Executive Summary

Regardless of the reason, discarding food that still has the capacity for consumption has a offers a slew of economic, environmental, and social consequences. In 2007, a global study showed that land used to grow wasted food occupied of almost 1.4 billion hectares, a space that translates to about 28% of the world's land area. If the land used to grow food that isn't eaten were a country, it would be the second largest country in the world behind Russia [7].

We developed a model to determine the ability of a state with given resources to feed it's food-insecure population using only edible and redistributable food waste. For this model, we ignored food waste generated through individual consumption, instead considering food wasted during the processes of production, handling, storage, and selling. Furthermore, we ignored the potential logistical limits and focused on obtaining an upper bound on the amount of people who could be fed using wasted food. We tested our model on 2015 data from Texas and concluded that the state would be able to feed about 29% of it's food-insecure population using food that would otherwise be thrown away.

We then created a model to estimate the amount of food waste that would be generated in a year by families with given characteristics. We found a positive correlation between the amount of money people spend on food annually and their annual income. In order to calculate household waste produced, we focused on the inputs of household income and number of members of the household. Our function outputs the estimated dollar amount of waste generated by the household, since analysis of food waste is often done in terms of financial loss. Larger families that made over $50 thousand a year produced substantially more food waste than other families.

Finally, we developed a model for determining an optimal strategy in dealing with food waste in our home of Guilford County by comparing standardized food labeling, centralized composting, and donation tax incentives on the merit of financial cost, amount of food recovered, and the ability to divert municipal waste. We accomplished this by evaluating several weighted comparison biases between the strategies and the three main criteria. We then inputted these figures through an analytic hierarchy decision process to determine a final global score of all three methods based on the resultant matrices and vectors. Based on our results, we found that the most effective strategy of the three was labeling followed by tax incentives and composting.

Better *ATE* Than Never

Team #10374

April 1, 2018

Contents

1 Just Eat It!

1.1 Restatement of the Problem

The problem asks us to do the following:

- Create a mathematical model that could be used to determine if a state can address its food-insecure population from the amount of food-waste
- Apply the model in the context of the state of Texas using the data given

1.2 Assumptions

1. **Assumption**: We do not need to account for money or other logistical problems such as methods of transportation for goods.
   Justification: Since we are trying to evaluate whether or not the amount of wasted food is enough to feed the food-insecure population rather than how feasible it is logistically, we choose to exclude the aforementioned extraneous factors. If the government wanted to distribute wasted food it could allocate sufficient resources.

2. **Assumption**: We do not consider food waste from the consumption stage.
   Justification: Leftover food from meals cannot be redistributed to people who are food-insecure as easily as "ugly" crops which farmers may simply discard.

3. **Assumption**: Food-insecure individuals require varying amounts of meals.
   Justification: Food-insecure is broadly defined and there are many people who can afford some meals, just not enough.

4. **Assumption**: Wasted food is edible food that can be used by food-insecure individuals.
   Justification: Food that would go bad could simply be redistributed before going bad and wouldn't become wasted. Often times the food that is thrown away is still edible, just not presentable.

5. **Simplification**: Commodities are sold at a constant price even with different vendors.
   Justification: When examining a single state, variances in price for a commodity would be minimal and measuring the variances would be too taxing for the scope of the project.

6. **Simplification**: The food wasted percentages in the post-harvest handline, storage stage, and processing and packaging stage can be added together.
   Justification: All food sold by a producer needs to go through the post-harvest handline and storage stage and processing and packaging stage, so it can be treated as one stage.

7. **Simplification**: Wasted food is defined as all the food not sold.
   Justification: All food that isn't sold and is thrown away can be counted as wasted, we will not account for other rare possibilities.

We began by constructing a simple model to obtain a percentage of food insecure people that could be fed by the available wasted food, represented as O:

$$O = \frac{N_f}{N_m \times P}.$$

based on the amount of available food (N_f), the number of meals needed for everyone (N_m), and the price of a meal (P).

Using the assumption that there are no logistical problems, our model develops an upper bound for the percentage of food-insecure people that can be fed using the food lost during the Agricultural production stage, handling and packaging stage, and supermarket stage.

1.3 Our Model

The model we developed to determine the percentage of a state's food-insecure population that can be fed using wasted food relied on six factors:

- Supermarket and Grocery store sales
- Agricultural Industry sales
- Estimated waste percentages at each step
- Average cost per meal
- Number of food-insecure people
- Income distribution of food-insecure people

1.4 Average Price of a Meal

According to a 2015 study done by Feeding America study, the average cost of a meal is \$2.59 [2].

1.5 Number of Meals for Food-Insecure People

In the same 2015 study by Feeding America, the state of Texas has a total food-insecure population of roughly 4 320 050, or about 15.7% of the population [2].

The amount of food needed per food-insecure person will vary according to several factors, but primarily due to variations in income. "Food-Insecure" is broadly defined, so while some people may be in need of 3 meals a day, others may only need 1. We split the food-insecure population into three groups according to their income levels, where those with income below 165% poverty require, on average, 3 meals a day, those with income between 165% and 185% require 2, and those with income greater than 185% require only 1 [2].

According to the Feeding American study, in 2015, 63.3% of the Texas food-insecure population had income below 165% poverty, 5.6% fell between 165% and 185% poverty, and 31% had income over 185%. Using our model and the fact that there are 4 320 050 food-insecure people, we determined that there would be a total need of 10 026 836 meals to feed them for the 2015 year.

1.6 Amount of Available Wasted Food

Using the assumption that food waste from the consumption stage cannot be redistributed, in order to find the total amount of available wasted food we need to sum the waste from the other four stages: production, storage, packaging, and supermarket sales. By using the cash receipts to find the total value of a commodity (C') as well as its specific waste percentage (W_c) [1], we can use the formula:

$$C = \frac{C'}{1 - W_c}$$

to find the original value of the commodity before being sold (C). Then we simply take C - C' to find the estimated waste for that particular commodity. This formula works with the Agricultural production and Supermarket stages as ways to estimate the waste caused from selling only the best looking products. For the postharvest handline and storage stage and processing and packaging stage, we directly applied their W_c to the value of their commodity to find the waste. In the end, we determined the value of food waste during the Supermarket stage to be \$732,724,141.71, the value of food waste during the Agricultural Production stage to be \$934,957,171.02, and the value of the food waste during the processing and packaging stage to be \$1,054,623,686.40. In order to determine the value of food waste during the Agricultural Production stage, we needed to estimate the breakdown of cereals and oilseeds commodity categories since the data didn't come separated into those categories. We used the 2017 data which was separated into individual items, found the ratio that year, and then used that same ratio to determine the breakdown and make our estimate more accurate [8].

An important note to be made: by using the simplification about the price of commodities being the same in a state, even though the data given is weight percentage of food lost in each stage, the ratio between weight and value allows us to take the percentage directly off of the value and not worry about conversions with weight.

1.7 Applying the Model to Texas

Now that we have found all the information needed to see the percentage of food-insecure people in Texas that can be fed using wasted food, we simply plug in numbers to the model to find O:

$$O = \frac{\$732,724,141.71 + \$934,967,171.02 + \$1,054,623,686.40}{10\,026\,836\,\text{meals} \times \$2.59}$$

So,

$$O = 28.72\%$$

which means that 28.72% of the food-insecure population in Texas could be fed using wasted food. This answer does seem reasonable because the majority of the food waste comes during the consumption stage. The largest food waste percentages are found during this stage [1] and whenever people cite food waste statistics they usually always consider this stage, which inflates the number. By using our model we develop a more realistic upper bound for percentage of food-insecure population that can be fed using wasted food, since we assumed there are absolutely no logistical errors or problems.

2 Food Foolish?

2.1 Restatement of the Problem

We have been tasked with:

- Create a mathematical model that considers household traits to determine the food waste they generate in a year.

2.2 Assumptions

1. **Assumption**: We can consider food waste to be any excess food purchased that was not necessary to consume. This includes food purchased and thrown away, as well as food purchased and unnecessarily consumed.
   Justification: Any food purchased that was not necessary for the purchaser is food that could have gone to those in need instead.

2. **Assumption**: There is a positive correlation between income and food expenditures.
   Justification: The more money a household makes, the more free and willing they are to spend money on food.

3. **Simplification**: We can ignore age as a factor determining amount of waste.
   Justification: Age is roughly correlated to income level, and not necessarily related to how much waste one produces. More thorough models might include age as a factor, but for the scope of this project it is sufficient to include only other, more relevant factors.

4. **Simplification**: The minimum amount of necessary spending on food goes up linearly as income goes up.
   Justification: Families with higher income levels typically are larger and thus have more food needs, so they may need to spend more, but we do not consider this wasteful.

2.3 Our Model

We used data from the August 2017 U.S. Bureau of Labor Statistics (USBLS) Consumer Expenditure Survey to determine a relationship between income and amount of money spent on food [6].

A plot of the average yearly food expenditures vs yearly income of each "Consumer Unit," both in dollars, is shown in Figure 1. We noticed that the in the bottom 25% of the income range, the increase in food expenditures was linear with income. We defined this linear increase as a "baseline" rate–the increase in food expenditure that is natural for increasing income. A household with more income will purchase more expensive food products, without necessarily wasting any food. The orange line in the plot is the linear regression based on the bottom 25% of the income range. The orange line represents this "baseline."

We defined the dollar amount of food waste generated by a household as the dollar amount of excess food expenditures, or the difference between their food expenditures and the baseline. This waste becomes noticeable for households with more than $50k in annual

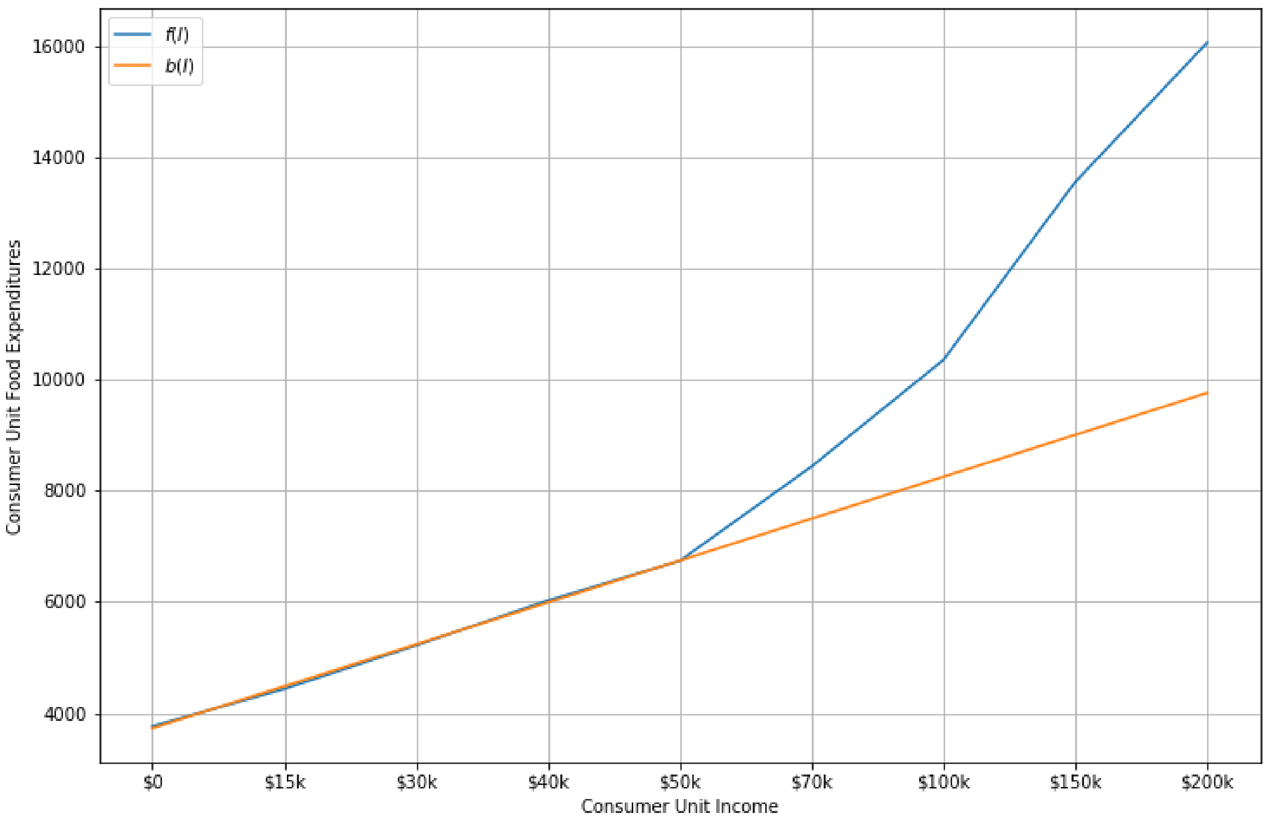

Figure 1: Plot of average food expenditures vs average income, with a linear regression applied to the bottom 25% of the income range. The difference between the curve and the linear regression represents excess food purchased.

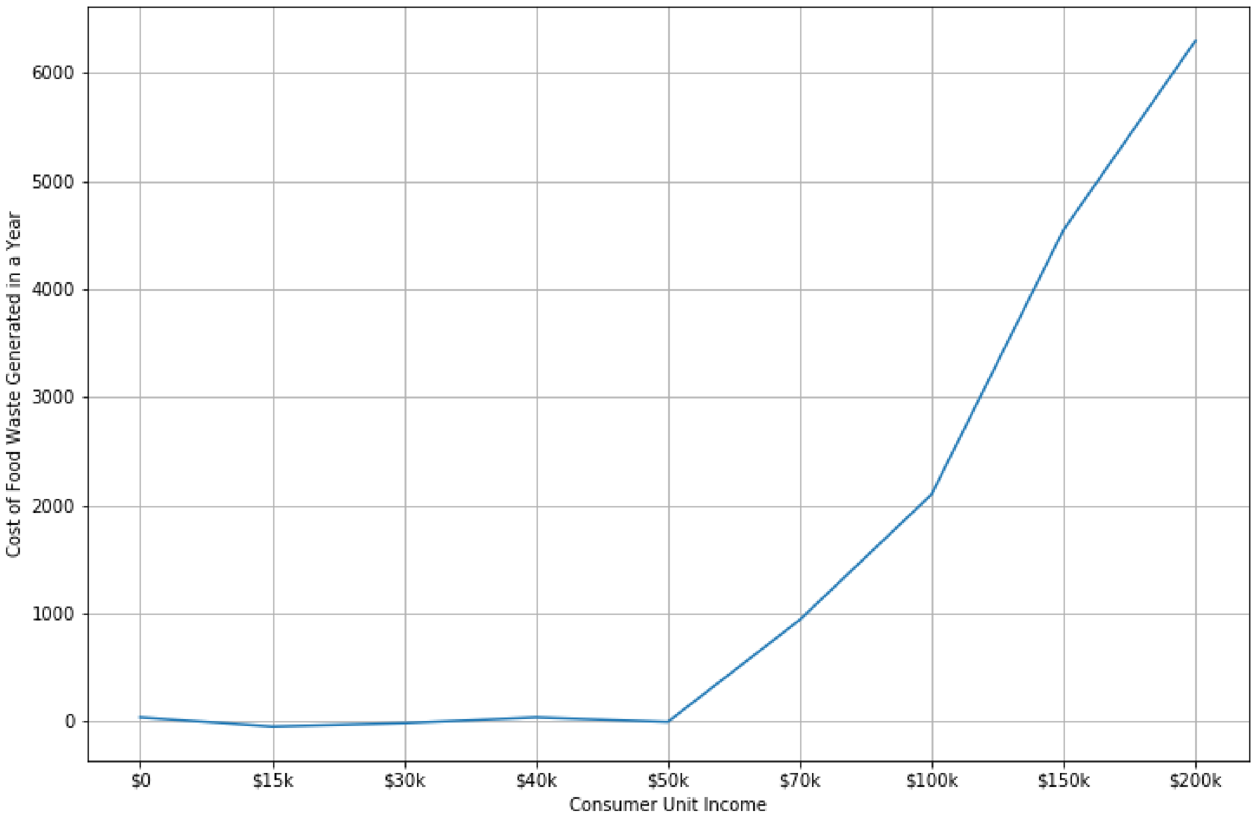

Figure 2: Plot of average waste produced in a year vs annual income, in dollars, for a consumer unit as defined by the USBLS

income. We will define functions $f(I)$ and $b(I)$ to represent food expenditure and the linear baseline, respectively, where I is income. With these functions in mind, we defined the waste of the consumer unit to be

$$W_c(I) = f(I) - b(I).$$

A plot of this function is shown in Figure 2. In order to make this scalable to households of different sizes, we defined another function $W_h(n, I)$ to represent the waste of a household with n family members and income I. We used the same USBLS survey to calculate that the average number of people in each consumer unit is 2.58 [6]. Thus,

$$W_h(n, I) = \frac{W_c(I)}{2.58} n.$$

2.4 Results

We used a python notebook to import the data from the USBLS survey, to define our functions, and to compute the results. The code can be found in Listing 1 in the Appendix. The functions return dollar amounts of food waste, much like our analysis of the amount of food wasted in Texas. For the test families given in the problem:

- Single parent with a toddler yields $W_h(2, 20500) = -\$28.70$. This returns a negative value because the average annual food expenditure for a family with these characteristics is almost exactly the baseline–in other words, this family cannot afford to waste anything. This makes sense, this family only has an income about 110% the federal poverty level, and would almost certainly qualify as food-insecure.
- Family of four yields $W_h(4, 135000) = \$5908.80$. A family of this size and income level would understandably waste a significant amount of food over the course of a year, as they can afford to purchase food that they will not eat or do not need. Furthermore, this value is not too high, as this family would be expected to spend about $12590 on food over the course of the year.
- Elderly couple yields $W_h(2, 55000) = \$178.10$.
- Single 23-year-old yields $W_h(1, 45000) = \$5.80$.

These last two results are not likely to be incredibly accurate as the income values are near $50k, where the plot in Figure 2 reaches a sharp increase.

3 Hunger Game Plan?

3.1 Restatement of the Problem

As local communities face evaluating multiple options for dealing with food insecurity, we are tasked with determining which strategies are most efficient in distributing the most amount of food with the lowest costs by

- Determining a mathematical model for evaluating the costs and benefits of strategies in a quantifiable manner.

3.2 Assumptions

1. **Assumption**: The only factors that need to be considered in our model are the monetary costs, meals recovered, and waste diverted.
   Justification: In keeping with the wording of the problem, taking into account mainly the financial aspect and the food waste related aspects of these solutions is most beneficial in evaluating the strategies.
2. **Assumption**: Financial benefit will maintain the highest priority out of any compared factors.
   Justification: To maintain a policy over longer periods of time, minimizing the monetary costs is especially important for it to be feasible even among other factors.
3. **Simplification**: All the waste in the landfills was redistributable and edible food that could've been given to food-insecure families
   Justification: A large majority of food that ends up end landfills comes from stores and other places where unnecessary food waste is generated.

3.3 Context of the Model

The community we chose to focus on for this problem is Guilford County, the county that our team lives in. As one of the most prevalent food deserts in the nation, Guilford County serves as a valuable subject for analysis in regards to food waste.

Through some preliminary research, we found the total food waste in landfills in 2010-11 to be 17 800 tonnes, or 35 600 000 lbs [9]. Given that there are 517 600 people in Guilford County, 93 510 of whom are food insecure, we can employ a method similar to that of section 1 to determine (1) how much food F is needed to feed those who are in need and (2) how much need can be met with re-purposing food waste F_m. [11].

First, we determined how much food the food-insecure citizens of Guilford County need by categorizing the population according to data from Feeding America. We found that 75% of food insecure individuals are below 200% poverty, while the other 25% are above 200% poverty [2]. Also using the fact that the average human requires 4 lbs of food per day to be satisfied [4], we determined that those under 200% poverty would need the full 4 lbs while those above that line would only need 1 lbs. Thus, the yearly food need for the food-insecure population of Guilford County is:

$$F = 365\,\text{days} \times ((0.75 \times 93\,510\,\text{persons} \times 4\,\text{lbs/person/day})$$

$$+\,(0.25 \times 93\,510\,\text{persons} \times 1\,\text{lbs/person/day})) = 110\,926\,237.5\,\text{lbs}$$

Now, we can simply compare this number with the total amount of food waste in Guilford County landfills to assess how much of the county's food needs can be met by re-purposing wasted food:

$$F_m = \frac{35\,600\,000\,\text{lbs}}{110\,926\,237.5\,\text{lbs}} = 32.1\%$$

In light of this statistic, it is impossible to ignore the issue of food waste in Guilford County. 32.1% of food insecure people, or 30,017 individuals, could meet their food needs with wasted food, so it is clear that strategies need to be employed to address this issue.

3.4 Highlighted Strategies

When determining the value of different strategies to address food waste, we decided to focus on three of the categories outlined by ReFED in their "solutions" list, which we have listed below in the order that we believe to be most important to sustaining food security in Guilford County [10]:

1. *Financial Benefit* The aggregate financial benefit to society (consumers, businesses, governments, and other stakeholders) minus all investment and costs per ton of food waste diverted. It shows the amount of benefit received per ton of reduction and is calculated as the Economic Value per Ton.

2. *Meals Recovered* Food recovery solutions recover perishable food that would otherwise go to waste and donate it to people in need. One pound of food waste diverted equals 1.2 meals.

3. *Waste Diverted* The tons of annual waste that can feasibly be diverted from landfills and on-farm losses per solution.

To make the process of mathematically quantifying the value of different strategies of addressing the issue of food waste, we preemptively reduced our list of possible strategies to only three, with each excelling in one of the previously stated categories[10]:

1. *Standardized Date Labeling* Standardizing food label dates, including eliminating visible "sell by" dates, to reduce consumer confusion. Excells in financial benefit.

2. *Centralized Composting* Composting is the process of transforming organic waste into humus, a critical component of healthy, fertile soil. In rural areas, this can be accomplished by periodically turning large piles, or windrows, of organic waste over themselves using specialized equipment. In more urban areas, Aerated Static Pile (ASP) composting is generally preferred, where piles can be covered and mechanically aerated in order to minimize the site's footprint and odors. Excells in waste diverted.

3. *Donation Tax Incentives* Expanding federal tax benefits for food donations to all businesses and simplifying donation reporting for tax deductions. Excells in meals recovered.

Throughout this solution, we will evaluate the efficiency through which each of these strategies address the three categories of food security mentioned above, coupled with the importance we have already set for each of these categories, to determine which strategy is the most optimal.

3.5 Our Model

To validate a particular strategy towards addressing food waste, an analytical hierarchy process (AHP) [3] was used to compute a quantified decision. We created a pairwise comparison matrix $\mathbf{A}$ which utilized the criteria of financial cost, meals recovered, and the amount of waste diverted. The alternatives evaluated within the process were represented by the three significant strategies we selected of standardized labeling, centralized composting, and donation tax incentives. In addition, we applied the Fundamental Scale for rating importance which utilizes weight biases ranging from 1 to 9 [3].

Furthermore, every entry a_{ij} represented a relative rating of importance where if it was greater than 1 then the i-th criterion was considered to be more important than the k-th criterion, values less than 1 were attributed to lesser importance, and values equal to 1 were attributed to equal importance. Instances where $i = j$ resulted in an entry of 1 and entries a_{ji} were reciprocals of entry a_{ij}.

The weights considered in $\mathbf{A}$ were decided by our previous assumptions on the importance of the criteria in Guilford county. This resulted in the following base comparison matrix:

$$\mathbf{A} = \begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 2 \\ 1/5 & 2 & 1 \end{bmatrix}$$

where the row and column order follow financial cost, meal recovery, and waste diverted. In example, a_{12} represents the comparison between cost and meal recovery.

We then normalized $\mathbf{A}$ by dividing each entry by the sum of the rows $\Sigma_{k=1}^{n} a_{ik}$. Following the AHP model, we determined a global weight vector, x, with entries calculated by averaging the i-th row.

$$\mathbf{A} = \begin{bmatrix} 0.652 & 0.667 & 0.625 \\ 0.217 & 0.222 & 0.250 \\ 0.130 & 0.111 & 0.125 \end{bmatrix}$$

$$x = \begin{bmatrix} 0.648 \\ 0.230 \\ 0.122 \end{bmatrix}$$

Additional pairwise comparison matrices, $\mathbf{C}^{(i)}$ comparing the alternatives with respect to the i criterion were generated (rows and columns follow cost, food recovery, waste diversion entry order). To evaluate the weights in each new PCM, we compared the statistics on each criterion between each strategy. The aforementioned norm-average procedure was then reiterated to generate a set of score vectors $s^{(i)}$ or otherwise columns of the score matrix $\mathbf{S}$.

Letting c represent financial cost, f food recovery, and w waste diversion,

$$\mathbf{C}^{c} = \begin{bmatrix} 1 & 9 & 5 \\ 1/9 & 1 & 1/7 \\ 1/5 & 7 & 1 \end{bmatrix}$$

$$\mathbf{C}^{f} = \begin{bmatrix} 1 & 1 & 1/9 \\ 1 & 1 & 1/9 \\ 9 & 9 & 1 \end{bmatrix}$$

$$\mathbf{C}^{w} = \begin{bmatrix} 1 & 1/7 & 1 \\ 7 & 1 & 7 \\ 1 & 1/7 & 1 \end{bmatrix}$$

From the pairwise comparison matrices generated, we found $\mathbf{S}$ to be

$$\mathbf{S} = \begin{bmatrix} 0.702 & 0.091 & 0.111 \\ 0.056 & 0.091 & 0.778 \\ 0.243 & 0.818 & 0111 \end{bmatrix}$$

We extrapolated a set of global scores from the multiplication of the final score matrix by the global weight vector:

$$\mathbf{S}x = \begin{bmatrix} 0.489 \\ 0.152 \\ 0.359 \end{bmatrix}$$

where the first entry corresponds to labeling, the second entry corresponds to composting, and the third entry corresponds to donation tax incentives.

3.6 Discussion of the Model

Based on the results that we calculated from our model, the most effective solution in terms of the factors considered (financial cost and food recovery taking a higher priority than waste diversion) was standardized labeling of food products in the county. Following labeling was the donation tax incentive and centralized composting came in last.

Our model relies on weighted biases to determine the most effective strategy for combating food waste in Guilford County. This is due to policy focus and future potential of the strategy dictating higher dependencies on certain factors over others. With a tight budget, the financial cost of a strategy remains a high concern for policymakers in Guilford County.

Our AHP model foregos various social factors that are difficult to compare numerically; as such, we only applied quantitative factors and characteristics in order to provide higher levels of objectivity in order to avoid confounding efficiency ratings.

One significant limitation of our model is that it compares strategies on a relative basis rather than on intrinsic merit. The weights given may also either overemphasize or excessively deemphasize how much more effective one strategy can be over another. Thus, the final scores given by the vector product should not be interpreted as how effective the strategies are individually. Finally, the addition of new factors may significantly increase calculation time considering that an increase in the dimension of the matrices takes place. However, continuous comparisons over numerous strategies will yield the comparatively optimal strategy amongst all others.

4 Conclusion

4.1 Strengths

1. The model is applicable to all states and is reasonably sound as long as the waste percentage holds up. Our model is accurate given the assumption that the government can supply the sufficient resources.

2. This model can be applied to a broad range of situations, as the model is based on national data and simply takes two inputs and returns one output. More data would improve the model, but new data is not necessary to apply the model to many different family situations.

3. Our model addresses quantitative factors rather than purely qualitative factors and bias scores based in policy directives may be factored in.

4.2 Weaknesses

1. Our model for part 1 relies very heavily on the accuracy of the estimate of food waste per type of commodity. That number is estimated with data that is not only from North America, which could make it inaccurate when being applied to any state. Also, the assumption that the price of commodities remains the same throughout a state is a bit of a stretch and it makes a big difference if the price does differ, since we can no longer directly relate weight and price.

2. The main weakness in this model lies the lack of data fed into the model. The sharp difference between the amount of waste generated for a household with income below \$50k and a household with income greater than \$50k is a result of the scarcity of data points. If more data were available, perhaps specific statistics for different family situations, we could make the model more accurate. Another weakness in the model lies in the simplification that family size is correlated to income, and thus that we do not need to include family size in the model of how much the family spends on food.

3. The third model can become calculation intensive if the model becomes extended to a large set of factors that may also have characteristic matrices associated with them. Our model does not develop a basis for evaluating how optimal individual methods, but rather how optimal they are relative to other similarly interacting methods.

Appendix

```python
import matplotlib.pyplot as plt
from numpy import *
from math import floor,ceil
from mpl_toolkits.mplot3d import Axes3D

data = loadtxt('foodexpenditures.txt')
income = [x for x in range(9)]
incomelabels = ['0','$0','$15k','$30k','$40k','$50k','$70k','
    $100k', '$150k','$200k']
food = data[0,1:]

### perform a least-square linear fit
x=array(income[0:5])
y=array(food[0:5])
N=5
Ex=(1/N)*sum(x)
Ey=(1/N)*sum(y)
Exx=(1/N)*sum(x*x)
Exy=(1/N)*sum(x*y)
m=(Exy-Ex*Ey)/(Exx-Ex*Ex)
c=(Exx*Ey-Ex*Exy)/(Exx-Ex*Ex)

### define a function to convert income to a list index value
    for graphing purposes
def income_to_index(I):
    if I<=15000:
        return 0+(I)/15000
    if 15000<I<=30000:
        return 1+(I-15000)/15000
    if 30000<I<=40000:
        return 2+(I-30000)/10000
    if 40000<I<=50000:
        return 3+(I-40000)/10000
    if 50000<I<=70000:
        return 4+(I-50000)/20000
    if 70000<I<=100000:
        return 5+(I-70000)/30000
    if 100000<I<=150000:
        return 6+(I-100000)/50000
    if 150000<I<=200000:
        return 7+(I-150000)/50000
    if I>200000:
```

```
        return print('Not enough data')
### define function for amount of money spent on food
def f(I):
    x = income_to_index(I)
    return ((food[ceil(x)]-food[floor(x)])/(ceil(x)-floor(x)))*(x-floor(x))+food[floor(x)]
### define function for the waste of a consumer unit
def Wc(I):
    x = income_to_index(I)
    return f(I)-(m*x+c)
### define function for the waste of a household
def Wh(n,I):
    return Wc(I)/2.58*n # 2.58 is the average # of people per consumer unit

therange = linspace(0,8,100)

plt.figure()
fig, ax = plt.subplots(figsize=(12,8))
ax.set_xticklabels(incomelabels)
plt.xlabel('Consumer Unit Income')
plt.ylabel('Consumer Unit Food Expenditures')
plt.plot(income,food,label=r'$f(I)$')
plt.plot([x for x in therange],[m*x+c for x in therange],label=r'$b(I)$')
plt.grid()
plt.legend()
plt.savefig('foodexpenditures_vs_income.png')

plt.figure()
fig, ax = plt.subplots(figsize=(12,8))
ax.set_xticklabels(incomelabels)
plt.xlabel('Consumer Unit Income')
plt.ylabel('Cost of Food Waste Generated in a Year')
plt.plot([x for x in range(9)],array(food)-array([m*x+c for x in range(9)]))
plt.grid()
plt.savefig('wastefunction.png')

print(Wh(2,20500),Wh(4,135000),Wh(2,55000),Wh(1,45000))
```

Listing 1: Python program used to produce Figures 1 and 2 and to define and compute the waste functions.

References

[1] Food and Agriculture Organization of the United Nations. Global food losses and food waste - extent, causes, and prevention, March 2018.

[2] A. Dewey A. Crumbaugh M. Kato Gundersen, C. and E. Engelhard. Feeding america map the meal gap, March 2018.

[3] S. Klutho. Mathematical decision making: An overview of the analytical hierarchy process, March.

[4] NPR. The average american ate (literally) a ton this year, March.

[5] United States Department of Agriculture Economic Research Service. Cash receipts by state, March 2018.

[6] United States Bureau of Labor Statistics. Consumer expenditure survey, March 2018.

[7] Academy of Nutrition and Dietetics. The state of america's wasted food and opportunities to make a difference, March 2018.

[8] Texas State Agricultural Overview. 2012 ranked items within the u.s., March 2018.

[9] Guilford County Planning and Development Department. Solid waste management plan 3-year update, March 2018.

[10] ReFED. Food waste solutions, March 2018.

[11] Poverty Southeastern University Consortium on Hunger and Nutrition. Food insecurity statistics in nc, March 2018.