MARSH & SANTA ROSA	31
PISMO & OSOS	31
BUCHON & OSOS	31
BUCHON & JOHNSON	23
SANTA BARBARA & MORRO	31
SYDNEY & JOHNSON	44
JOHNSON & LAUREL	45
LAUREL & ORCUTT	56
BROAD & SANTA BARBARA	31
HIGUERA & TANK FARM	76

Table 9

Intersection Name	Grid #
FOOTHILL & BROAD	10
CHORRO & FOOTHILL	10
SANTA ROSA & FOOTHILL	10
FOOTHILL & CALIFORNIA	11
HWY 101 NB & CALIFORNIA	18
MILL & CALIFORNIA	18
GRAND & SLACK	12
GRAND & FREDERICKS	12

GRAND &101SB	18
GRAND &101 NB	18
MONTEREY & GRAND	23
OLIVE & SANTA ROSA	17
WALNUT & SANTA ROSA	22
MONTEREY & CALIFORNIA	23
CALIFORNIA & MARSH	23
MONTEREY & JOHNSON	23
MARSH & JOHNSON	23
MONTEREY & SANTA ROSA	22
HIGUERA & NIPOMO	30
HIGUERA & BROAD	30
HIGUERA & CHORRO	30
MARSH & NIPOMO	30
MARSH & BROAD	30
MARSH & CHORRO	30
MARSH & MORRO	30
HIGUERA & SANTA ROSA	23
MARSH & SANTA ROSA	31
PISMO & OSOS	31
PISMO & SANTA ROSA	31
PISMO & JOHNSON	23
BUCHON & OSOS	31
BUCHON & JOHNSON	23
SANTA BARBARA & MORRO	31
BISHOP & JOHNSON	43

SYDNEY & JOHNSON	44
JOHNSON & LAUREL	45
LAUREL & ORCUTT	56
BROAD & SANTA BARBARA	31
MADONNA & OCEANAIRE	62
HIGUERA & TANK FARM	76

Table 10

Intersection Name	**Grid #**
FOOTHILL & BROAD	10
CHORRO & FOOTHILL	10
SANTA ROSA & FOOTHILL	10
FOOTHILL & CALIFORNIA	11
HWY 101 NB & CALIFORNIA	18
MILL & CALIFORNIA	18
GRAND & SLACK	12

GRAND & FREDERICKS	12
GRAND &101SB	18
GRAND &101 NB	18
MONTEREY & GRAND	23
OLIVE & SANTA ROSA	17
WALNUT & SANTA ROSA	22
MONTEREY & CALIFORNIA	23
CALIFORNIA & MARSH	23
MILL & SANTA ROSA	22
PALM & SANTA ROSA	22
MONTEREY & JOHNSON	23
MARSH & JOHNSON	23
MONTEREY & SANTA ROSA	22
HIGUERA & NIPOMO	30
HIGUERA & BROAD	30
HIGUERA & CHORRO	30
MARSH & NIPOMO	30
MARSH & BROAD	30
MARSH & CHORRO	30
MARSH & MORRO	30
HIGUERA & SANTA ROSA	23
MARSH & SANTA ROSA	31
PISMO & BROAD	30
PACIFIC & OSOS	31
PISMO & OSOS	31
PISMO & SANTA ROSA	31

PISMO & JOHNSON	23
BUCHON & OSOS	31
BUCHON & JOHNSON	23
SAN LUIS & JOHNSON	24
LIZZIE & JOHNSON	32
ELLA & JOHNSON	32
SANTA BARBARA & MORRO	31
BISHOP & JOHNSON	43
SYDNEY & JOHNSON	44
JOHNSON & LAUREL	45
LAUREL & ORCUTT	56
BROAD & SANTA BARBARA	31
MADONNA & OCEANAIRE	62
HIGUERA & TANK FARM	76
HIGUERA & GRANADA	76
HIGUERA & PRADO	64
TANK FARM & BROAD	79

Table 11

Type of Bin	Cost of Bins ($)	Capacity of Bins	Return Rate (%)
A	1000	50	50
B	2000	80	70
C	3000	140	90

Table 12

Calculations	
Cost/Bin	Initial Cost of Each Bin
Initial Cost of Washing Facility	Pre-existing Washing Facility on Cal Poly Campus
Inital Cost of Bins	(# of Bins) * (Cost of Bins)
Return Rate_Bin	Container Return Rate based on Bin Ergonomics
Return Rate_Locations	Container Return Rate based on Assumption of not 100% Return
Containers Returned/Year	(# of Containers Used/ Year) * (Return Rate_Bin) * (Return Rate_ Location)
Income from Initial Container Purchase/Year	(# of Containers Used/Year) * (Initial Cost of Container)
Income from Returns/Year	(Cost Saved from Reusable Container going to Landfill) * (Containers Returned/Year)
Tax From Disposable Use/Year	(Charge of Disposable) * (Number of Times Eaten Out/Year) * (% Not Likely to Recycle) * (Population of San Luis Obispo)
Tax From Non-Returned/Year	(Charge of Disposable) * (Number of Times Eaten Out/Year) * (Total Return Rate)
Capacity	# of Containers Each Bin Type Holds
Expected Containers/Day	(Containers Returned/ Year)/ 365
Collection Trips/Day	(Containers Returned /Day) / (Capacity * Number of Bins)
Collection Trips/Week	(Collection Trips/Day) * 7
Minimum Trips/Week	(Collection Trips/Week) OR 2
Cost of Trips/Week	(Cost of Trip) * (Number of Trips/Week)

Cost Trip/Year	(Cost of Trips/Week) * 52
Income/Year	(Income from Initial Purchase/Year) + (Income from Returns/Year)
Cost to Run Washing Facility/Year	Cost to Maintain and Run Facility based on Water Treatment Plant
Total Cost/Year	(Cost to Run Washing Facility/Year) + (Cost of Trips/Year)

Table 13

Assumptions	
Cost Saved For City per Reusable Container Use to	0.05
How Many Users/Year	31717.13
Percentage of Food Eaten Out	30.00%
Number of Meals Eaten a Week	21
Number of Meals Eaten Out in a Week	6.3
Number of Meals Eaten Out in a Year	327.6
Number of Containers Used to Full Life	6.552
Number of Uses/Container	50
San Luis Obispo Population	47339
% San Luis Obispo Likely to Recycle	67%
% San Luis Obispo Not Likely to Recycle	33%
Initial Cost for Container	2
Charge on Disposables	0.15
Cost of Average Trip	1000

Table 14

Type of Bin	Number of Bins	1	2	3	5	10
A	20	$ (2,204)	$ 15,591	$ 33,387	$ 68,978	$ 157,956
B	20	$ (20,934)	$ (1,867)	$ 17,199	$ 55,332	$ 150,665
A	30	$ (12,204)	$ 5,591	$ 23,387	$ 58,978	$ 147,956
C	20	$ (39,663)	$ (19,325)	$ 1,012	$ 41,687	$ 143,373
A	40	$ (22,204)	$ (4,409)	$ 13,387	$ 48,978	$ 137,956
B	30	$ (40,934)	$ (21,867)	$ (2,801)	$ 35,332	$ 130,665
A	50	$ (32,204)	$ (14,409)	$ 3,387	$ 38,978	$ 127,956
C	30	$ (69,663)	$ (49,325)	$ (28,988)	$ 11,687	$ 113,373
B	40	$ (60,934)	$ (41,867)	$ (22,801)	$ 15,332	$ 110,665
B	50	$ (80,934)	$ (61,867)	$ (42,801)	$ (4,668)	$ 90,665
C	40	$ (99,663)	$ (79,325)	$ (58,988)	$ (18,313)	$ 83,373
C	50	$ (129,663)	$ (109,325)	$ (88,988)	$ (48,313)	$ 53,373
C	10	$ (61,663)	$ (93,325)	$ (124,988)	$ (188,313)	$ (346,627)
B	10	$ (52,934)	$ (85,867)	$ (118,801)	$ (184,668)	$ (349,335)
A	10	$ (96,204)	$ (182,409)	$ (268,613)	$ (441,022)	$ (872,044)

Table 15

Bin Type	Allowable Bins	Break Even Point (Years)
A	20	2
A	30	2
B	20	3
A	40	3
A	50	3

Table 16

Bin Type	Allowable Bins	10 Years Estimated Profit ($)
A	20	$158,000
B	20	$151,000
A	30	$148,000

C	20	$143,000
A	40	$138,000

Figure 1

Figure 2


California Polytechnic State University
1
101
W Foothill Blvd
San Luis Obispo
101
Johnson Ave
Madonna Inn
Irish Hills Natural Reserve
S Higuera St
227
101
Buckley Rd

Figure 3

1. How many times a week do you eat out on average?
    a. 0-1
    b. 2-3
    c. 4-5
    d. 6 or higher
2. When you do go out to eat, how often do you take food to go?
    a. 0%
    b. 25%
    c. 50%
    d. 90%
3. If a reusable take out container system was available, would you be interested?
    a. Yes
    b. No
    c. No Opinion

Figure 4

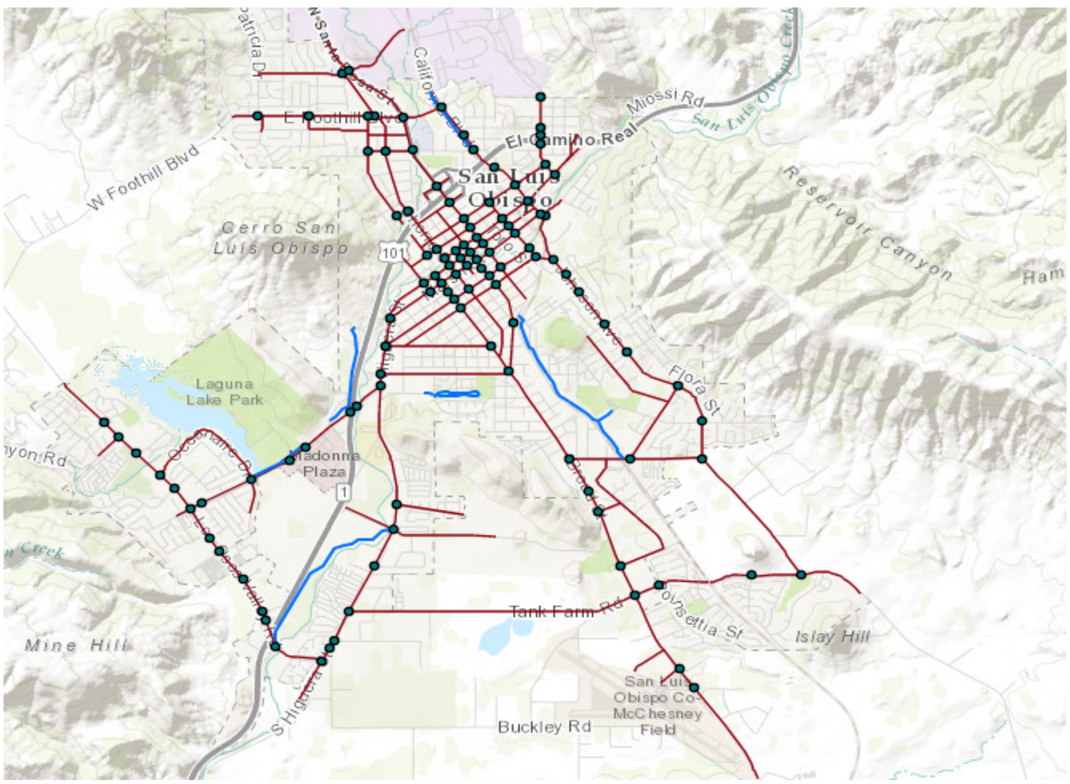


Figure 5

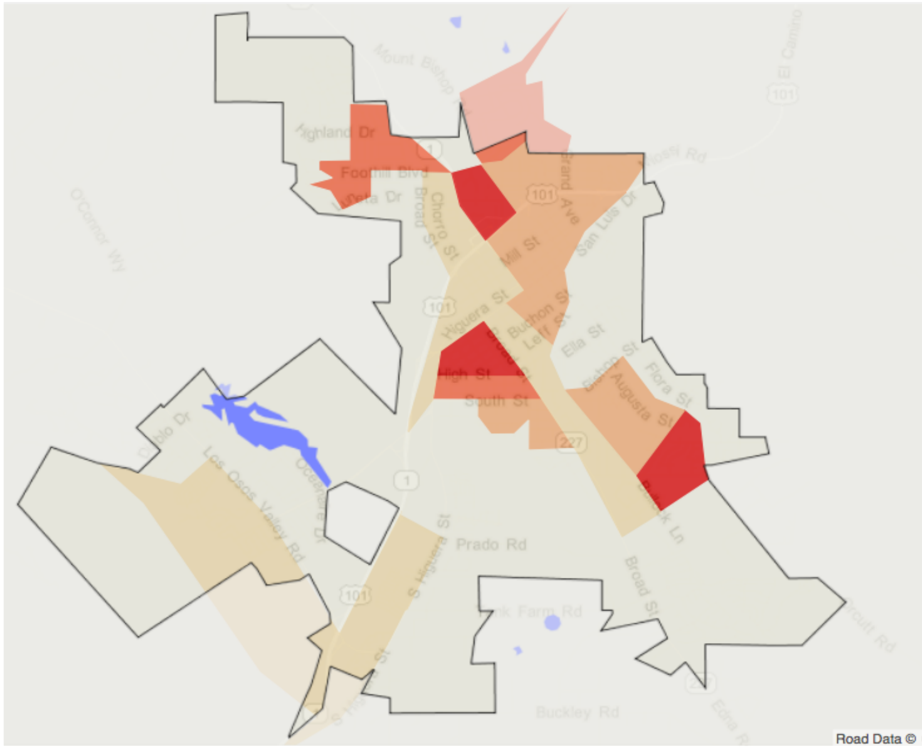


Figure 6

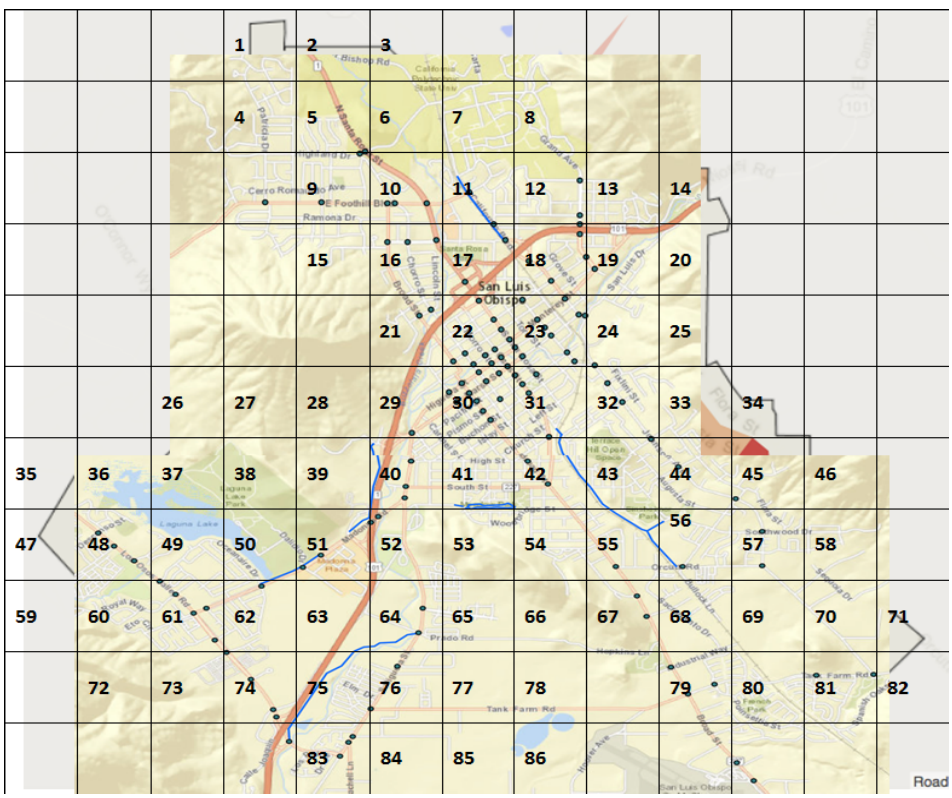


Figure 7

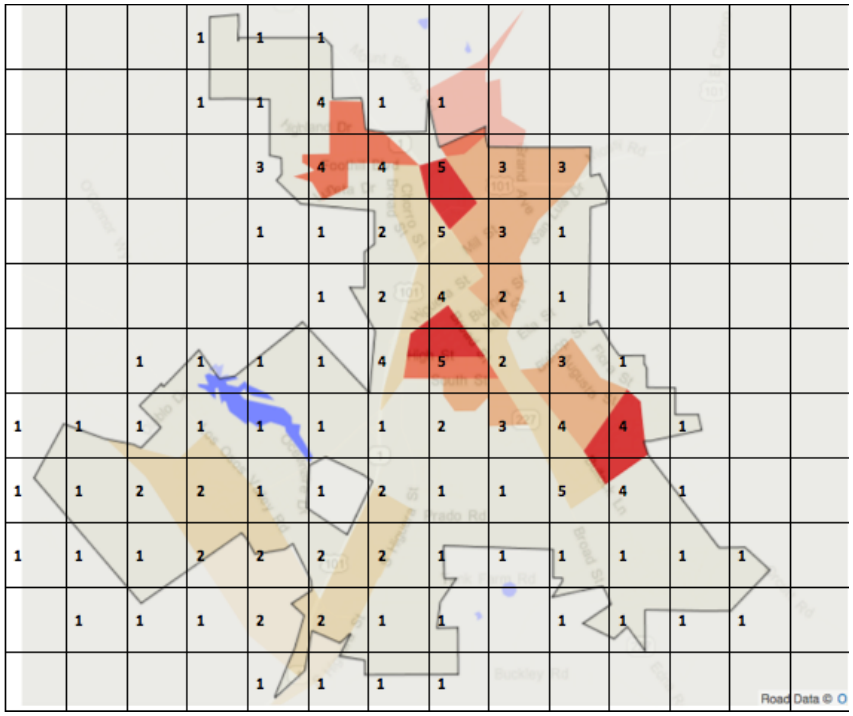
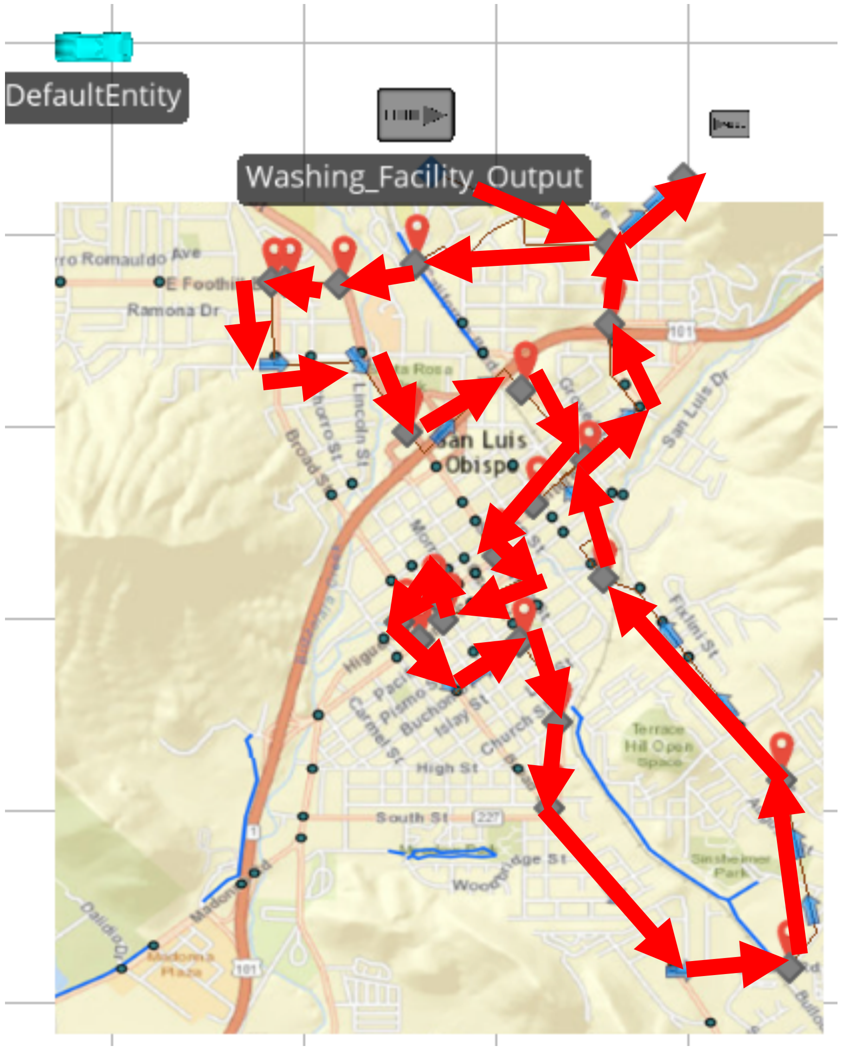


Figure 8

Figure 9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Washing_Facility_Output
San Luis Obispo
Ramona Dr
E Foothill
Lincoln St
Broad St
Higuera
Pismo St
Buchon St
Islay St
Church St
High St
South St
Terrace Hill Open Space
Sinsheimer Park
Madonna Plaza

Figure 10


Highland Dr
Cerro Romauldo Ave
Ramona Dr
Santa Rosa Park
Chorro St
Lincoln St
Broad St
San Luis Obispo
Grand Ave
Grove St
San Luis Dr
High St
South St
227
101
Terrace Hill Open Space
Laguna Lake Park
Sinsheimer Park
Augusta St
Madonna Plaza
Oceanaire Dr
Dalidio Dr

Figure 11

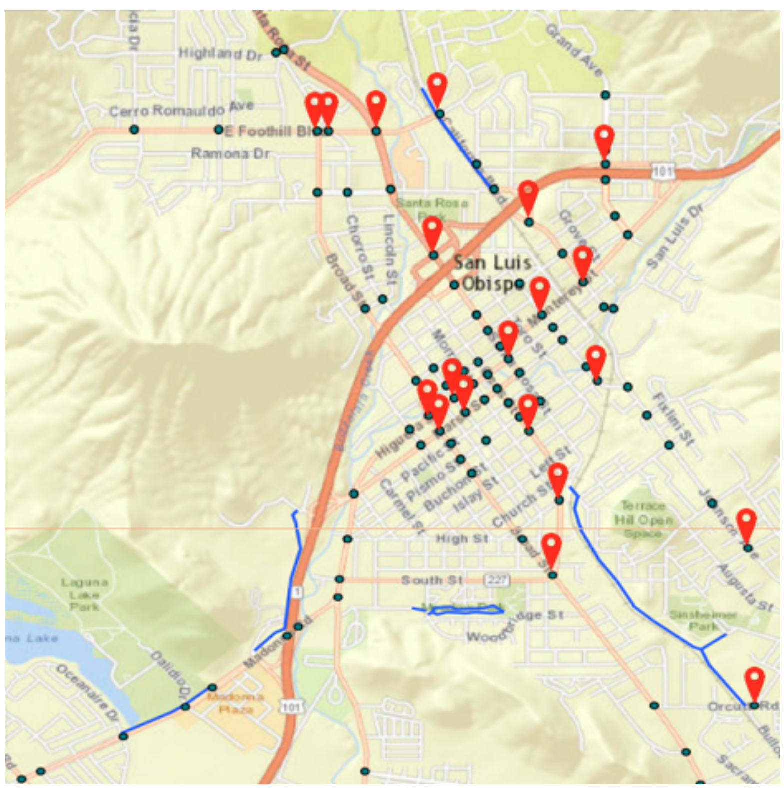
Highland Dr
Cerro Romauldo Ave
Ramona Dr
Santa Rosa Park
Chorro St
Lincoln St
Broad St
San Luis Obispo
Grand Ave
San Luis Dr
High St
South St
227
101
Terrace Hill Open Space
Laguna Lake Park
Sinsheimer Park
Augusta St
Madonna Plaza
Oceanaire Dr
Dalidio Dr

Figure 12

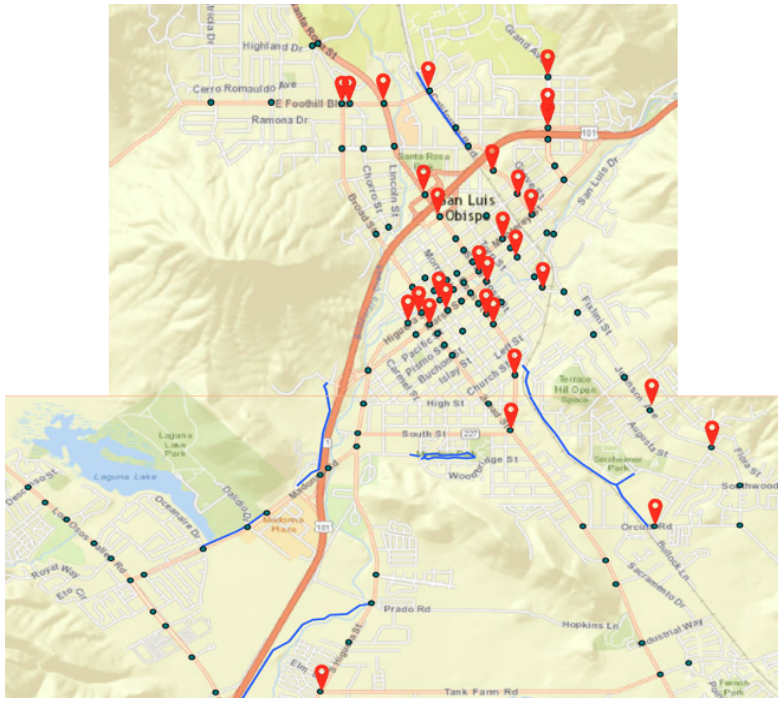

Figure 13

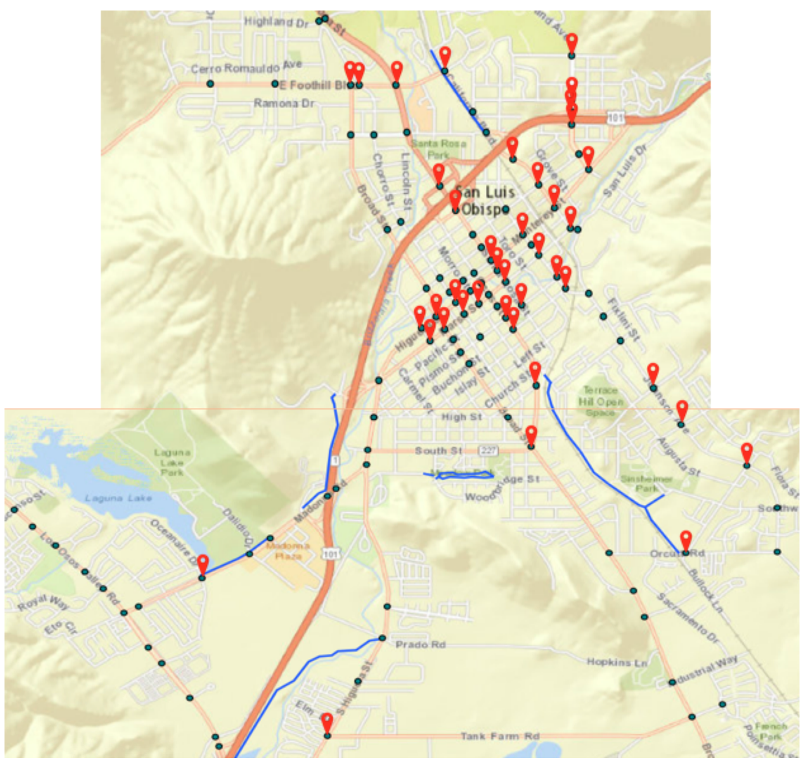

Figure 14

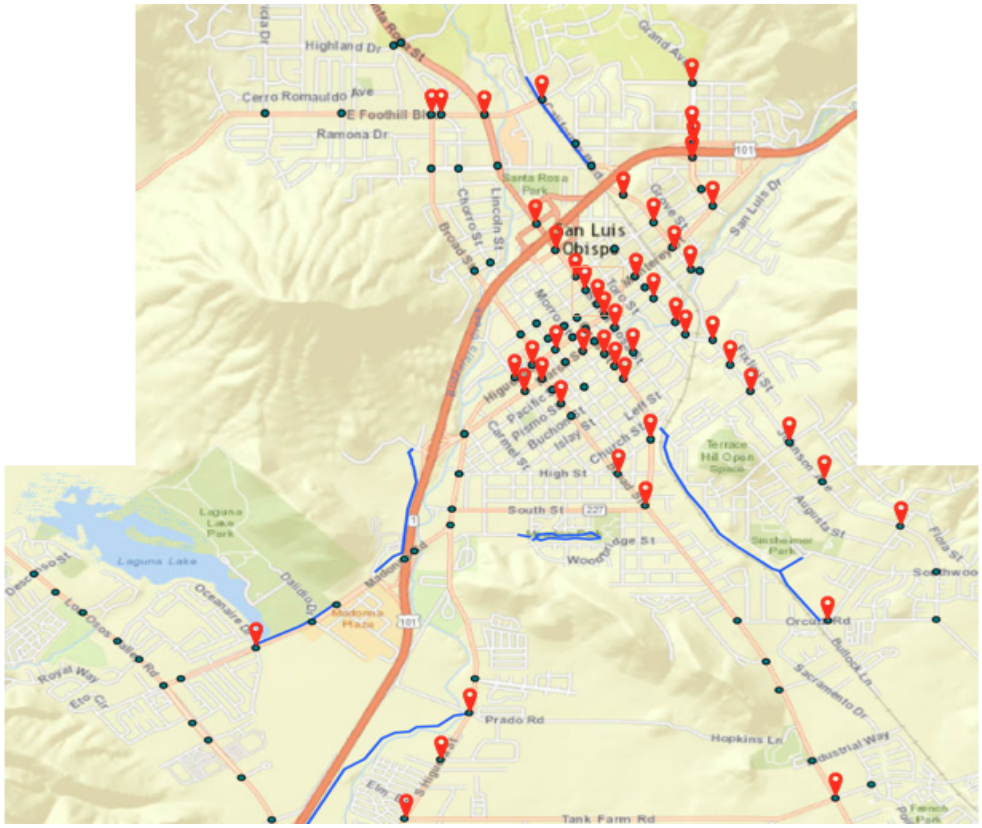

Figure 15