MathWorks Math Modeling Challenge 2018

Pine View School–

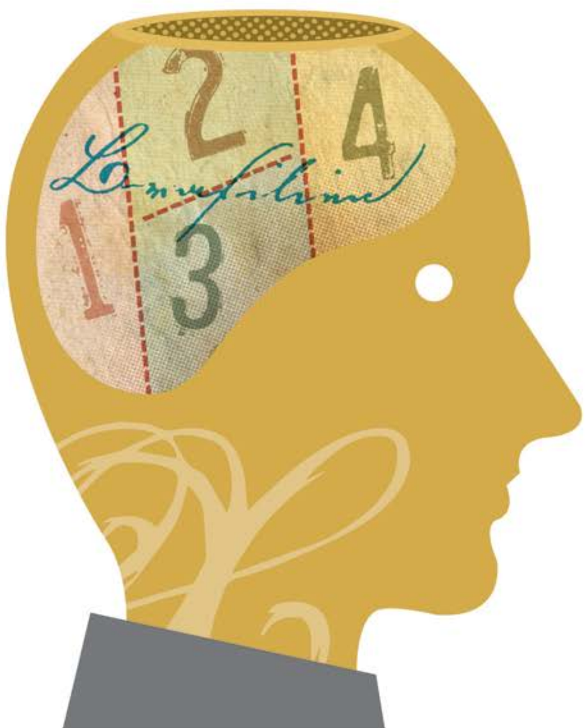
Team # 10494 Osprey, Florida

Coach: Mark Mattia

Students: Chloe Harris, Dylan Hull, Tristan Lee, Zoe McDonald, Sarah Mihm

MathWorks Math Modeling Challenge Third Place

$10,000 Team Prize



Team 10494

Don't Waste the Taste:
Biting Back at Food Insecurity

1 Executive Summary

The world is suffering from two conflicting dilemmas simultaneously: food waste and hunger. A staggering thirty percent of food produced intended for consumption goes to waste, while thirteen percent of the world goes hungry. Such a discrepancy leads to the question, can the wasted food be re-purposed to feed the hungry?

We believe it can. America specifically has the capability and resources to accomplish such a goal, it only lacks a program in place. Historically, when there is a fixable problem in sight, Americans will not only solve said problem, but will also strive to do so better than any other country before them. In the realm of food waste, the room for improvement in America is staggering. This will not only take community cooperation, but also personal action.

However, it is the modern-day American habits that contribute to the food waste. With the ease and accessibility of food the average American holds, it is no question that there is a needless waste as a result. With garbage trucks that visit weekly, food waste leaves a house, restaurant, supermarket, or farm and is typically never seen again. The proverb ”Out of sight out of mind” plays an integral role in Americans’ apathy towards their food waste.

The first step to solving food waste and hunger is identification of the food being wasted and the amount of people going hungry. In the first model, we determined the total food waste directly relates to the price of food being wasted. The price of food needed to feed the hungry is then calculated, and ultimately the need can be subtracted from the waste to obtain a net surplus or deficit. We determined that if all of the waste was transferred to feed all of the hungry, there would be a net surplus of food in the state of Texas. If Texas was then used as a model for the entire United States, this implies that the country’s hungry population could be eliminated, if not severely diminished.

In the next model, the waste of an individual household, based on its traits, was determined in order to ascertain the effects personal choices have on consumption, or the lack there of. We determined income to be reflective of personal habits, and thus the waste produced. A monetary value of waste produced by an individual in the household was calculated, leading to the approximation of the total household waste based on both income and number of occupants. With this, the logical conclusion was that the number of household occupants is the main determinant of waste, but income also had a moderate effect when the income exceeded $100,000. This was concluded to be a result of the times the wealthier households would eat out, a habit that produces more waste than in-home dining.

When analyzed on both a large scale, by state, and a small scale, by household, waste was seen to have a large effect on the community. In order to turn this effect into something positive, we created a model that would create a strategy for building drop-off centers in our very own county. Widespread change starts with an small step forward, and with a plan such as this implemented in our own community, a true difference in feeding the hungry could occur. By creating a Monte Carlo simulation that creates a hypothetical county with a certain number of food distribution centers and households that are randomly distributed, the total economic profit could be determined by taking the cumulative value of donations minus the cost of building the food donation centers. Using this simulation, we sought to maximize economic profit.

Through the three different models, the problem of both food waste and hunger was tackled statewide, within a household, and within our own community. This trifecta is what it will take to diminish both food waste hunger in America and potentially around the world.

Table of Contents

List of Figures

2 Introduction

2.1 Background

In the time before refrigeration, vast amounts of food would be wasted if not immediately eaten or cured to increase longevity. Fast forward hundreds, if not thousands of years, to the mid eighteenth century when the concept of refrigeration was first utilized. This was the first revolution in regards to food waste. As refrigerators were slowly integrated into commercial and person use, people found that they could now elongate the life of some foods. The second revolution has been a more gradual one, but nonetheless poignant. This has been the accessibility of food to Americans. Not only have the numbers of restaurants drastically increased, but so have supermarkets. In general, Americans can go out and buy new food at almost any moment, which can create a large amount of waste. With accessibility comes the ability for Americans to be picky about what they purchase. This is specifically in regards to supermarkets, where blemished or "ugly" food may be dismissed, and thus wasted [9].

In today's world, waste has far exceeded what our ancestors could have ever imagined. We are only starting to see the detrimental effects, and if such waste patterns continue, the waste may become too difficult to accommodate. This is a drastic juxtaposition to the many people in our nation suffering from a lack of food. If these two extremes could meet, hunger in America could potentially be solved.

2.2 Restatement of Problem

1. Construct a model in which it is determined if the food waste generated in a state can feed the food-insecure population in the same state. Run the model with the state of Texas.
2. Every time food in consumed, there are personal choices that lead to either total consumption or some amount waste. Construct a model in which the food waste that a household accumulates in a year, based on traits and habits specific to the type of household, can be determined. Run the model for each of the following households:
   - Single parent with one child, annual income of $20,500
   - Family of four, annual income of $135,000
   - Elderly couple, annual income of $55,000
   - Single 23-year-old, annual income of $45,000
3. Food waste has become a prevalent issue that many communities are trying to address. Construct a model in your own community that would provide reasonable strategies in order to re-purpose wasted food while balancing amount of food and cost. The model needs to address quantifiable costs and benefits of such strategies.

2.3 Global Assumptions

1. There will be no major climate change, parasitic induced agriculture disaster, or technological advances.

No major changes in agriculture have occurred in the past twenty years, so it is assumed that such a trend will continue into the immediate future and cause no change in food production.

2. Wasted food is defined by edible food that is not being eaten.
In order to re-purpose wasted food, it must be edible. It does not, however, have to conform to current cosmetic or taste standards. This can be assumed because such deformities do not diminish nutritional value, but the food must be edible in order for it to provide safe, sufficient and proper nutrition.

3 Just Eat It!

3.1 Discussion

A large portion of the food that ends up in landfills is actually edible, and is discarded due to appearance, mishandling, processing, distribution, or simply just not being consumed. Many communities have a proportion of their population that is food-insecure, an issue that could be solved using the edible, but wasted food.

3.2 Assumptions

1. Transportation (of food waste to the food-insecure) will not lead to spoilage of food and the cost of such transportation is not taken into account.
The amount of food-insecure people per county should be relatively proportional to the overall population of the county so it can be assumed the wasted food per county is enough to help the food-insecure within the county, minimizing transportation costs as it does not need to be transported long distances.

2. The monetary value of food is representative of the amount of food.
Within the same time period, inflation will not rise sufficiently to create any discrepancies. This allows the money spent on food to accurately portray a standard amount of food.

3. Children in the food-insecure population will consume as much food as adults.
A child will at least be sufficiently fed by an adult size portion, and thus will not go hungry, and thus the slight extra left over will be negligible to the overall totals.

4. North American data is indicative of Texan data. *Texas is in North America, and thus its data should be consistent with that of North America.*

3.3 Model Description and Justification

Food waste in the United States is specific to both the types of food wasted and where in the creation to consumption process the waste occurred. In order to determine if a transfer of the food waste from all stages of production to food-insecure populations is feasible, both waste of food and need of food must be calculated.

The total money spent in the farm sector for a specific state (shown in the cash receipts) [6] is only the money spent in a state on farm-based commodities, and therefore does not include any potential money spent by a state on wasted food. The loss of product (% waste) is due to agricultural production, post-harvest handling and storage, processing, distribution, and consumption [5]. If a state had no waste in the processes leading up to consumption, money potential, mp, where

$$mp = \frac{\text{cash receipts}}{1 - (\text{total \% waste} - \text{\% waste from consumption})}$$

would represent the theoretical cash receipts for a specific type of food assuming no waste. To calculate the money that farms are wasting via losing products from production, handling, storage, processing, and supermarkets, the production money waste, mw_p, represented by

$$mw_p = \text{money potential} - \text{cash receipts}$$

would give waste on the production side for that same specific type of food. However, there is also waste after a consumer has already paid for a product, but does not consume said type of food. To determine this consumer money waste, mw_c, we multiply the money spent on each food group by the % of waste on the consumption side of each food group. The equation

$$mw_c = \text{cash receipts} \times \text{\% of waste from consumption}$$

will show the money that is lost as a result of the uneaten or unused food. In the cases where multiple types of food, as specified in the North American food loss data [5] fit into a single category in the diet plan (categories found in Table 1) [3], mw_p and mw_c would be repeated with each subcategory for the specific category of food. Ultimately, the total money waste, mw_t

$$mw_t = mw_p + mw_c$$

would represent the aggregate money wasted by a state in relation to the specific type of food waste.

The total money needed to provide a food-insecure individual three meals a day would cost $2,606.10 [1] for a year when using a low cost plan. The low cost plan was chosen over the thrifty, moderate, and liberal options in order to provide the most amount of people with food, while maintaining a relatively respectable portion of food for these people. Using the percentages in Table 1,

Food Category	Proportion of Diet
Protein	8.6%
Fruits, Vegetables, Roots, and Tubers	51.4%
Grain	4.3%
Dairy	34.3%
Oil	1.4%

Table 1: Proportions of Food in Daily Diet. The proportions are a result of averaging suggested amounts of each food group for different ages and gender, then dividing by the total suggested amount in one day [3].

where mn_i is the money needed for a food group per one individual,

$$mn_i = 2,606.1 \times \text{\% of diet}$$

would be the cost of food category for the entire year for a single food-insecure individual. Ultimately, where mn_t is the total money need for a specific population,

$$mn_t = mn_i \times \text{population of food-insecure individuals}$$

would represent the aggregate need by a state in relation to the specific category of food waste.

When total money waste and total money needed for a food group are calculated,

$$F = mw_t - mn_t$$

where F is either the surplus or deficit of money, and thus the surplus of deficit of food.

For example, the food category of protein is comprised of both meat and fish. Meat (m) has a total 24% waste and an 11% waste from consumption.

$$mp_m = \frac{11,264,767,000}{1-(.24-.11)} = 12,948,008,050 \text{ dollars}$$

Fish (f) has a total 60.5% waste and a 33% waste from consumption.

$$mp_f = \frac{17,722,000}{1-(.605-.33)} = 24,444,138 \text{ dollars}$$

The total production money waste can then be calculated by adding the potential money waste of meat and fish.

$$mw_p = (12,948,008,050-11,264,767,000)+(24,444,138-17,722,000) = 1,689,963,188 \text{ dollars}$$

The consumer money waste can be calculated with the percent waste from consumption for meat and fish, 11% and 33% respectively.

$$mw_c = (11,264,767,000 \times .11) + (17,722,000 \times .33) = 1,244,972,630 \text{ dollars}$$

When added together, the aggregate waste is determined.

$$mw_t = 1,689,963,188 + 1,244,972,630 = 2,934,935,818 \text{ dollars}$$

Protein composes 8.6% of the recommended diet

$$mn_i = 2,606.1 \times .086 = 224.1246 \text{ dollars.}$$

The total population of food-insecure people in Texas is 4,320,050.

$$mn_t = 224.1246 \times 4,320,050 = 968,229,478 \text{ dollars}$$

With the total money waste and the total money need for the state of Texas, it can be determined that there is enough protein food waste to sufficiently provide the food-insecure population with protein for a year.

$$F = 2,934,935,818 - 968,229,478 = 1,966,706,340 \text{ dollars.}$$

By repeating these same calculations with produce (fruits, vegetables, roots, and tubers), grain, dairy, and oil, the F value was determined and showed if there was a deficit, a negative number that is shaded red, or surplus, a positive number that is shaded green. This was done overall, taking into account all food groups. Two of the five food groups had a surplus, meaning all of the hungry were fed with that food group. The remaining three, along with the overall analysis, showed a deficit.

	mw_p in dollars	mw_c in dollars	mw_t in dollars	mn_t in dollars	F in dollars
Protein	1,689,963,188	1,244,972,630	2,934,935,818	968,229,478	1,966,706,340
Produce	1,118,138,575	485,105,800	1,603,244,375	5,786,59,905	-4,183,615,530
Grain	181,807,868	248,415,660	430,223,528	484,114,739	-53,891,211
Dairy	111,711,538	277,221,000	388,932,538	3,861,659,431	-3,472,726,893
Oil	144,122,707	26,262,360	170,385,067	157,618,752	12,766,315
Overall	2,870,092,159	2,258,613,256	5,128,705,415	11,258,482,310	-6,129,776,895

Figure 1: Deficit or surplus of food categories and overall food

3.4 Analysis

Based on the data inputted into the model created in section 3.3, it can be seen that Texas can supply sufficient protein and oil to its food-insecure population. Unfortunately, there remains a deficit in produce, grain, and dairy, and most importantly, a deficit overall. However, there are two possible ways that Texas can slightly adjust policy in regards to creating a surplus: the population of food-insecure individuals and the cost of the plan used to provide food to the food-insecure individuals.

In the data regarding population initially plugged into the model, the state of Texas would be providing food to all food-insecure individuals, including those on federal aid programs. If a new population of food-insecure individuals of Texas is defined as solely those who do not receive federal aid, then there is a new mn_t. This creates a new F, which causes a surplus in all categories except dairy and produce. Most importantly, this does solve the overall deficit problem, as can be seen below in Figure 2.

	F in dollars	F in dollars (federal aid)
Protein	1,966,706,340	2,634,784,680
Produce	-4,183,615,530	-190,682,196
Grain	-53,891	280,147,959
Dairy	-3,472,726,893	-808,181,886
Oil	12,766,315	121,523,253.9
Overall	-6,129,776,895	1,638,575,899

Figure 2: Changes in deficits or surpluses by excluding recipients of federal aid

In the data regarding cost plan initially plugged into the model, the state of Texas would be opting for the second lowest plan in order to balance the desire to provide adequate food to the hungry and the restraint on the amount of food that is wasted in Texas. If the thrifty cost plan [1] is used instead, there is a new mn_t and thus a new F. By combining the thrifty cost plan and the new population of solely giving food to those who do not receive federal aid, the dairy remains as the only deficit.

Only dairy continues to have a deficit throughout the model even after the manipulation of the population and food plan variables. This seems to be due to the fact that the amount of dairy that is purchased in Texas is not consistent with the amount that should be consumed in a healthy diet. Dairy only makes up 8.8% [6] of the food purchased in Texas despite the fact that it should

	F in dollars	***F*** in dollars (thrifty cost plan)	***F*** in dollars (thrifty cost plan and federal aid)
Protein	1,966,706,340	2,192,689,711	2,704,839,525
Produce	-4,183,615,530	-2,832,970,733	228,017,692
Grain	-53,891	59,100,474.2	315,175,381.3
Dairy	-3,472,726,893	-2,571,421,123	-528,777,096.9
Oil	12,766,315	49,554,305.3	132,927,530.9
Overall	-6,129,776,895	-3,502,063,277	2,453,167,120

Figure 3: Changes in deficits or surpluses with thrifty cost plan and excluding recipients of federal aid

account for 34.3% [3] of a healthy diet. One important thing to note is that both the protein and oil food groups have a surplus even prior to more conservative aid plans being implemented. Dairy is largely consumed for the protein and fat content and meats and oils can act as substitutes in the protein and fat categories respectively [3]. Luckily, protein and oils are the two categories that already have surpluses under even the most liberal plans proposed and can therefore make up the deficit caused by the continued lack of dairy products available to food-insecure people. Thus, the overall prediction of a surplus of food being able to be re-purposed and distributed to food-insecure people makes sense.

3.5 Strengths, Weaknesses and Sensitivity Analysis

The strengths of this model are in its ability to combine a wide variety of factors within a comprehensive and simplistic approach. By simply subtracting need from want, either surplus of deficit of a food group may be determined. The model results in logical surpluses or deficits based on known production and consumption of each food category. It is also is easily adjustable by simply imputing slightly different numerical values for variables such as population size and a cost plan.

However, the model does have weaknesses. In the model, the percentage of each food group in a person's diet is based on the recommended diet [3], not what they would prefer nor are used to eating. In America, protein has a much higher percentage of an average individual's diet. Also, it is not taken into account that there are multiple sources of protein aside from just meat and fish. This can also be seen in the oil category. A second weakness of this model lies in that the storage and timely delivery of foods that can spoil may be inconceivable in some instances.

A sensitivity analysis of the grain, produce, and the overall computations was performed by changing a parameter of the model. This was accomplished by removing the production waste in order to determine if the model would yield similar results. The reason that waste from production was taken out of the amount saved is that oftentimes the waste caused by production is due to farmers determining it is not profitable to harvest [8], a factor that cannot easily be changed as it is unlikely that a farmer would agree to lose profit. Therefore, it is reasonable to assume that the waste might have to be taken out of the equation. Once the model was run again with production waste removed, the money potential mp decreased causing a subsequent decrease in total waste mw_t and surplus F.

It can be seen from Table 2 that the categorical and overall waste do not change from a deficit

Food Category	F (without production waste)	F (without production waste and with federal aid)
Grain	-$79,665,851	$254,373,319
Produce	-$4,890,398,223	-$897,464,889
Overall	-$7,201,779,911	$566,572,883

Table 2: The surplus of certain food categories after production waste was factored out of the model as well as when aid was only given to those not receiving federal help.

to a surplus or vice versa but simply have an increase in preexisting deficits and a decrease in preexisting surpluses. This was expected because removing production waste from the model will remove some waste that could be re-purposed and lower the amount that can be used to fulfill the needs of the food-insecure.

4 Food foolish?

4.1 Discussion

Personal choices for food consumption are influenced by household income. Household income influences how much food in each food category can be purchased as well as how often a household can afford to eat out. The proportion of food wasted is unique to each category, so the amount of food wasted can be calculated by relating the proportion wasted to the money spent on each category. The model aimed to provide the total value of food wasted per occupant per year for a select income bracket, which takes into account food wasted from eating at home as well as in restaurants. This allows us to get a better estimate for households of varying sizes within the same income bracket.

4.2 Assumptions

1. The proportion of food wasted for each food category is equal across all income brackets.
   The proportion of food wasted for each food category depends on characteristics of the food itself and has nothing to do with the income of the household consuming it.

2. A household occupant contributes the same amount to the household consumption and waste regardless of age or gender.
   The data obtained from the U.S. Bureau of Labor Statistics are household averages for each income bracket, data for individual characteristics were not given.

3. All food not consumed in a restaurant is waste.
   This allows the food waste generated away from home to remain separate from the food waste generated at home.

4.3 Model Description and Justification

The traits and habits of households at different levels of income are measured by their consumption of different types of food. Different food groups are wasted in different proportions, indicating that different households will waste differing amounts of food according to their typical expenditures within each food category.

The total share of food wasted for a given household is given by

$$W_h = \sum_{i=1}^{N} p_i E_i,$$

where W_h is the total monetary value of food wasted for the given household of income category h, p_i is the proportion of food category i wasted through the consumption stage and E_i is the amount spent by household type h on food category i.

Food Category	Proportion Wasted
Cereals	27%
Roots and tubers	30%
Oilseeds and pulses	4%
Fruits and vegetables	28%
Meat	11%
Fish and seafood	33%
Milk	15%

Table 3: Estimated proportion of food wasted by food classification. Proportions include only waste at the consumption level.

The U.S. Bureau of Labor Statistics (BLS) provides datasets containing information on the mean expenditures on food by household income, for which selected data is shown in Table 4 below.

Food Category	Selected Income Category			
	15,000 to 29,999	40,000 to 49,999	50,000 to 69,999	100,000 to 149,999
Cereals and bakery products	374	521	524	700
Meats, poultry and eggs	584	678	716	1,002
Fish	83	95	124	188
Dairy products	298	384	393	565
Fruits and vegetables	549	704	738	1,120

Table 4: Expenditures on each food classification by household unit income. All values are given in US dollars [4].

Unfortunately, expenditures on food types such as "Oilseeds and pulses" (see Table 3) aren't readily available. The value of wasted food at home can be found by multiplying the proportion of food wasted (values found in Table 3) by the money spent on each food category from Table 4. The total value of wasted food for each income bracket at home can be found by summing the values in each food category.

The USDA and NRDC estimate that restaurant diners leave about 17% of their meals uneaten [8]. By multiplying the money spent on food away from home by 17% we can calculate the value of food wasted away from home.

Food Category	Selected Income Category			
	15,000 to 29,999	40,000 to 49,999	50,000 to 69,999	100,000 to 149,999
Cereals and bakery products	100.98	140.67	141.48	189
Meats, poultry and eggs	64.24	74.58	78,76	110.22
Fish	27.39	31.35	40.92	62.04
Dairy products	44.70	57.60	58.95	84.75
Fruits and vegetables	153.72	197.12	206.64	303.60
Total value of wasted food	391.03	501.32	526.75	749.61

Table 5: Value of food wasted at home by household unit income. All values are given in US dollars. [4]

Income Category	Money Spent on Food Away From Home	Value of Food Wasted Away From Home
15,000 to 29,999	1,533	260.61
40,000 to 49,999	2,157	366.69
50,000 to 69,999	2,847	483.99
100,000 to 149,999	4,797	815.49

Table 6: The estimated value (in US Dollars) of food wasted away from home at restaurants per household per year. [4]

Combining the values from Table 5 and Table 6 the total value of food wasted from eating at home and away from home can be found in Table 7. These values were then divided by the mean number of occupants of a household with specified income bracket found by the BLS.

Income Category	Mean Number of Occupants	Total Value of Food Wasted	Total Value of Food Wasted per Occupant
Less than 15,000	1.6	547.49	342.18
15,000 to 29,999	1.9	651.64	342.97
30,000 to 39,999	2.3	779.79	339.04
40,000 to 49,999	2.5	868.01	347.20
50,000 to 69,999	2.6	1,010.74	388.75
70,000 to 99,999	2.9	1,259.48	434.30
100,000 to 149,999	3.1	1,565.10	504.87
150,000 to 200,000	3.1	2,091.13	674.56
200,000 or greater	3.2	2509.64	784.26

Table 7: Estimated total monetary value of food wasted in US dollars by household income [4]. Additional income brackets were added using the same methodology, the income brackets not relevant to the problem were excluded from previous tables for brevity.

4.4 Analysis

Using the value of food wasted per occupant from Table 7 and multiplying by the number of occupants in each unique household category, assuming each occupant contributes equally to the waste regardless of age, we find the total value of food waste for each household.

- Single parent with one child, annual income of $20,500: $685.94
- Family of four, annual income of $135,000: $2019.48
- Elderly couple, annual income of $55,000: $777.50
- Single 23-year-old, annual income of $45,000: $347.20

The model uses income to describe the characteristics and traits of a household. The data provided by the US Department of Labor Statistics [4] is consistent with this assumption. Higher income households tend to eat out more. The following values were calculated by dividing the expenditures on each category by the total food expenditures.This data proves the link between income and how much a household eats out.

Income Category	Proportion Spent on Food at Home	Proportion Spent on Food Away From Home
Less than 15,000	65.02%	34.08%
15,000 to 29,999	65.45%	34.55%
30,000 to 39,999	58.69%	41.31%
40,000 to 49,999	60.65%	39.35%
50,000 to 69,999	57.77%	42.23%
70,000 to 99,999	56.57%	44.43%
100,000 to 149,999	53.66%	46.34%
150,000 to 199,999	49.58%	50.42%
200,000 or greater	44.44%	55.56%

Table 8: The proportion of food expenditures spent on food consumed at or away from home per household per year based on income.[4]

As seen in Figure 4, the bar graph on the following page, there is minimal differences in per occupant food waste in income brackets less than $\$100,000$. However, this value increases at a much faster rate once the household income exceeds $100,000. This can be accounted for with the proportion of food eaten away from home. Larger increases in proportion spent on eating out corresponded to a larger amount of waste. Theoretically, everyone should eat the same amount of food. If waste was determined by a income dependent proportion, food waste across income should also be constant. However, we know that low income households may not be able to afford even the necessities and therefore cannot afford to waste food, while high income households can afford to let food go to waste, over purchase, or eat out.

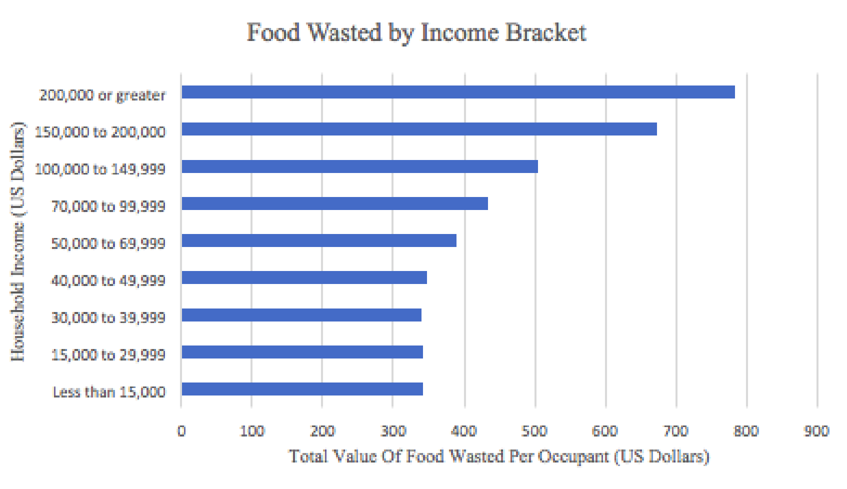


Figure 4: Total food waste per occupant per year based on household income

4.5 Strengths, Weaknesses and Sensitivity Analysis

The greatest strength of this model is that it allows for unique results on a case-by-case basis. It is able to create a more accurate representation of the amount of waste a household produces. This is done by evaluating the waste produced by each occupant in a household rather than by using a mean value. This creates a system in which an increase in the number of residents would have a resultant increase in the amount of waste that is generated.

Having said that, the model does have some weaknesses. The model relies solely on household income and the number of values only averages residents in a house to determine waste produced. This means that the amount of waste that a toddler produces is considered to be the same amount as that of an adult. This is due to the data failing to contain specific values for each age group, only averages per income bracket [4]. Additionally, restaurant eating is strictly dependent on income in this model, whereas in reality it is also contingent on time restraints and ability to cook for oneself. Another weakness is that this model did not take into account dietary restrictions and preferences of fresh versus frozen. With the ongoing organic movement, many people with higher incomes are opting to purchase fresh fruits and vegetables which spoil much faster than buying frozen produce.

To test the sensitivity of this model, we considered three other sample household compositions:

- Low income family of four, annual income of $29,500: $1,371.88
- Middle class couple with no children, annual income of $120,000: $1,009.74
- Very wealthy family of five, annual income greater than $200,000: $3,921.30

The results received were reasonable. It is sensible that a family with kids would produce a larger amount of waste than a couple without children. It is also rational that a family with a higher income would produce more waste than one that can not afford to buy and waste as much. The model functioned not only under the four requested scenarios, but also under an additional three cases verifying that the model is reliable.

5 Hunger Game Plan?

5.1 Discussion

The most effective way to re-purpose potentially wasted food is to donate it before it becomes inedible. Hungry people in the community directly benefit by being provided with potentially wasted food. To help facilitate the donation of unused food products, the local community should seek to increase the number of drop off locations to a number that minimizes cost and maximizes benefit. This was found by performing a Monte Carlo simulation to determine the theoretical number of donation centers needed based on household characteristics such as income level and distance to the nearest food waste donation center. The Python code for the simulations may be found in Appendix A.

5.2 Assumptions

1. The benefits earned from donating food is equal to the cost of the food and all food donated will used by the food bank.
   We will assume that all donated food met donation standards and the value of the food has not decreased since its purchase.

2. The population of our county is distributed according to a uniform random distribution.
   Assuming uniform random distribution allows us to give equal responsibility to each drop off location, which allows us to build uniform drop off locations.

3. Food banks can be built anywhere in the county for the same price, regardless of zoning.
   Assuming that food banks can be built anywhere within the county allows us to distribute the population in such a way that it does not cause donation overflows in some food banks while there are shortages in others.

4. The speed limit is thirty miles per hour.
   Our state's law states that the standard speed limit on municipal roads is thirty miles per hour [14].

5.3 Model Description and Justification

To obtain a numerical approximation for the minimum number of donation centers that must be included in the authors' home county, we perform Monte Carlo simulations to determine the number of theoretical donation centers necessary to yield the maximum value of food donations. In order to properly simulate the entire county, we generate 175,576 households, which corresponds to the current number of households in the authors' home county [7]. Each household is uniformly allocated a coordinate pair (x, y) according to a uniform random distribution with bounds given by both pairs of boundaries for x and y, respectively. Each household is also given a level of income. The income of each simulated household is assigned by drawing a random integer corresponding to the income brackets seen in Table 9 and drawing a uniform random real number I with lower and upper bounds given by the applicable income bracket.

Salary Lower Bound ($000)	Salary Upper Bound ($000)	Probability
0	15	10.1%
15	25	11%
25	35	11.3%
35	50	15.1%
50	75	19.2%
75	100	11.9%
100	150	11.6%
150	200	4.4%
200	1,000	5.4%

Table 9: Salary bounds in our county given in thousands of U.S. dollars. Percentages are based on population of our county being 414,899 [7].

Approximating the landmass of the authors' home county as a square of side lengths $s = \sqrt{556} = 23.5797$ mi, we distribute N food donation centers uniformly with $\sqrt{N}$ rows and $\sqrt{N}$ columns.

Each household is assigned a distance to its nearest donation center on the simulated map, which is given by the "taxicab" distance formula:

$$d = |x_d - x_h| + |y_d - y_h|,$$

where (x_d, y_d) is the coordinate pair corresponding to the *nearest* food donation center and (x_h, y_h) is the coordinate pair corresponding to the household under consideration.

Each household makes a decision regarding whether to expend the time and energy necessary to donate food to the nearest center by measuring the inequality

$$U(u, d) = B(u) - G(d) - C(d) > 0,$$

where $U(u, d)$ is the arbitrary "utility" function of the value of food the household has to donate u and distance to their nearest donation center d. We construct a benefit function $B(u)$ of the potential food donation value (in US Dollars) u_0 as

$$B(u_0) = 0.001u_0.$$

The potential value of food a household has to donate u_0 depends on the household's level of income I, and is computed by finding the total value of food wasted from Table 7 corresponding to the income level I. The benefit function uses an arbitrary coefficient 0.001 on u_0 to provide an *economic* quantification of the moral gratification derived from donating some quantity of food. The amount one would expend on gasoline to travel by motor vehicle to the nearest donation center is given by the function $G(d)$ of distance d:

$$G(d) = \frac{2p_{Gasoline}d}{g_{econ}},$$

where $p_{Gasoline}$ is the theoretical price of gasoline at the time of the simulations' executions, d is the distance to the nearest donation center, g_{econ} is the fuel economy of the average household car in miles per gallon. We estimate the opportunity cost of forgone wages by computing the theoretical hourly wage of the household

$$w = \frac{I}{24 \times 365},$$

where I is the household's income per annum. The forgone wages for the duration of the drive to the food donation center and to return from the food donation center are given by

$$C(d) = \frac{2wd}{v},$$

where v is the assumed average velocity of the vehicle on its journey to and from the food donation center. Thus, the utility function function is given by

$$U(u, d) = 0.001u_0 - \frac{2p_{Gasoline}d}{g_{econ}} - \frac{2wd}{v}.$$

In order for the "household" to decide to donate their food waste, the following inequality involving the utility function must hold:

$$U(u, d) > 0,$$

stipulating that a household will determine whether the benefit derived from donating their food waste, which includes the moral gratification experienced when donating food waste to food-insecure households, exceeds the cost of doing so.

The optimal number of food donation centers to build is directly associated with the economic value of food donated which is a function of aggregate food donations. The number of households choosing to donate their food waste will invariably depend on the minimum distance to access a food donation center, which will decrease for each household as the number of donation centers is increased. To ensure relatively simple implementation of the model, we assume that the theoretical county is subdivided into N regions, in the center of which is a food donation center. From this, we obtain the coordinates for each food donation center by calculating the midpoint of the interval in each dimension x and y. The economic "profit" from all food donation centers is given by

$$P = \left(\sum_{k=1}^{N} D_k\right) - cN,$$

where D_k is the value of food donations at center k and c is the cost associated with building a single food donation center.

The Monte Carlo simulations are repeated 10 times.

5.4 Analysis

We assumed that the cost of building a single food waste donation center is $c = \$100,000$, which roughly includes the cost of a new refrigerated semi-truck trailer [15], but does not assume the need for salaried staff. Testing the hypothesized values of $N = 1, 4, 9, 16$, the economic "profit" is given for the following values in Table 10 below. Given that the set of possible of centers is given by $N \in \{1, 4, 9, 16\}$, the aggregate economic profit is maximized by building 4 food waste donation centers.

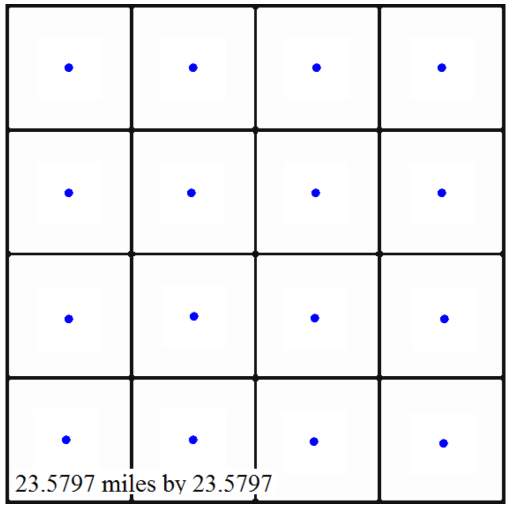


Figure 5: A depiction of the placement of food donation centers within the simulated county.

Number of Centers	Economic Profit
1	554,011.28
4	1,019,177.70
9	581,932.40
16	-138,547.21

Table 10: Economic profit derived from 10 independent Monte Carlo simulations of our county. Economic profits are given in US Dollars.

5.5 Strengths, Weaknesses and Sensitivity Analysis

The strength of this model lies in its ability to respond to small changes in parameters, such as the value of fuel economy for the average household motor vehicle. (For example, a 5 mile per gallon change in fuel economy produces a difference of approximately $200,000 in economic profit, but this value is insufficient to cause significant changes in the value which maximizes the economic profit) Since the number of donation centers is limited in interval, the number of donation centers which maximizes economic profits does not change for small differences in the global parameters.

The greatest weaknesses of the model lie in that the area of the county was assumed to be perfectly square and that residents are randomly distributed. We limit the possible numbers of donation centers to integers with integer square roots, which severely constrains the interval over which numerical maximization is performed. In other words, the set is limited by the fact that we assume that the subdivided areas of the county are perfect square tracts of land. Although our simulation has the capacity to handle different donation center configurations within the county, we limit our analysis for the sake of brevity and completeness of the theoretical model in Subsection 5.4.

The model assumes that residents of the authors' home county are randomly distributed according to a uniform random distribution with bounds corresponding to the boundaries of the simulated map. While this approximation seems to be the least objectionable means of simulating population distributions without detailed insight into the population densities within our county, it is nonetheless a limiting assumption of the model.

6 Conclusions

6.1 Recommendations

Given the results of our models, we recommend implementing two methods to promote the donations of food wastes to those who are food-insecure. Our first suggestion is to analyze what number food donation centers would benefit your community the most. By making the distance to a food bank shorter for the average household, less time, and therefore less money, is spent during the donation process. This makes donating much easier for the contributor, encouraging more people to donate their excess food. If the the amount of time it takes to get to the donation site is optimized in terms of the benefits of donating, the community will benefit the most. Our second recommendation is to employ more tax incentive programs for businesses and individuals that donate their food wastes. By providing monetary motivation, people that were not already donating their wastes frequently through the food donation centers would be encouraged to do so. Between the new centers and the tax break system, most people will be willing and able to donate any wastes they have to the food-insecure. This will simultaneously reduce our food wastes and keep the members of our communities from going hungry.

6.2 Further Investigations

Our models focused mostly on how to re-purpose food that was already determined to be wasted. Given more time, it would have been useful to assess the benefits of preventing food from becoming wasted to begin with. We could have proposed changes to the production, handling, storage, and distribution of food that would minimize the amount of food waste generated. Topics of further research could include the effects of more pronounced expiration dates, taxes or fees for excess waste, or minimizing food that gets wasted due to appearance by decreasing the cosmetic standards. In our second model, we made the assumption that a person contributes equal amounts to the waste produced by a household regardless of age and ignored unique dietary needs of individuals. This is unrealistic; a toddler has different nutritional needs and consumes a much smaller portion of food than an adult. A much more accurate picture of a household's traits and habits could be found by analyzing the more unique aspects of a household.

References

[1] United States, Congress. *Official USDA Food Plans: Cost of Food at Home at Four Levels, U.S. Average, November 2016*. United States Department of Agriculture, Dec. 2016.

[2] Venkat, K. *The Climate Change and Economic Impacts of Food Waste in the United States*. International Journal on Food System Dynamics, 2(4), 431-446, 2011.

[3] United States, Congress. *Choose My Plate*. United States Department of Agriculture, 26 Jan. 2018.

[4] United States, Congress. *Consumer Expenditure Survey: Average expenditure, share, and standard error tables*. Bureau of Labor Statistics, U.S. Department of Labor.

[5] Jenny Gustavsson, Christel Cederberg, Ulf Sonesson, Robert van Otterdijk, and Alexandre Meybeck. *Global Food Losses and Food Waste - Extent, Causes and Prevention*. Food and Agriculture Organization of the United Nations, Rome, 2011.

[6] United States, Congress. *Cash Receipts by State, Commodity Ranking and Share of U.S. Total, 2016* United States Department of Agriculture Economic Research Service, 7 Feb. 2018.

[7] Sarasota County Government. *Household Income Profile*. Sarasota County, Planning and Development Services, 2017.

[8] Dana Gunders. *Wasted: How America Is Losing Up to 40 Percent of Its Food from Farm to Fork to Landfill*. National Resources Defense Council, August 2012.

[9] McClellan, Jennifer. *Give Ugly Food a Chance: 'Nobody Is Stoked about Food Waste'*. Azcentral, The Republic, 19 Dec. 2017.

[10] Gundersen, C., A. Dewey, A. Crumbaugh, M. Kato, E. Engelhard. *Map the Meal Gap 2017: Food Insecurity and Child Food Insecurity Estimates at the County Level.* Feeding America, 2017.

[11] United States, Congress. *QuickFacts: Sarasota County, Florida - Geography*. United States Census Bureau, July 1, 2016.

[12] United States, Congress. *Food Expenditures*. United States Department of Agriculture, 27 Feb. 2018.

[13] United States, Congress. *2007-10 National Health and Nutrition Examination Survey (NHANES)*. Center for Disease Control, 2010.

[14] Florida Drivers Handbook. *Florida Speed Limits*. Florida Driver's Association LLC, 2018.

[15] Truck Paper. *High, Low, Average*. North America Listings, 2018.

Appendix A

The Python code used to perform the Monte Carlo simulations described Section 5 is given below.

```
# sim.py

import numpy as np

width = np.sqrt(556.0)  # miles (556 is the Area of our county in square miles)
height = np.sqrt(556.0) # miles (556 is the Area of our county in square miles)
num_households = 175576
v = 30 # miles per hour
g = 20 # miles per gallon
fp = 3.00 # fuel price US dollars/gallon
center_rows = 2
center_columns = 2
num_simulations = 10
center_cost = 100000.0   # US dollars



county_incomebrackets = [
    [0, 15000, 0.101, 547.49],
    [15000, 25000, 0.11, 651.64],
    [25000, 35000, 0.113, 779.79],
    [35000, 50000, 0.151, 904.39],
    [50000, 75000, 0.192, 1010.74],
    [75000, 100000, 0.119, 1259.48],
    [100000, 150000, 0.116, 1575.10],
    [150000, 200000, 0.044, 2091.13],
    [200000, 1000000.0, 0.054, 2509.64]
]



def drawfrom_incomedist():
    pvec = [row[2] for row in county_incomebrackets]
    bracket = np.random.choice(len(county_incomebrackets), p=pvec)
    lowerbound = county_incomebrackets[bracket][0]
    upperbound = county_incomebrackets[bracket][1]
    return np.random.uniform(lowerbound, upperbound)



def drawfrom_popdist():
```

```
    generated_x = np.random.uniform(0, width)
    generated_y = np.random.uniform(0, height)
    return [generated_x, generated_y]



def potential_donation(income):
    for bracket in county_incomebrackets:
        if (bracket[0] <= income) and (income <= bracket[1]):
            return (bracket[3] / bracket[1])*income



def nearest_center(coord):
    x = coord[0]
    y = coord[1]

    xint = width / center_columns
    yint = height / center_rows

    for i in range(0,center_columns):
        for j in range(0,center_rows):
            x_lower = i * xint
            x_upper = (i+1) * xint
            y_lower = j * yint
            y_upper = (j+1) * yint

            if (x_lower <= x) and (x <= x_upper)
                and (y_lower <= y) and (y <= y_upper):
                x_center = (i + 1) * (xint / 2)
                y_center = (j + 1) * (yint / 2)
                return np.abs(x_center - x) + np.abs(y_center - y)



def compute_benefit(u_0):
    return 0.001 * u_0



def actual_donation(u_0, inc, distance):
    wage = inc / (24*365)

    benefit = compute_benefit(u_0)
```

```
    util = benefit - (2 * fp * (distance / g)) - (2 * wage * distance / v)

    if util > 0:
        return u_0
    return 0.0



def sim_county():
    households = []

    cmdonations = 0.0
    for i in range(num_households):
        inc_i = drawfrom_incomedist()
        coords_i = drawfrom_popdist()

        distance = nearest_center(coords_i)

        u_i_0 = potential_donation(inc_i)
        u_i_D = actual_donation(u_i_0, inc_i, distance)


        households.append([ inc_i, coords_i, distance, u_i_D ])

        cmdonations += u_i_D


    # print stats!
    print("Total Value of Donations: %s" % (cmdonations))

    return cmdonations



def compute_implementation_costs(numcenters):
    return (center_cost * numcenters)



def run_simulations():
    print("-----------------------------------")
    print("Number of Centers: %s" % (int(center_rows * center_columns)))
    print("-----------------------------------")
    donationamounts = 0.0
    for i in range(num_simulations):
```

```
        donationamounts += float(sim_county())

    avg_donation_amt = donationamounts / num_simulations
    print("Average Donation Amount: %s" % (avg_donation_amt))
    print("")

    impl_costs = compute_implementation_costs(float(center_rows*center_columns))
    print("Total Center Costs = %s" % (impl_costs))
    total_util = avg_donation_amt - impl_costs
    print("Profit = V_D - Cost = %s" % (total_util))


run_simulations()   # Finally, run the Monte Carlo simulations


# end_sim.py
```