Team 1497

Waste Not, Want Not: Efficient Recycling in a World Dominated by Plastic

Executive Summary:

In an era of ever increasing pollution and waste and dwindling resources, recycling is more important than ever before. In this study, our team prepared a report on plastic waste accumulation in the United States and extrapolated to predict the amount of plastic that will be festering in landfills at the end of the next decade.

The incredible rate of plastic consumption today continues to grow in sync with the population and wealth of American citizens. In fact, the results of our study show that plastic waste production increases linearly from year to year, mirroring the near-linear growth of the population. Assuming a slow but steady recovery of the economy after the recession of 2008, the production of plastic waste is fairly simple to predict.

At the same time, it is less straightforward to calculate the total amount of plastic waste that will lie in landfills across the country by 2023. While agencies such as the EPA provide data on plastic waste produced by weight, the plastic within the landfill is slowly compressed over time so that its weight no longer predicts total volume. In order to calculate the mass of plastic in landfills, we used a linear regression coupled with a nonconstant landfill density function derived from real data.

We also considered the factors involved in choosing a successful recycling program for a given city. There are many different possible recycling programs that a city could use, but due to data availability we focused on five programs: drop-off single stream, weekly curbside single-stream, biweekly curbside single-stream, weekly curbside pre-sorted, and biweekly curbside pre-sorted. There are benefits and challenges associated with each of these programs, so in order to select the one best suited to a certain city we examined a selection of variables that we thought might affect the recycling program. We looked at available data for twenty-six United States cities to establish the strength of the relationships between the percent participation in the existing recycling programs and two variables that quantify economic resources and two variables that measure education level. We found that the average house value for a city and the percent of its population that has bachelor's degrees both affect the percentage of participation in recycling programs. Using our least-squares regression lines and coefficients of determination, we created a formula for predicting the percent participation in a city's program. We then created a model for calculating the cost of implementing each of our five programs in a city based on its population and its predicted percent participation. We applied this model to three specific US cities (Wichita, KS; Price, UT; and Fargo, ND) and by comparing the program costs to the predicted municipal budget allocated to recycling, we found the optimal programs for those cities to be drop off single-stream, biweekly curbside single-stream, and biweekly curbside pre-sorted, respectively. This model can be utilized for any US city with accessible census data, which makes this very applicable.

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PART I: How Big is the Problem?

Terminology

Waste generated: Amount of waste by weight that is collected by waste management organizations. We took this term (which is used in EPA reports) not to include waste that is "lost," meaning dumped in waterways or littered.

Waste recovered: Products that are recycled or taken out of the landfill track to be repurposed in some way.

Waste combusted: Trash that is burned, usually to reduce volume or for power (Municipal Waste Combustion). The waste generated that is *not* combusted was taken to equal the waste sent to landfills.

Assumptions

- Economic conditions will remain relatively stable for the next ten years. During economic recessions, overall consumption tends to decrease, which leads to a lower volume of disposed consumption by-products [Daysog]. It appears that plastic waste levels decreased in conjunction with the 2008 recession in America (Figure 2) , but we will not take possible upturns or dips into account in our model.
- We began our calculations at 1960 for amount of waste (plastic or not) sent to landfills. This is the first year for which the EPA has comprehensive data on trash levels, and also around the time that landfills became a common waste management strategy in America [Landfills].
- With the exception of the above-mentioned drop in disposal levels, the amount of plastic waste generated per year in the United States has increased in a fairly linear fashion since 1960 [Municipal Solid Waste Generation, Recycling, and Disposal in the United States Tables and Figures for 2010]. We believe it is valid to assume the continuation of this trend, because the country's population has also been growing in the same manner since that time period (Figure 7). Assuming a linear rather than exponential population model produces a difference of only 3% for 2023's U.S. population, using a growth rate of 0.5% [Human Population Growth].
- Our forecasted value assumes no change in recovery rate (from the most recent published value, 13.5% [Municipal Solid Waste Generation, Recycling, and Disposal in the United States Tables and Figures for 2010]) throughout the next ten years. Part II of our model is concerned with how best to *increase* the recovery rate.
- Combustion rate for total municipal waste has remained constant from 1960 to the present, and will remain constant for the next ten years.

Our Model

Our goal was to determine the total volume of plastic in landfills by 2023. Using predicted values for total weight of plastic packaging waste generated nationwide, as well as percentages of plastic waste sent to landfills, we determined the weight of plastic that will be sent to landfills. We did the same for total municipal waste (which includes plastic as well as other forms of trash). We used EPA data on plastic and municipal waste generation to find the current amount of plastic already buried.

Since burying trash on top of itself applies pressure to the material at the bottom, a simple mass/density conversion will not suffice in determining total volume. We used experimental data collected at an actual landfill to estimate the volume of a given mass of trash in a landfill, and from that, the volume of plastic, specifically.

Methods

We assumed a prism-like shape for landfills, with a uniform depth of 200 ft. Although this depth is on the high end of average landfill depth in the United States, we used this value because it is consistent with the source of our data [McCready]. McCready et al took measurements of effective density at a landfill with depth 200 ft at constant intervals:

Depth (ft)	Effective Density (lb/ft^3)
10	35
50	50
100	65
150	74
200	83

The graph of effective density vs. depth reveals a linear trend, as shown in Figure 1.

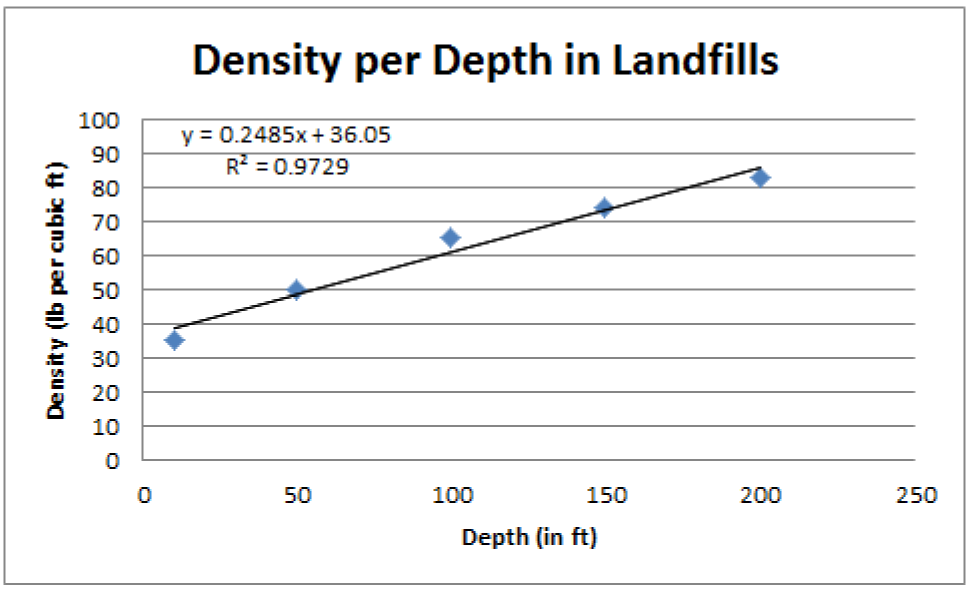

Figure 1, Density per depth in landfills.

This trend supports our assumption of a constant cross-sectional area (prism shape), because presumably the pressure of all the trash above causes a change in density which is proportional to the above trash's mass—and therefore volume. As you descend, the only dimension that is varying (assuming constant cross-sectional area) is height; hence, the linearity.

So, our density equation with respect to depth is

$$p(d) = .2485*d \text{ lbs/ft}^4 + 36.05 \text{ lbs/ft}^3 . \qquad (1)$$

Since

$$M_{tot}/V_{tot} = \text{average density}, \quad (2)$$

we can find volume by using our predicted weight of trash in the landfill, and the average density in the landfill, given our density function:

$$\text{Average value of } p(d) \text{ over a depth of 200 feet}$$
$$= \left(\int_0^{200} p(d)\, dd\right)/200 \text{ ft} = 60.9 \text{ lbs/ft}^3. \quad (3).$$

Now we have a formula for volume of total waste in landfills in terms of a constant and the unknown weight of waste in landfills. In order to determine a predicted total amount of plastic in landfills by 2023, we needed to determine how much there already is: the amount that has been accumulated since 1960. We used data on the following values: Total weight of municipal waste generated, percent of generated waste that is recovered, and the current combustion rate for municipal waste (assumed constant at 11.7% throughout the model)—see the appendix [Recycling basics]. Recall that

$$G = R + C + L, \quad (4)$$

where G = waste generated, R = waste recovered, C = waste combusted, and L = waste sent to landfills. Since the only percentages of total waste generated available were G (100%), R (variable), and $C+L$ (together make up disposed; also variable), we used our constant combustion rate of 11.7% to determine how much waste (by weight) ended up in landfills. Once we had that number, we used a trapezoidal Reimann sum to estimate the weight of waste sent to landfills:

$$W_1 = 6.25*10^9 \text{ tons} = 1.25*10^{13} \text{ lbs.}$$

By a similar procedure, we estimated the weight of plastics sent to landfills:

$$W_2 = 2.83*10^8 \text{ tons} = 4.61*10^{11} \text{ lbs.}$$

The second half of this model projects a value for the amount of plastic added to landfills in the next ten years (i.e., up until the year 2023). We assumed a constant rate value for L from equation (4), the most recent value available, which was 54.2 %. Here, we used a linear model to predict the total weight of municipal waste sent to landfills (Figure 6), following the assumption that its growth will be linear (along with national population). We used the prerecession growth trend in waste generation, because there were more data points available to form a regression. Summing the predicted annual values for total municipal waste to landfills gave

$$W_3 = 8.05*10^9 \text{ tons} = 3.3*10^{12} \text{ lbs.}$$

By a similar procedure, we estimated total plastic waste generation over the next ten years. Again, we used a linear regression from the years 1980 to 2007 (Figure 3), rather than postrecession data, because there was more numerical information available in that time period. We omitted the points from 1960 and 1970 since historical sources suggest that plastic use was not yet growing at the same pace in those decades [A History of Plastics]. Summing the predicted annual values for plastic waste to landfills gave

$$W_4 = 4.81*10^8 \text{ tons} = 2.73*10^{11} \text{ lbs.}$$

The average density of municipal waste (Residential and Commercial/Industrial waste) is 42 lbs/ft^3 [Material Density and Volume Conversion]. The average density of plastic is 74.2 lbs/ft^3 [Density Values—Specific Resins]. So,

$$V_1 = (W_1+W_3 \text{ ft}^3)/42 \text{ lbs}$$

and

$$V_2 = (W_2+W_4 \text{ ft}^3)/74.2 \text{ lbs},$$

where V_1 equals the volume of total municipal waste sent to landfills *before it is buried*, and V_2 equals volume of plastic waste sent to landfills, also *before it is buried.* So, V_2/V_1 is the percentage of waste sent to landfills which is plastic. We will assume that this ratio remains constant; in reality this may not be true, since certain materials may compress more than others.

So, according to equation (2),

$$(W_1+W_3)/Vf = 60.9 \text{ lbs/ft}^3,$$

where Vf equals volume of total municipal waste sent to landfills *after it is buried*. We find that Vf = 2.60*10^11 cubic feet, so the volume of plastic which has accumulated in landfills from 1960 to the present equals $Vf*(V_2/V_1)$, giving the final projected volume of plastic in landfills (Vp) by 2023:

$$Vp = 7.10*10^9 \text{ cubic feet.}$$

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<u>Graphs</u>

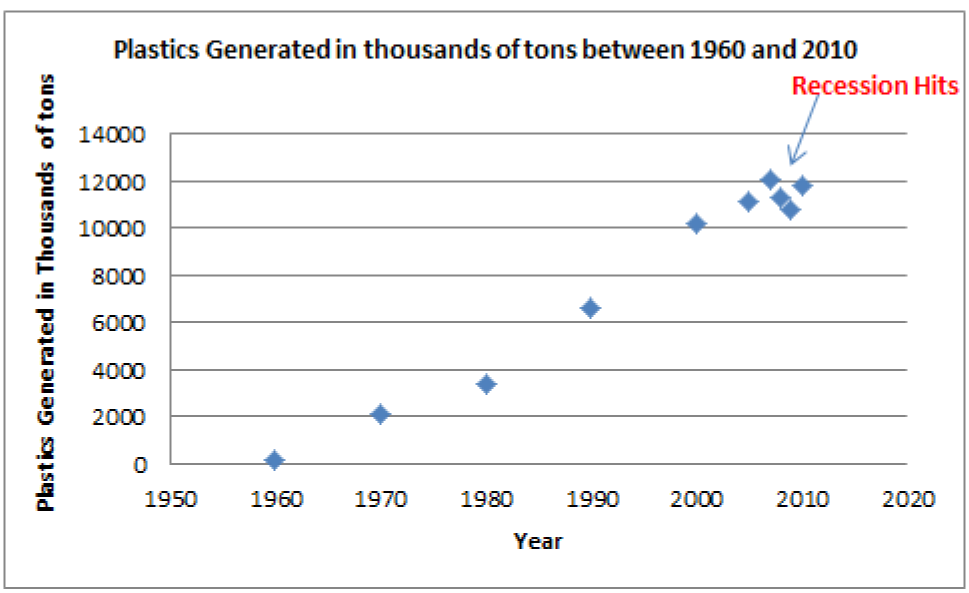

Figure 2, Source: Municipal Solid Waste Generation, Recycling, and Disposal in the United States.

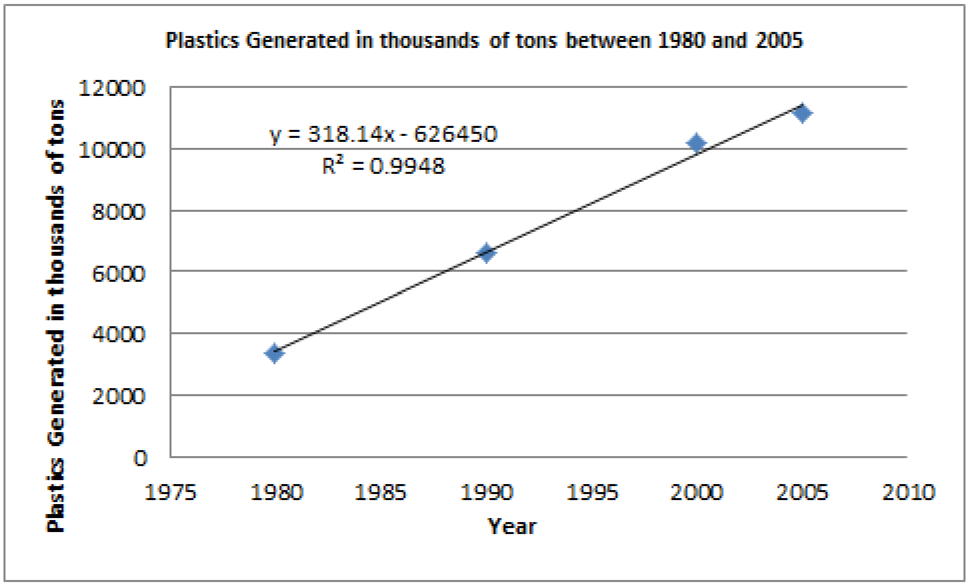

Figure 3, Regression used for prediction of plastic waste to landfills.

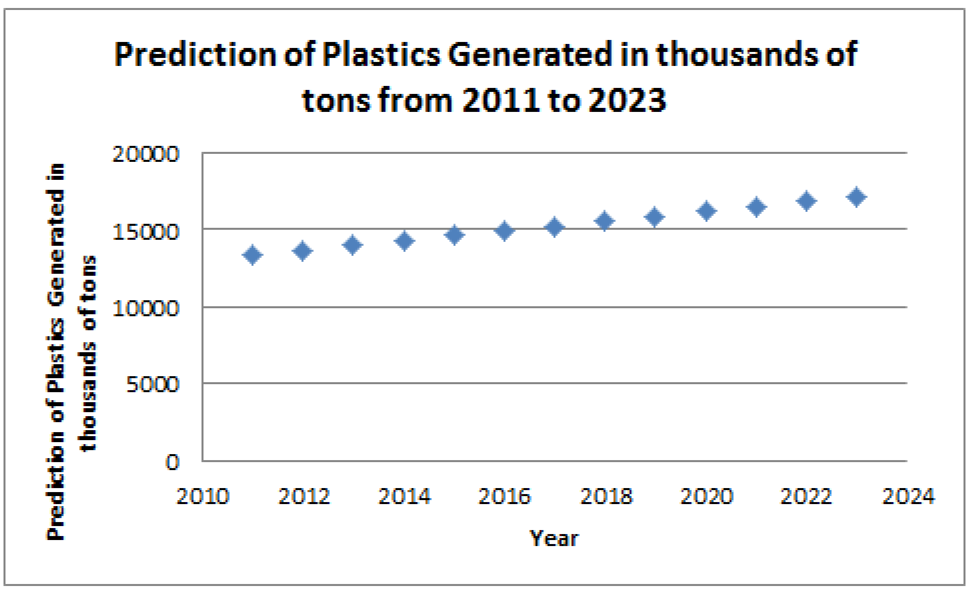

Figure 4.

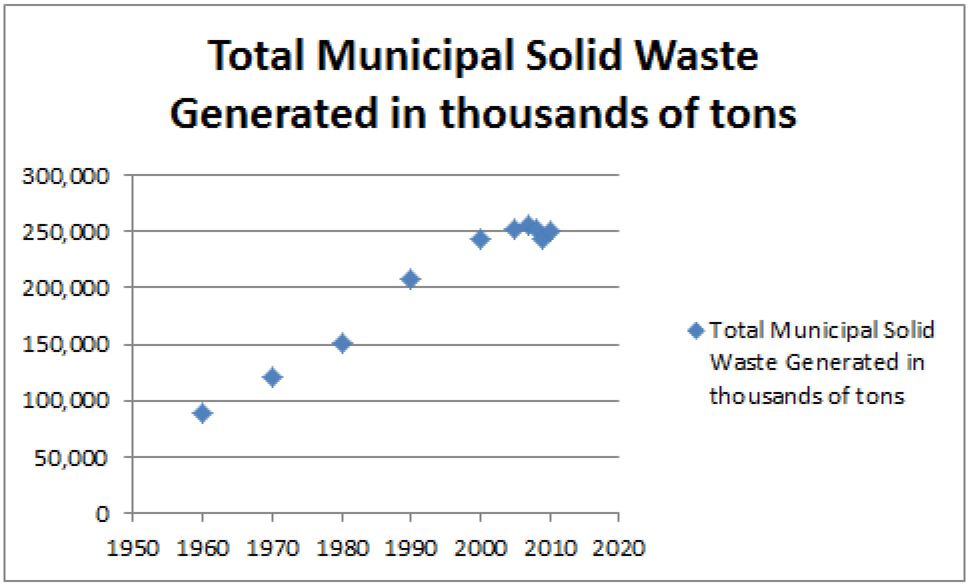

Figure 5, Source: Municipal Solid Waste Generation, Recycling, and Disposal in the United States.

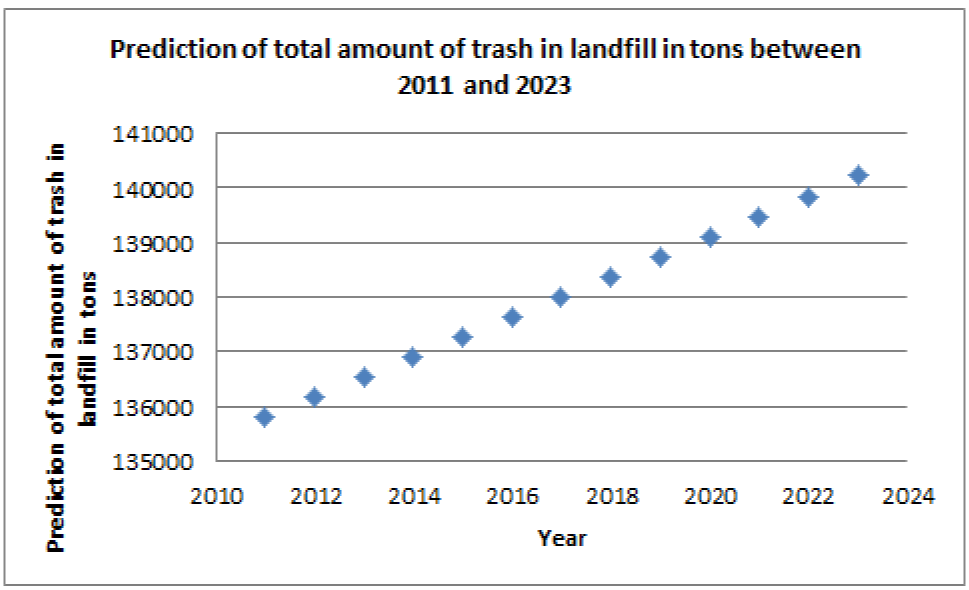

Figure 6.

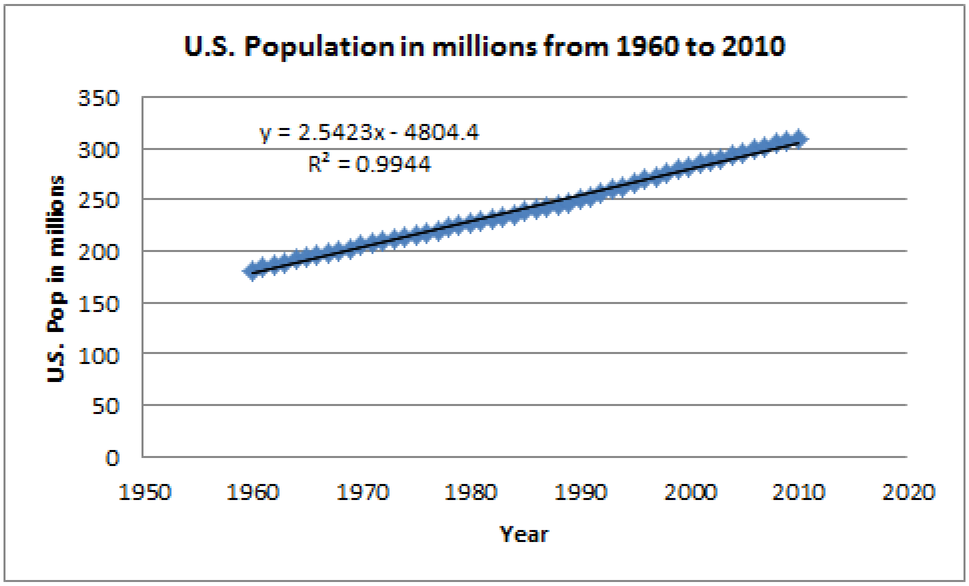

Figure 7, Source: "U.S. Population Data."

Conclusion and Analysis

According to our model, the volume of plastic alone in our country's landfills (assuming a uniform depth of 200 ft) will equal about $7.10*10^9$ cubic meters by 2023, if current recycling rates and landfill practices continue. Since this is a compacted volume of plastic, the quantity is truly astounding.

If we had additional time and resources, we would have liked to investigate the decomposition of plastic in landfills and the effect that would have on total volume.

PART II: Making the Right Choice on a Local Scale

Introduction

Our model identifies the optimal recycling program for any US city, working within the city' budget and the likelihood of its residents to participate in the recycling program. We considered 3 characteristics of a recycling program: whether it offers curbside pickup or drop off at a center, whether or not it requires residents to presort their recycling at home, and whether or not the curbside pickup comes weekly or biweekly.

Our model measures "success" of a city's recycling program by the percentage of its residents who participate in the recycling effort. More people recycling means that more material is recycled, which is ultimately our goal.

Background

Recycling is a large component of any city's waste disposal, processing vast amounts of waste that otherwise would have ended up in a landfill. Unfortunately, no one recycling system is of optimum design for all cities. Several different recycling programs exist throughout the country, differing in method of pickup and whether or not the recyclables must be presorted by the consumer.

Concerning method of pickup, there are two dominating practices: curbside pickup and drop off. Curbside pickup requires workers from the local municipality to come to each individual household and collect any recycling that has been placed out on the curb or street. This reduces the amount of work the consumer must perform in order to recycle, since he or she doesn't have to travel farther than a few feet from the door. However, such a means of recycling has high costs, since it requires significant time and labor from the municipality. Drop off, on the other hand, requires little work from the municipality, since it requires the consumer to travel to local recycling sites and dispose of their recycling for themselves. Unfortunately, the added work of travel forced on the consumer significantly decreases overall willingness to participate in the recycling program.

The other main factor under consideration is whether or not the consumer should be required to presort his or her recycling. Single stream recycling allows for the consumer to place all recycling in one receptacle, with no sorting requirements. The recycling is then processed at an MRF (Material Recovery Facility) designed to sort and process all types of recycling together (Single Stream Recycling). This method requires no consumer education about the proper methods of sorting recycling, a potentially confusing task that reduces overall participation rates in recycling programs. In addition, this method reduces collection costs, since single-compartment collection trucks are less expensive than multiple-compartment collection trucks. The alternative to single stream is presorted recycling. Presorted recycling tasks the consumer with placing specific types of recycling into specific receptacles, so that the MRF receives recyclables of specific types and can process them individually. Presorted recycling requires greater consumer involvement, but results in the MRF performing a simpler task, and therefore a less expensive MRF. The average capital cost of a single stream MRF is $7,551,000, whereas the average capital cost of a presorted MRF is $4,907,000 [Dual Stream vs. Single Stream Collection and Processing of Recyclables]. Although some drop off centers accept presorted materials only, we were unable to find any data about the cost of implementing such a program within the time constraints, and so we have eliminated that option from our model.

Within the varying methods of curbside pickup, an important differentiating factor is whether the recycling is collected on a weekly or a biweekly basis. Weekly recycling pickup results in a smaller build-up of recycling between pickups and is therefore more convenient for the consumer. However, the increased frequency of pickup increases the cost of the recycling program.

An additional suggestion for encouraging recycling collection is requiring consumers to pay for each container of garbage collected. Ideally, this would encourage consumers to cut back on their garbage output through increased recycling. Although a good idea hypothetically, research has failed to find a significant correlation between paying for garbage and participation in recycling programs (Lockhart). Therefore, we concluded that garbage fees are not a viable option for our analysis.

<u>Assumptions</u>

Over the course of building our model, we made several key assumptions concerning the consumer population and the nature of recycling involved:

- Population demographics such as race and age do not factor into the tendency to recycle.
- We will deal only with municipal wastes because industrial/hazardous wastes are rarely collected by city recycling programs.

- Our newly implemented recycling program will be as effective as an older program, because we have not seen evidence that the age of a recycling program corresponds with success.
- Although forms of housing (rental, apartment, etc.) and their respective recycling systems vary, average resident housing situation will be constant between cities and thus will not impact our model.
- Data taken from recycling efforts in St. Paul, MN is used as average data for a recycling program in any US city.

<u>Methods</u>

In order to properly assess the most effective type of recycling program for a given city, we considered two main factors: likelihood of household participation in the program, which we intend to maximize, and the municipality's ability to pay for the program.

We identified the likelihood of participation by analyzing several possible influences and noting which ones correlated most with participation rate. We did this by first compiling information from 26 different cities on their percentage of people in poverty, percent of people with a high school diploma, percent of people with a Bachelor's degree, and average home value. We then graphed each of those sets of data against the participation rate of each city's recycling program and recorded the strength of each correlation. High strength correlations such as average home value were then used in the model; low strength correlations such as percentage of people in poverty were discarded.

We then used the two strongest correlations—average home value and percentage of people with a bachelor's degree—to predict the percent participation in a recycling program for a given city. The two factors were weighted using their corresponding coefficients of determination to extrapolate a final prediction. This prediction determines whether a single stream or presorted program would be more effective. Since the goal of any city should be to involve the majority of the population in recycling, the city should use a single stream program if the predicted participation rate is below two-thirds (66%). If the participation rate is below 66%, a single stream option will ensure that no additional participation is lost due to a more complicated recycling process. However, if the predicted participation rate is above 66%, then a presorted option is more effective, since such a city would have a high number of people recycling already and should opt to save money by using presorting. In addition, a city with a high participation rate is more likely to be willing to sort recycling into the correct types, increasing the efficiency of the presorted method further.

The second step of our method is to choose between drop off, biweekly curbside, and weekly curbside programs. Through an analysis of the average amount spent on recycling in municipality budgets in comparison to city population size, we determined that cities should, on average, spend $6.64 per person annually on recycling programs. Using this fact and the size of a given city, we predicted the budget for recycling for that given city. We then predicted the cost of the drop off, biweekly curbside, and curbside programs using the city population, city recycling rate (from the consumption rate of recyclables of the average American and the predicted recycling participation rate of the city), and the cost of each of the types of programs in dollars per ton recycled. The best fit program for a given city was the one that cost closest to the city's allocated budget from our reasonable budget determination. This determines if the city should choose a drop off, biweekly curbside, or weekly curbside program. Coupled with the single stream or presorted determination from the predicted participation rate, our process will tell a given city to try one of six possible programs. A visual representing the five options is given below in Figure 8.

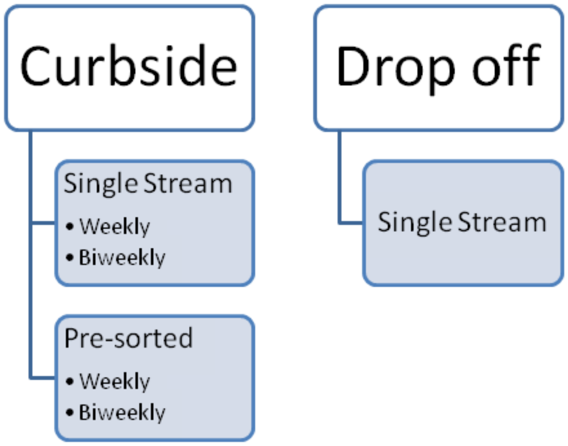

Figure 8.

Percentage Participation Data

In order to create the most cost-effective program for a specific city, we need to try to predict the percent participation of that city's population in a recycling program. By finding a least-squares regression line for plots of percent participation versus different variables, we found the ability of those variables to predict the variability of percent participation in a given city's recycling program. There are many variables that could potentially contribute to the likelihood of a certain citizen recycling. Based on available data and relationship to factors that could logically affect a person's knowledge of recycling, we chose a few statistics to compare to the percent participation of a city's population in recycling. The variables we examined were the percent of the population living under the poverty line, average home value, percent of the population with a high school diploma, and the percent of the population with a bachelor's degree.

The percent of the population living under the poverty line was a variable of interest. It seemed logical that people with more economic resources would be more likely to think about recycling because they have fewer monetary concerns. In other words, recycling would be a higher priority. However, our data shows that the percent of the population living under the poverty line does not have a statistically significant effect on the percent participation in recycling programs. The least-squares regression line for the twenty-six state capitals is as follows:

$$\text{\% participation} = 0.1349(\text{\% of population under the poverty line}) + 47.429. \quad (5)$$

The coefficient of determination for that linear relationship is $R^2 = 0.0009$, which suggests that the model accounts for 0.09% of the variability of the data. This relationship is so weak as to be negligible, so the percent of the population living under the poverty line is not included in our calculations for predicting the recycling program participation.

The average value of houses provides a different way to quantify economic security, so we selected it as another potential variable of interest. According to the data used, the average value of houses appears to have an enormous impact on the percent participation of citizens in recycling programs. The least-squares regression line is

$$\% \text{ participation} = 0.0005(\text{average house value}) + 2.033. \qquad (6)$$

The coefficient of determination for that linear relationship is $R^2 = 0.2716$, so the model accounts for 27.16% of the data's variability. Since this is an extremely strong relationship, average home value appears to be a relatively accurate indicator of percent participation in a city's recycling program, and therefore it should be a large component of our prediction.

Along with economic resources, we hypothesized that education level might have an effect on percent participation in a recycling program because more educated people could be more likely to be aware of environmental issues and the importance of recycling. We can quantify education level by the percent of the population with high school diplomas. When plotted against percent participation in recycling programs, the percent of a population that has high school diplomas does not appear to have a substantial impact on the percent participation in recycling programs. The calculated least-squares regression line is as follows:

$$\% \text{ participation} = 0.3527(\% \text{ of population with high school diploma}) + 20.4. \qquad (7)$$

The coefficient of determination for that linear relationship is $R^2 = 0.0088$, so this model accounts for 0.88% of the variability of the data. Since this is again a very weak relationship, the percent of the population that has a high school diploma is not factored into our predictions for recycling program participation.

Since a high school education did not have a significant impact on percent participation, we looked at the percent of the population with bachelor's degrees. When plotted against percent participation in recycling programs, the percent of a population that has bachelor's degrees does appear to have a small effect on the percent participation in recycling programs. The calculated least-squares regression line is as follows:

$$\% \text{ participation} = 0.6217(\% \text{ of population with bachelor's degree}) + 30.903. \qquad (8)$$

This linear regression has a coefficient of determination of $R^2 = 0.0484$, so this model accounts for 4.84% of the variability of the data. For real data, 4.84% is a considerable amount. Therefore the percent of the population that has a bachelor's degree can be included in our predictions for recycling program participation. To find the final predicted participation, we took a weighted average using the two coefficients of determination:

a = % participation from average house value
b = % participation from % bachelor's degrees

$$\text{Predicted } \% \text{ participation} = \frac{.2716 * a + .0484 * b}{.2716 + .0484} \qquad (9)$$

We then used these program participation predictions to predict program costs, and to pick whether to do a single stream (if participation is 66% or larger) or a presorted (if participation is lower than 66%) program, to maximize participation but reduce costs as explained in our outline of the method. See Table 1 in the appendix for data.

Model

Percent participation prediction:

% participation = 0.0005(average house value) + 2.033
R^2 = .2716
% participation = 0.6217(% of population with bachelor's degree) + 30.903
R^2 = .0484

Use each least-squares regression to obtain a predicted percent of participation in recycling program value. Then, weight the predicted values according to the strength of the model.
a = % participation from average house value
b = % participation from % bachelor's degrees

$$\text{Predicted \% participation} = \frac{.2716 * a + .0484 * b}{.2716 + .0484}$$

Cost prediction:

The following equation was used to predict the cost of a recycling program in a given year for a city with a given population and participation prediction. It first calculates the total tons recycled in a given year, and then multiplies by the cost per ton to recycle that plastic, which varies depending on what program is being implemented:

(Pop. City X)*(Avg. tons recycled per person/yr)*(% City X participation)*(Cost for a given program/ton to recycle) = Annual cost of recycling for City X for a given program.

We know that the average American recycles roughly 1.5 pounds per day = 0.2739 tons per year [Municipal Solid Waste]. We found values for the cost per ton to recycle in single stream and presorted curbside weekly and biweekly in St. Paul, which we used as an approximation of the national average cost per ton. Since St. Paul is a mid-sized city with relatively average per capita income, we felt that it was a valid source to predict a general average cost [State and County QuickFacts].

Budget Prediction:

In order to predict what a reasonable budget would be for a city of a given population, we found the average number of dollars spent per person on recycling in an average city budget. To do this we found the average spent on recycling in city budgets. Due to limited recycling budget availability, we will estimated our recycling budget based on the average municipal recycling budget of Pennsylvania [Beck]. We also assumed that recycling costs are proportional to number of people living in a city.

Average recycling budget in PA = $339,000
Total population of PA = 12,763,536
Approximately 250 cities/towns/boroughs in PA

12,763,536/250 = 51,054 people/city
$339,000/51,054 = $6.64/person

Thus, to determine the reasonable budget for a recycling program in a given city, we take the population of the city and multiply it by $6.64.

Implementing the Model

We tested our model with data from the following three cities: Wichita, KN; Price, UT; and Fargo, ND.

Table 2 gives us the data from our calculations on projected participation in each city as well as the cost of running each type of recycling program.

TABLE 2

	Wichita, KN	Price, UT	Fargo, ND
People/Square Mile	2,400.40	1,720	2,162
Population	384,445	8,682	107,349
% of population with Bachelor's Degrees	27.9	15.0	38.6
Average House Value	114,800	127,600	148,500
% participation from house value	59.43	65.83	76.28
% participation from % bachelor's degrees	48.25	40.23	54.90
predicted % participation	57.74	61.96	73.05

Estimates for recycling budgets for given cities:

TABLE 3

	Wichita, KS	Price, UT	Fargo, ND
City budget	213,952,836	8,601,905	80,500,000
Approximate recycling budget	2,552,715	57,648	712,797
Percent of actual city budget	1.19%	0.670%	0.885%

Estimated costs to implement each program for the three cities:

TABLE 4

	St. Paul	Wichita	Price	Fargo
Cost of Curbside Recycling...				
Weekly 1 Stream	139	4742394.0	114925.9	1675347
Weekly Pre-Sorted	89.4	4012794.9	97245.0	1417602
Biweekly 1 Stream	141	4134394.8	100191.8	1460559
Biweekly Pre-Sorted	103	3465595.6	83984.3	1224292
Cost of Using Drop Off Centers		759999.0	18417.6	268485.1

[A Comparative Analysis of Applied Recycling Collection Methods in Saint Paul]

Conclusion

After applying our model to three dissimilar towns across the United States, we came up with a recommendation for the optimal recycling program for each one. Our two prime considerations, the percentage of people projected to participate in the program and the projected financial capability of the city, are not independent of one another. When more people recycle, the city actually makes more money. Using curbside pickup methods requires the city to check every bin for recycling regardless of its residents' participation, and once the processing plant is set up the profits are worth more than the costs. Because of this interdependence, our model recognizes the percentage participation first. If that percentage is higher than 66.7%, the city should require pre-sorting for its residents. If not, it should accept single-stream recycling. The next step is to choose between curbside and drop off collection methods, and weekly or biweekly pickups. There are four possible programs based on those options which differ in cost and amount of recycling they bring in. For Wichita, we recommend the least expensive, a drop-off program, based on budget limitations. For Price, a participation level of only 61.9% eliminates the possibility of requiring pre-sorting. Accordingly we recommend a biweekly single stream program. In Fargo, the participation level of 73.05% is high enough to allow a presorting program, and so we recommend a biweekly presorting program.

Discussion and further research

Creating a model is difficult because we are forced to rely on many assumptions. We did our best to remain consistent in these decisions, but were not always able to do so to the degree that we would have liked. We were forced to work within the constraints of data availability, which complicated calculations and prevented us from being as consistent as we ideally would have been. For example, we were only able to find certain information for the city of St. Paul, Minnesota, so we decided to assume that other cities followed similar trends. We tried to continue to use St. Paul as our "average city" throughout the rest of our model calculations, but were unable to do so because the St. Paul recycling budget was not available. Instead we were forced to use the average recycling budget for a city in the state of Pennsylvania as our "average city." The model we created is based on numerous assumptions, but we would not have been able to make predictions without them.

The largest weakness of our model is our failure to obtain data from single sources and single years. We attempted to maintain some degree of consistency in our data, but were often forced to work off of what we could find, which was not ideal. For instance, we were not able to find the municipal budgets for Wichita, KS, Price, UT, and Fargo, ND from the same fiscal year, so we used the numbers of the 2013 budgets for Wichita and Fargo, but the 2012 budget for Price. We believe that it is a valid assumption that the Price budget for 2013 would strongly resemble the 2012 budget because when we compared the 2011 budget with the 2012 budget, they were extremely similar.

Along with these apparent flaws, our model is far from complete. Due to time constraints we were limited in the number of variables that we were able to analyze. One such variable that we attempted to look at for a potential relationship with recycling costs is population density. Since more concentrated houses would require less pick-up time for curbside recycling, and consequently would require fewer labor hours and lower transportation costs, in theory more densely populated areas should be more optimal locations for implementing curbside pick-up. We attempted to look into the relationship of population density with cost of recycling, but were forced to abandon that line of inquiry due to the restriction on time.

Part III: Extending to a National Scale

The Environmental Protection Agency was created "to protect human health and the environment" [About EPA]. Recycling is an essential part of that mission. By making recycling in the United States a more efficient, manageable process, the EPA could greatly decrease the nation's damage to the environment. Using the aforementioned method for calculating the costs of different possible recycling methods for a given city, the EPA could aide cities across the nation in finding the recycling program to meet their individual needs, while staying within their resources. In order to apply our model to any city in the nation, the only data needed would be reasonably accessible census information, including population size, average home value, and percent of population with bachelor's degrees.

In general, noticeable trends applicable to the country as a whole are as follows: Biweekly pickup is more efficient than weekly pickup for a curbside program, since both encourage participation in the recycling program by being more convenient to consumers, but weekly pickup is more expensive. Such can be seen in the results achieved with Fargo, North Dakota and Price, Utah. In addition, small to midsized cities should consider drop off as a potentially efficient means of recycling, especially if they are in need of budget cuts - in cities such as Wichita, Kansas, the drop off method is efficient, since the small but concentrated population means that a few drop off sites could easily accommodate the city effectively.

Appendix

TABLE 1: % Participation Data

City	% Participation	% Below Poverty Line	% Holding High School Diploma	% Holding Bachelor's Degree	Home value
Montgomery	38	17.7	80.7	29.4	86,800
Sacramento	75	20	77.3	23.9	128,800
Tallahassee	39	24.7	89.9	45	102,500
Atlanta	50	24.4	76.9	34.6	130,600
Boise	73.5	8.4	91.1	33.6	120,700
Springfield	33	11.7	87.4	30.6	88,600
Indianapolis	3.5	11.9	81.3	25.4	98,200
Des Moines	46	11.4	83	21.8	81,100
Topeka	4	12.4	85.9	25.3	68800
Baton Rouge	42	24	80.1	31.7	94,700
Augusta	75	15	81.4	19.2	80,500
Lansing	55	16.9	82.4	21.2	73,500
Saint Paul	70.9	15.6	83.8	32	105,400
Jackson	30	23.5	79.1	27.1	64,400
Trenton	37	21.1	62.4	9.2	65,500
Raleigh	50	11.5	88.5	44.9	156,000
Salem	80	15	81.5	24.1	131100
Columbia	80	22.1	82.3	35.7	98500
Pierre	45	7.8	89.6	35	94800
Nashville	52	13.3	81.1	29.7	113300
Austin	70	14.4	83.4	40.4	124700
Salt Lake City	65	15.3	83.4	34.9	153300
Richmond	40	21.4	75.2	29.5	87300
Olympia	87.5	12.1	91.6	40.3	143500
Charleston	28	16.7	83.8	32.6	101400
Cheyenne	20	8.8	89	24.5	102400

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