A METHOD FOR DETERMINING PROCESSIBLE WASTE FOR A RESOURCE RECOVERY FACILITY

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ABSTRACT

Accurate estimates of available waste are of vital importance to the design of an efficient and economical resource recovery facility. In work for the Department of Energy (DoE), Franklin Associates, Ltd. has developed and successfully tested a technique to estimate collected municipal solid waste based upon readily available socioeconomic and demographic data. Details of the technique are discussed, including seasonal effects and caveats to assist planners/designers in determining waste supply.

INTRODUCTION

Resource recovery emerged in the 1970s as one useful alternative for easing solid waste disposal problems and for conserving energy and material resources. As we enter the 1980s, resource recovery appears to be emerging as a solid waste management alternative that will be of particular importance in regions of the country where landfill space is scarce for geologic or political reasons and/or very expensive. It is here that resource recovery systems can be economically competitive with conventional sanitary landfill, especially under the landfill standards of RCRA. With energy sources becoming increasingly expensive, resource recovery is being further stimulated.

THE IMPORTANCE OF DESIGN PARAMETERS

Most of the first generation energy recovery facilities have operated below their design capacity for one reason or another, including inadequate waste supply in the area, inability to capture the waste supply, and mechanical and operating problems of the plant. A resource recovery facility is designed to process a specific quantity of solid waste on a regular basis. Regardless of whether the waste processing schedule involves continuous 24 hr/day service or 8 hr daily shifts, it is extremely important to utilize accurate waste quantity data when selecting and designing the appropriate facilities. Inadequate estimates of solid waste availability can result in resource recovery facilities which are either too large or too small to efficiently process the actual solid waste quantity and/or serve its customer(s). An improperly sized facility can experience operational problems as well as the adverse economic situation which could be expected under such conditions.

Frequently, national average per capita solid waste generation must be utilized as the basis for sizing an energy recovery facility, especially where local solid waste weight data are unavailable. Members of our firm have made EPA's municipal solid waste (MSW) generation calculations annually for several years [1], and although several refinements have been made in the methodology, we feel the national average MSW generation data should be used for general planning purposes only. Usually these data are inadequate for design of specific energy recovery plants. In addition, there is often confusion about whether waste generated is actually available and suitable for processing in a recovery plant.
In a waste stream analysis, it is important to make careful distinctions of the amount of waste generated, the amount discarded, the amount collected, and the amount which could be usefully processed by a resource recovery system. Much waste generated—agricultural waste in particular—is disposed of on-site and does not enter the waste stream. Further, not all waste discarded is actually collected by entities which could or would channel the waste to a resource recovery facility. Some waste becomes litter, some is source separated before entering the municipal solid waste stream, and some—particularly industrial, hazardous, and commercial waste—is often disposed of privately. Finally, not all waste collected is suitable for processing in a resource recovery facility. In short, it is desirable to know how much waste is deliverable to a recovery facility.

The oversizing of plants may be desirable in some instances, but certainly not where it arises from inadequate documentation of MSW supply. Too many facilities located throughout the United States could encounter problems without a better way to determine MSW quantity (and composition). It is apparent that a definite improvement in analysis, including better prediction capabilities for waste generation and waste collection, would help planners and engineers in facility design.

PURPOSE OF THE STUDY

The purpose of our recent study [2] was to identify alternative methods of estimating solid waste generation estimating procedures. This study related actual solid waste collection to several factors, including land use zones, population density, and household income, with the intent of developing a set of parameters which could be used to estimate waste collection in any geographical region.

The desired estimation technique should stress collectible (and processible) waste and not the theoretically generated waste, some of which never enters the processible municipal waste stream. Several previous attempts to develop average MSW generation rates have been based upon estimates of total waste generation corrected for recycling. Little or no attempt has been made to modify such values to account for collectible waste only.

Only residential and commercial solid waste collection was examined in this analysis. Industrial process waste generation is extremely variable and depends upon the nature of the industrial operations. In determining the available solid waste in a given region, specific industrial sources must be examined in some detail. Waste generation factors which have been developed for various industry groups can be utilized to estimate the quantity of industrial waste which could be expected in a given area. Residential and commercial solid waste collection is more uniform, thus general estimation techniques are more suitable to these categories. However, to completely characterize a waste stream, the estimates of residential and commercial waste quantities must be added to separately-derived estimates of industrial waste quantities.

RESEARCH METHODOLOGY

Our general approach used to develop residential and commercial collection factors involved extensive gathering of actual waste collection data on a day by day and truck by truck basis from six communities. These data were then analyzed and related to land use and demographic data to determine useful relationships.

Data were gathered from six municipalities in different geographical regions throughout the United States. They are listed below along with their respective populations.

<table>
<thead>
<tr>
<th>City</th>
<th>Estimated Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. San Francisco, California</td>
<td>720,000</td>
</tr>
<tr>
<td>2. Garland, Texas</td>
<td>130,000</td>
</tr>
<tr>
<td>3. Milwaukee, Wisconsin</td>
<td>720,000</td>
</tr>
<tr>
<td>4. Lawrence, Kansas</td>
<td>50,000</td>
</tr>
<tr>
<td>5. Kansas City (metro area)</td>
<td>1,290,000</td>
</tr>
<tr>
<td>6. St. Louis, Missouri</td>
<td>519,000</td>
</tr>
</tbody>
</table>

Prior to the selection of these cities, preliminary research was carried out to assure the availability of adequate data to perform the planned analyses. Of primary importance was detailed weight data which quantified solid waste collection by area, preferably down to small geographic areas such as individual collection routes within a city. Although this criterion does not appear overly stringent, careful examination of the actual data often revealed problems which would greatly distort actual solid waste collection in a city if it were not based only on a small area.

A detailed data base was developed for each area selected for study. The primary sources of information were municipal solid waste collection agencies, which provided waste collection weight and route data, and the U.S. Census Bureau, which provided recent demographic and socioeconomic data for each city.
RESIDENTIAL SOLID WASTE COLLECTION

Several factors were examined to determine their potential value as predictors of solid waste collection. Each factor is discussed separately in the following sections.

LAND USE ZONES

The structures which characterize the residential zones of a given area of a city are restricted by various ordinances. Usually the restrictive characteristic is lot size per dwelling unit; however, the height and other characteristics of the structure are also often restricted. Since residential zoning classification schemes are similar in most cities, an attempt was made to relate "zones," or more specifically lot sizes, to solid waste collection rates. The reasoning behind this is that type of residence may be uniquely related to life style, which in turn may be uniquely related to waste generation.

Each solid waste collection route was examined to determine the land area (acres) of each type of residential zone within the route boundaries. The solid waste quantity collected within that route (derived from actual weight data) came partly from each specific zone in the route. A mathematical procedure including use of simultaneous equations was developed to determine whether the solid waste collection rate for a specific zone was consistent from route to route. The procedure was designed to identify initially if zones within a city were consistent, then carry the analysis a step further to compare a given zone of one city with a comparable zone of another city.

The results of this analysis indicate that there is little consistency in solid waste collection in comparable zones. Collection rates for different waste collection routes in a single type of zone in Milwaukee were found to vary by as much as 55 percent, with lesser variations quite common.

Several problems which decrease the value of land use zones as predictors of waste collection were identified. Foremost is the accuracy of zoning restrictions. Zoning restrictions only "restrict" in one direction. That is, the restrictions do not prohibit the building of a "more desirable" living unit (i.e., single family home on large lot) in a "less desirable" zone (i.e., commercially zoned property). However, the reverse situation is restricted by zoning ordinances.

Another problem with using land use zones as predictors of waste collection is that although an area may be zoned for some specific purpose, the degree of development in the zone may change rapidly, and not be accurately known at any particular time. The periphery of a city is highly susceptible to changes as development moves outward. Large areas may be zoned as single family housing, for example, but only a small part may actually be developed into housing complexes. The remainder of the land may be in a developmental waiting stage as an idle field or a woods.

Other problems include the presence of schools, churches, and parks in a residential zone (which can distort solid waste collection based on land area rates), and inconsistent population densities in a specific type of zone.

Consequently, these problems were sufficient to cause us to dismiss this method of predicting municipal solid waste collection as impractical.

HOUSEHOLD INCOMES AND PER CAPITA COLLECTION RATES

In search of a simpler estimation technique, household income was related to solid waste collection. Mean and median household incomes were determined for each residential route for the cities for which we had adequate waste collection data available. The analysis could not be performed for all six cities originally selected because of uncertainties in the data bases. Four of the six cities did provide adequate data:

1. Milwaukee, Wisconsin
2. Garland, Texas
3. Lawrence, Kansas
4. St. Louis, Missouri

Route data were available for each city except St. Louis, which had only a single solid waste total which could be compared to the median household income in the city.

Per capita solid waste collection rates were derived for each route using data obtained from the Census Bureau and from interviews with public works officials [3, 5-9]. Median household incomes for each route were also determined from U.S. Census data [3]. Although mean household incomes were calculated, they were not used in the analysis because the mean is often distorted by a very few high or low incomes. Median income is less affected by this phenomenon.

Per capita solid waste collection rates were plotted against median household incomes for the route data (Fig. 1). Using the 65 data points representing three distinct geographical regions (north, midwest, and south), a best fit line was determined
by linear regression. The line clearly shows there is
an increase in per capita solid waste collection
with increasing income. The slope of the line is
0.054, which means the per capita collection rate
increases 0.054 lb (0.024 kg) for every $1,000 in­
crease in household income within the income
ranges documented.

The slope of the line is small, which is what
would be expected. Much solid waste which is col­
lected is from food and yard wastes, as well as
packaging of staple items. The waste collection
from these items should be relatively insensitive
to income. Also, the pounds of packaging per dollar
value for items tends to decrease for higher value
items. Thus, it is expected that the line in Fig. 1
would have a small slope. To insure that there is a
slope, a t-test was performed on these data to deter­
mine the degree of certainty that the slope is dif­
ferent than zero. For these data, t = 4.7. (A “t”
value of 3.5 indicates 99.9 percent certainty that
the slope is not zero, while higher “t” values indi­
cate an even greater degree of certainty.) Conse­
quently, it can be concluded that median income
is related to residential solid waste collection to a
significant degree.

One may question the use of a line through such
a wide scattering of points, rather than a band. The
ultimate purpose of this exercise dictates the use
of a line because a band could be misleading. If a
band were used, it would be possible to predict
with a certain degree of confidence the range of
per capita solid waste collection for a particular
median household income for a route. While this
may be important for some other purpose, what
is actually desired here is the ability to make that
same calculation for an entire city. The band
which could be developed for city averages would
probably be much narrower than the band for
each route. Routes are relatively small and may
have special characteristics which contribute to
the variation in per capita collection rates along
with income. The age, ethnic background, and
size of the yards of the people living on a par­
ticular route are three examples of such
characteristics.

In support of the above discussion, a figure was
developed using only a single data point for each
city (Fig. 1). When several routes from each city
are combined to give a single data point, the point will be close to the line if the scatter of points for individual routes is evenly distributed about the line. This is true for these three cities, as can be seen in Fig. 2. Note also that a single data point for St. Louis has been included on this figure.

In addition to the regression line developed for the 65 data points shown in Fig. 1, the best fit curve for the four data points representing the four different cities is included in Fig. 2. At first glance the two lines do not appear to differ significantly; however, the slopes differ by 25 percent. The "new" equation which represents city averages predicts that per capita residential solid waste collection will increase by 0.040 lb (0.018 kg) per day per $1,000 increase in median household income. This may be a better estimation than the 0.054 lb (0.024 kg) per $1,000, which is based upon the equation developed from individual routes. Although only four points have been used to develop this line, it should be realized that these points represent average collection rates for large heterogeneous populations. The correlation coefficient for this equation is $r = 0.94$, with a "t" value equal to 3.8.

Ideally, data points for several more cities could be developed and included along with the four points in Fig. 2. If several points were known, a band for cities could be developed which would be appropriate and useful as a predictor of residential solid waste collection based on median household income. With only four data points a band is not useful.

**POPULATION DENSITY**

The relationship between population density and per capita residential solid waste collection was examined to determine its potential value as a predictor of total waste collection. This relationship is illustrated in Fig. 3. While it does seem that per capita collection decreases with increased population density, this estimation technique appears to be less reliable than the technique which utilizes household income.

**COMMERCIAL SOLID WASTE COLLECTION**

The commercial solid waste which is collected in a given locality comes from four primary sources:
1. Retail Establishments
2. Wholesale Establishments
3. Services
4. Offices

In most instances the solid waste collected from retail establishments dominates that collected from the other three sources. For this reason, an attempt was made to relate commercial solid waste collection to retail dollar sales. This methodology would not be reasonable for small areas such as collection routes or neighborhoods. The presence of a single establishment, such as a high volume jewelry store which has high dollar sales but relatively little waste, could greatly distort estimations. However, if a large area with a diverse mixture of commercial establishments is treated collectively, this estimation technique is more appropriate.

In this analysis, commercial solid waste per $1,000 retail sales was calculated for the cities which have provided the necessary data. Retail dollar sales data are readily available for any city from the local Chamber of Commerce or from published state sales (tax collection) data. On the other hand, commercial solid waste collection is

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### FIG. 3. THE EFFECTS OF POPULATION DENSITY ON PER CAPITA SOLID WASTE COLLECTION QUANTITIES. CONVERSION FACTORS:

\[ \text{kg/PERSON/DAY} = \frac{2.205}{0.4536} \times \text{lb/PERSON/DAY}. \]

### TABLE 1 COMMERCIAL SOLID WASTE COLLECTION AND RETAIL DOLLAR SALES

<table>
<thead>
<tr>
<th>City or County</th>
<th>Total Retail Sales*</th>
<th>Total Commercial Solid Waste</th>
<th>Commercial Solid Waste Collection Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($1,000/year)</td>
<td>(10^3 lb/year)</td>
<td>(10^3 kg/year)</td>
</tr>
<tr>
<td>Lawrence, Kansas</td>
<td>201,222</td>
<td>16,984</td>
<td>7,702</td>
</tr>
<tr>
<td>Garland, Texas</td>
<td>474,491</td>
<td>42,263</td>
<td>19,167</td>
</tr>
<tr>
<td>Johnson County, Kansas</td>
<td>1,100,169</td>
<td>90,800</td>
<td>41,179</td>
</tr>
<tr>
<td>Total</td>
<td>1,775,882</td>
<td>150,047</td>
<td>68,048</td>
</tr>
</tbody>
</table>

*Values obtained from local Chambers of Commerce for each area for 1977. Conversion factor: 1 kg = 2.205 lb

Source: Franklin Associates, Ltd.
very difficult to estimate unless excellent records are kept by the solid waste disposal services of the city. Of the cities selected for study, only three had adequate records to determine commercial solid waste quantities. They are listed below.

1. Lawrence, Kansas
2. Garland, Texas
3. Johnson County, Kansas (suburban Kansas City)

The total retail dollar sales for each area, the total commercial solid waste, and the number of pounds per $1,000 retail sales are shown in Table 1. The commercial solid waste collection rates show excellent agreement for the three areas. The largest deviation from the mean is only about 5 percent, which indicates good potential in terms of predictive capabilities.

It is important to note that the cost of living in these three areas differs by less than one percent. This is an important factor with respect to the validity of the analysis.

**UTILIZATION OF ESTIMATION TECHNIQUE**

The end result of the analysis was the development of a provisional method for estimating residential solid waste collection by relating it to income data readily available from government documents; and also a provisional method for estimating commercial solid waste collection by relating it to readily available retail sales data. The estimation technique is applicable to any city or region for which definite boundaries have been established.

The total solid waste (in pounds per day) which could be collected for potential delivery to a resource recovery facility for any city can be calculated from the two equations below.

1. **Total Collectible Residential Waste Per Calendar Day in Pounds**

   \[ P \times \left(0.040I + 1.07\right) \]  

   where:  
   - \( P \) = Population of city  
   - \( I \) = Median household income for city in thousands of dollars per year  
   - 0.040 = Slope of regression line defined as pounds per person per day per $1,000

2. **Total Collectible Commercial Waste Per Calendar Day in Pounds**

   \[ R \times 0.085 \]  

   where:  
   - \( R \) = Average retail dollar sales in city per day

Conversion Factors:  
- 1 kg = 2.205 lb

To convert this to annual data multiply each by 365 (days/year). Of course seasonal variations are documented in a daily or annual average, but do not show what the seasonal effect is.

The value of using a waste estimation technique based upon local characteristics rather than national averages is illustrated by the following examples. The actual residential and commercial solid waste collection in three of the selected cities is compared to the predicted waste quantity for those cities based upon national average municipal solid waste generation rates in Table 2.

An average generation rate of 3.5 lb (1.6 kg) per person per day [10] was applied to the populations of each city to determine the total available waste. As can be seen, the actual collected waste differs considerably from the estimated quantities for each city. For Lawrence, the actual waste collected is 29.2 percent less than would be expected using national average generation rates. This is not surprising, since a significant fraction of the population is university students living in large multi-family dwellings. The disposable incomes for the students are relatively low, and there is little yard waste associated with multi-family homes. Thus, the national average per capita generation rate is not applicable to Lawrence, Kansas.

The actual waste quantities collected in Garland, Texas and the Golden Gate District of San Francisco are 15.0 and 75.6 percent higher, respectively, than would have been expected if estimated using national average generation rates. Again, the natures of these cities explain the discrepancies. Garland is a relatively affluent suburb of Dallas. Most homes are single family dwelling units with large, well kept lawns. The yard waste generated from such areas is considerably higher than average, which could reasonably account for the total difference. The
TABLE 2 A COMPARISON OF ACTUAL COLLECTED SOLID WASTE WITH ESTIMATED QUANTITIES CALCULATED USING NATIONAL AVERAGE GENERATION RATES

<table>
<thead>
<tr>
<th>City</th>
<th>Collected Solid Waste(^*) (tons per year)</th>
<th>Estimated Solid Waste(^\dagger) (tons per year)</th>
<th>Percent Difference from Estimates Calculated Using National Average Generation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lawrence, Kansas</td>
<td>24,200</td>
<td>34,200</td>
<td>-29.2</td>
</tr>
<tr>
<td>Garland, Texas</td>
<td>56,600</td>
<td>48,800</td>
<td>16.0</td>
</tr>
<tr>
<td>San Francisco, California(\dagger)</td>
<td>182,400</td>
<td>103,900</td>
<td>75.6</td>
</tr>
</tbody>
</table>

\(^*\) Includes residential and commercial solid waste only.
\(\dagger\) Residential and commercial solid waste was estimated using a national average generation rate of 3.5 lb (1.6 kg) per person per day \([10]\).

Golden Gate District of San Francisco is a highly developed commercial area with a significant population density as well. The breakdown of solid waste collection data from San Francisco is not adequate to distinguish residential from commercial waste; however, the ratio of the quantities of each type probably differs significantly from national averages. It is quite likely that there is an abnormally high quantity of commercial waste for the local population.

It is apparent from these three examples that national average generation rates may not be applicable to specific cities or regions due to local characteristics.

CONCLUSIONS

In our study, several possible indicators of processible solid waste collection were examined for suitability as planning aids in design of resource recovery installations. Although the data base was not extensive enough to allow this work to be definitive, some promising indicators were developed. Four tentative conclusions were reached as a result of the work done.

1. Land use zones are not reliably related to waste collection because of the large variability in pounds per day of collected waste in the same zone categories on different collection routes.
2. A weak inverse relationship was found between per capita solid waste collection and population density. However, the reliability was judged to be too low to be useful.
3. Median household income was found to be strongly correlated with residential solid waste collection. A straight line relationship was found, showing an increase of approximately 0.04-0.05 lb (0.018-0.024 kg) per person per day associated with a $1,000 increase in median household income. A predictive equation was derived.
4. For areas with diverse mixtures of commercial establishments, retail dollar sales appears to be a good predictor of collectible commercial solid waste.

STUDY LIMITATIONS AND ADDITIONAL RESEARCH

This study performed for the Department of Energy was limited in scope and was not intended to be a definitive work. Rather, its purpose was to show the feasibility of developing predictive procedures which are more accurate than those now in use but simple enough to apply and sufficiently general in application so as to be useful. In that regard, the study has shown that predictive factors of that nature can be developed, and provisional relationships have been shown. However, some additional research should be performed to provide refinement of numerical factors and more secure validation of the procedures. This could be accomplished by obtaining similar data for additional cities, preferably in different geographical areas.

An expansion of this study would attempt to account for seasonal fluctuations in the “average” collection rates developed in this study. Such fluctuations are known to be quite large and very significant with regard to resource recovery operations.

In addition, the waste generated from office buildings and other nonretail establishments needs further investigation. Although this waste is accounted for in the commercial collection factor, an abnormally high concentration of nonretail
businesses could distort this procedure, which is based on retail dollar sales.

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The authors also wish to acknowledge John W. Mitchell and Robert G. Hunt, both of Franklin Associates, Ltd., for their significant contributions to the original study performed for the Department of Energy.

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[5] City Sanitation Department, Lawrence, Kansas.
[9] Department of Streets, Refuse Division, St. Louis, Missouri.

Key Words

Collection
Facility
Mathematical Model
Planning
Refuse
Size
Weight