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A Solid Waste Economic Planning Model for Nonmetro Counties: An Ohio Simulation Analysis

MICHAEL L. McCULLOUGH

FRED J. HITZHUSEN

OHIO AGRICULTURAL RESEARCH AND DEVELOPMENT CENTER
Wooster, Ohio

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A Solid Waste Economic Planning Model for Nonmetro Counties: An Ohio Simulation Analysis

MICHAEL L. McCULLOUGH and FRED J. HITZHUSEN[1]

INTRODUCTION

This research develops an economic planning model designed to compare solid waste management alternatives in nonmetropolitan counties. All phases of solid waste management—collection, storage, transportation, disposal, and recovery—have been included in the model, with primary emphasis on rural collection alternatives. The model is designed to facilitate solid waste planning efforts at the county or multi-county level on questions regarding the optimum number and size of sanitary landfills, economic feasibility of resource recovery, and least-cost rural collection alternative(s).

BACKGROUND AND PROBLEM

Solid waste management in nonmetro areas was relatively simple prior to the 1970's. Most townships operated their own "dump," conveniently located for residents. Other disposal alternatives commonly used included disposal on one's own property by burying, burning, or finding a convenient ravine along a highway (10). Transportation and disposal costs were minimal.

In the 1960's, the realization came that solid waste management practices needed improvement. It was discovered that solid waste disposal sites were contributing to both surface and ground water pollution and to air pollution. There have been a substantial number of cases associating water supply contamination with disposal sites (6). These disposal sites were also potential health hazards because they provided excellent breeding grounds for disease-carrying vectors such as insects and rodents. Health and environmental issues plus aesthetic considerations led to legislation for solid waste management.

The Solid Waste Disposal and Anti-Stream Dumping Laws in 1967 and the implementation of Ohio Environmental Protection Agency (OEPA) open burning standards resulted in the closing of more than 1,300 rural township open dumps and the establishment of "sanitary" landfills in most Ohio counties (13). The OEPA has established strict regulations for the licensing and operating of a sanitary landfill. These licensing and operating procedures were formulated to deal with the environmental, health, and aethetic concerns expressed above.

In 1976, the Resource Conservation and Recovery Act (RCRA) was passed by Congress. RCRA imposes further environmental restrictions on the licensing and operation of sanitary landfills. As its title implies, RCRA stresses resource recovery, and its implementation will probably improve the economic advantage of solid waste resource recovery vs. landfilling.

The results of government regulation and enforcement have led to a reduction in the number of operating landfills. The average solid waste hauling distance in a particular county has increased and the owning and operating cost of the disposal site has increased. The direct monetary costs of solid waste management have increased due to the government regulation. Nonmonetary costs and indirect monetary costs, such as aesthetics and environmental pollution, have been reduced in many cases, but roadside littering and dumping, especially in rural areas, have remained a problem in some counties. Legal solid waste management practices have become less attractive due to increasing costs.

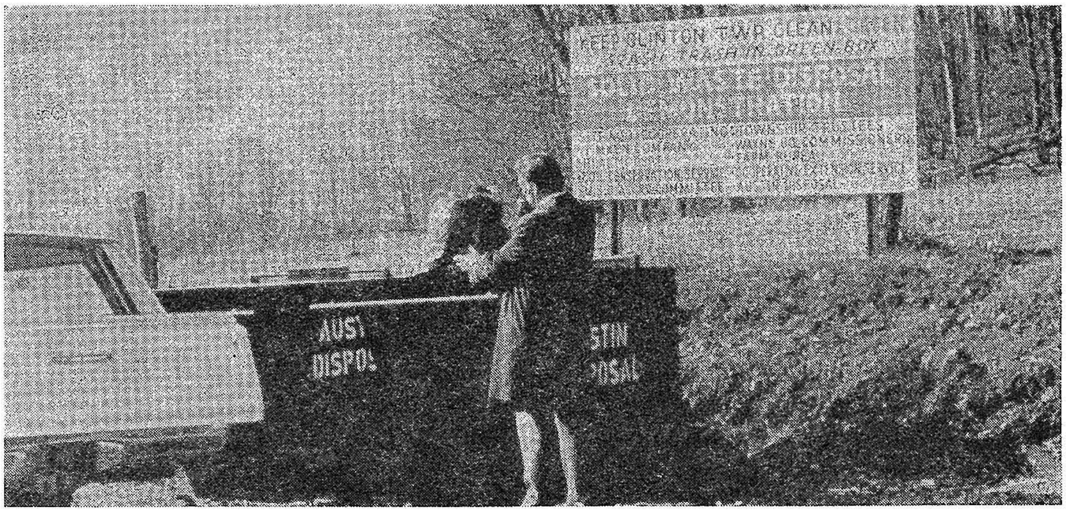
The importance of solid waste planning in nonmetro areas has grown for several reasons. Generally, the disposal (or recovery) cost per ton for sanitary landfills (or resource recovery facilities) is inversely proportional to the size of the facility in tons per day. As the quantity of waste handled at a particular facility is increased, the disposal (or recovery) cost per ton decreases (12). Consequently, there is an economic trade-off between transportation costs and disposal (or recovery) costs. Fewer disposal (or recovery) facilities will mean higher transportation costs but lower disposal (or recovery) costs. In order to capture economics of scale, the solid waste management plans in both rural and urban areas should be integrated.

Solid waste management in rural areas must address the problem of roadside dumping and littering. In 1973, 42% of the United States rural population and only 3% of the urban population had no household collection by either public or private sources (10). Providing a means of collection for all rural residents is one method which has reduced roadside dumping and littering.[2]

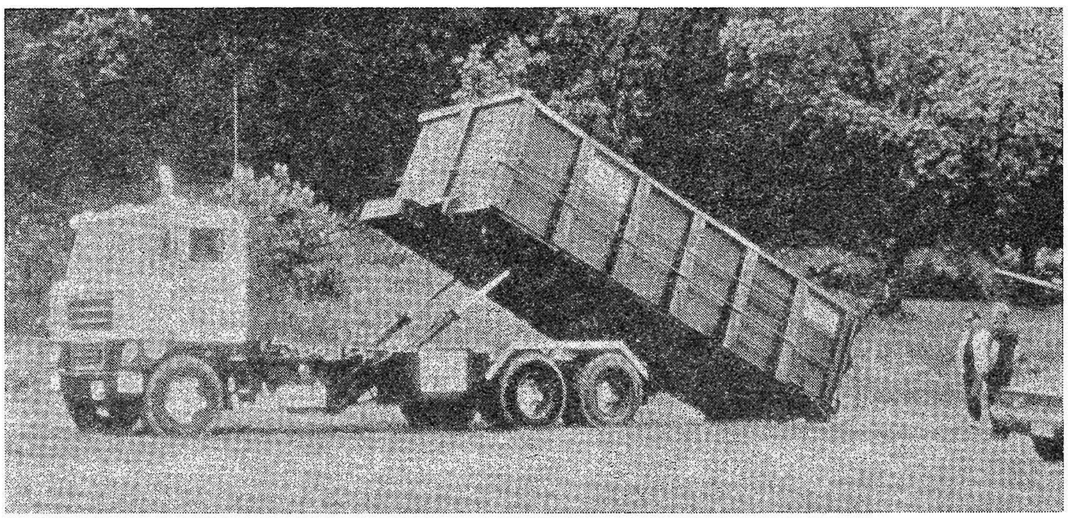
[1]Graduate Research Associate and Associate Professor, Dept. of Agricultural Economics and Rural Sociology, The Ohio State University and Ohio Agricultural Research and Development Center.

[2]There are other potential methods of reducing roadside dumping and littering, including stricter enforcement and fines for littering, reducing the number of throwaway containers, "bottle bills," and education. Enforcement and fines have shown little promise of reducing littering. Reducing the number of throwaway containers, "bottle bills," and education all may help reduce the problem over time, but they will not eliminate it.

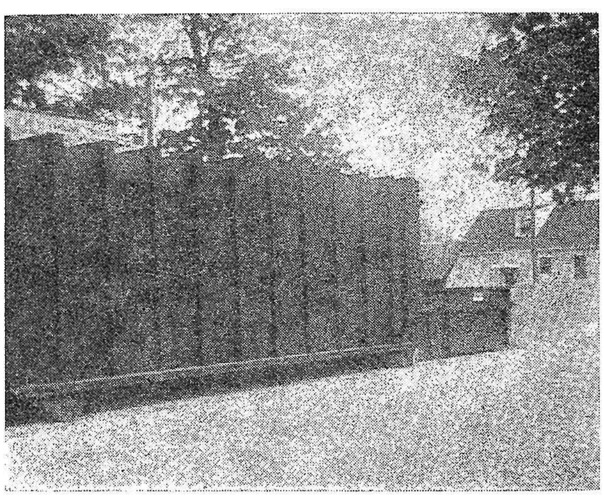
FIG. 1.—Three rural collection systems in Ohio.



Green Box Pilot Project, Clinton Township, Wayne County.



Large (30 cu. yd.) drop box and truck in Union Township, Knox County.



Compaction box (42 cu. yd.) and stationary compactor in Baughman Township, Wayne County.

Four alternative rural collection systems, all of which have been used in Ohio (13), include: 1) mailbox pickup; 2) "green" box system; 3) large, open-top box system, and 4) the compaction box system. The mailbox system requires that rural residents place their solid waste at the mailbox on designated days. A rear-loading packer truck (rear-loader) then picks up the waste. The green box system requires the rural residents to bring their waste to a central location where the boxes are located. In this analysis, the green boxes are 8 cubic yards in capacity; when full, they are emptied into a front-loading packer truck (front-loader). The large, open-top box (40 cubic yard capacity) and the compaction box (42 cubic yard capacity), when full, are hoisted onto a tilt-frame which is attached to a truck chassis. The box and its contents are hauled to a disposal, transfer, or recovery point and the solid waste is discharged. The compaction box system requires a stationary, hydraulic compactor at each box site to achieve the desired 4 to 1 compaction within the box. Figure 1 shows the green box, open-top, and compaction box systems.

A major reason for the increase in importance of nonmetro solid waste planning is the increase in collection and disposal costs. The funds required to implement a solid waste plan are generally substantial. Solid waste programs must compete with many other services for scarce resources. Consequently, it is important that the most economical solid waste management plan be determined.

The basic problem is being able to analyze nonmetro solid waste alternatives, using a single model. The analysis of alternative rural collection systems, the urban area transportation alternatives, and the disposal (or recovery) options needs to be done on an economic basis so that a single least-cost plan can be determined for one or more nonmetro counties

OBJECTIVES

The overall objective of this research is to develop a nonmetro solid waste management planning model. The model includes collection, storage, and transportation of rural waste, transportation of urban waste, and disposal (or recovery) of waste. The three basic objectives of the research are: 1) to develop a general conceptual model and unit cost estimates for each subset (collection, transport, disposal, and/or recovery) of the model; 2) to develop a descriptive composite of pertinent nonmetro county data which will determine the most dominant solid waste scenarios in nonmetro Ohio and a range of values for waste generation and distance; and 3) to simulate and compare the dominant nonmetropolitan solid waste scenarios, using the model developed in objective 1 and using the range of values for waste generation and distance developed in objective 2.

GENERAL METHODOLOGY

The Conceptual Model

The county has been chosen as the unit of analysis for the solid waste planning model. Using the nonmetro county as the unit of analysis allows a run or solution of the model to include both urban and rural areas. Selection of the county as the unit of analysis is also consistent with any attempts to implement the model Most rural collection systems have been instituted on a countywide basis. In addition, the disposal (or recovery) phase of solid waste management is generally associated with economies of scale if the service area is at least as large as the county.

The planning model includes only those subsets and alternatives for solid waste management which previous experience and research have shown potentially feasible for nonmetro counties (3, 4, 13, 14, 16, 19) The subsets included in the model are· 1) collection, transportation, and storage of rural waste, 2) transportation of urban waste; and 3) disposal (or recovery) of waste Figure 2 shows the individual subsets and alternative systems within the model.

Subset 1, or rural collection alternatives, is included in the model in order to provide rural residents with a cost estimate of an alternative to roadside littering and dumping, or private transfer of waste to the transfer, disposal, or recovery site. Rural collection is not a widespread phenomenon in Ohio or elsewhere, and has not been analyzed economically. Given that roadside littering and dumping are illegal, it becomes necessary to evaluate the cost of possible alternatives to the private transfer of waste. The four alternatives were included because they are systems which have been used It was hypothesized that each of these systems might be relatively more economical given certain values of throughput, distance, and volumes of large, bulk goods. The open-top box system was expected to be most economical in situations involving short hauling distances and high volumes of bulk goods. The green box and the compaction box systems were expected to be most economical in situations involving low and high throughputs, respectively, and relatively long haul distances, due primarily to the approximate 4 to 1 compaction ratios. Mailbox pickup was expected to be the most economical system in counties with relatively dense rural populations when private time and travel costs were considered.

Landfilling and resource recovery, or subset 3, are alternatives to littering, burning, burying, etc. of solid waste in nonmetro areas. More stringent en-

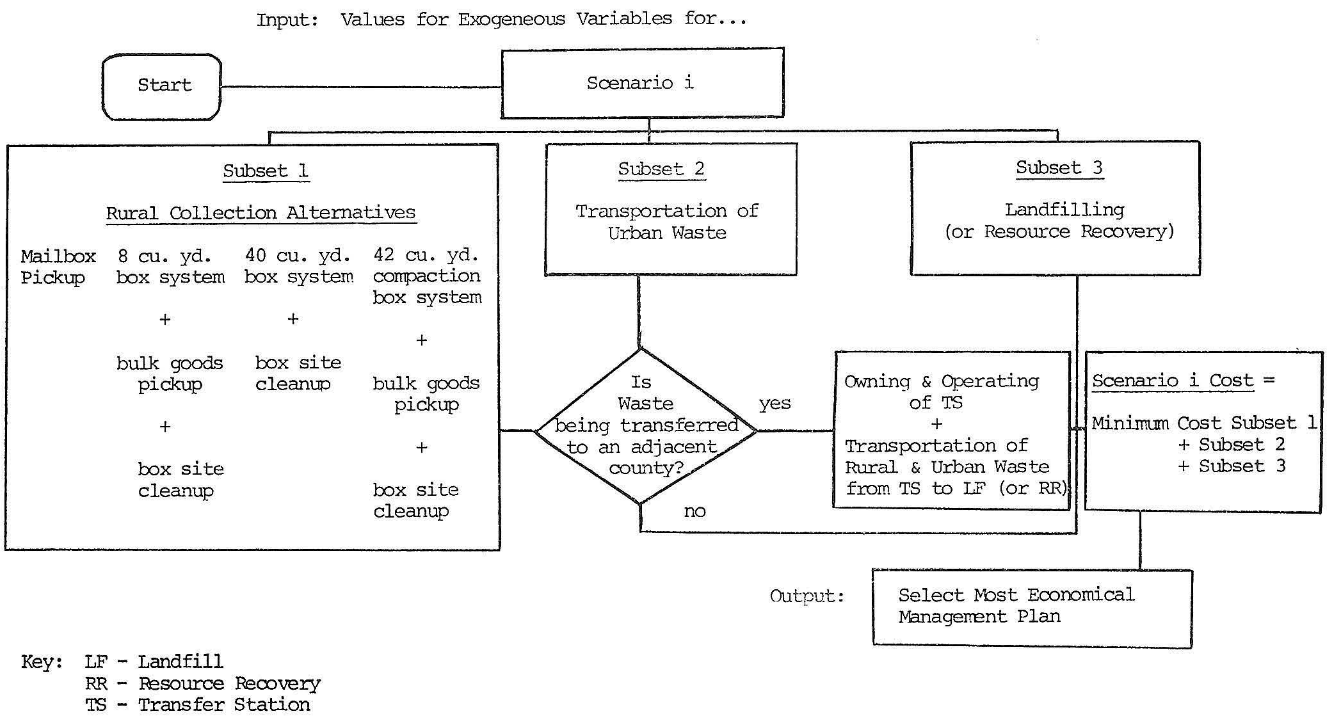


FIG. 2.—Flow diagram of the economic planning model.

vironmental legislation and laws such as RCRA which promote and enhance the relative feasibility of resource recovery have necessitated the economic analysis of both landfilling and resource recovery alternatives, even in nonmetro areas.

The transportation of urban waste, subset 2, is closely tied with the feasibility of a solid waste transfer station in situations where the waste is being transferred long distances. The feasibility of the transfer station was expected to be primarily dependent upon the waste generation and spatial orientations of urban areas. In order to reduce transportation costs as much as possible, the transfer station needs to be considered in alternatives involving relatively long hauling distances. Figure 3 shows the exterior of a transfer station.

Determination of the most economical alternative for a particular subset is dependent upon the specification of the other two subsets. Selection of a landfill location determines the distance of haul for

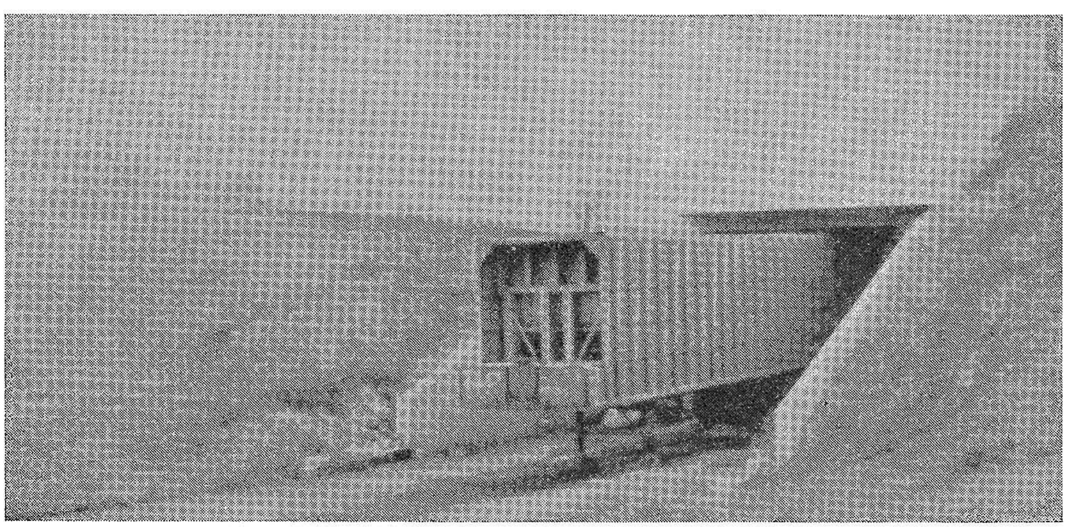


FIG. 3.—Transfer station and compactor trailer in Van Wert County.

both the urban and rural waste subsets and will affect the determination of the most economical rural collection system. The disposal (or recovery) cost per ton is determined in part by the amount of waste delivered to that facility by the rural and urban subsets. The rural and urban haulers will rationally transfer their waste to the alternative which will result in the lowest total transportation and disposal cost for them. Because of the economies of scale in land filling and resource recovery, the total transportation and disposal (or recovery) cost for an urban area will depend upon the waste generation and the most economical alternative selected for the rural subset and vice versa. These interdependencies make it necessary to analyze all three subsets simultaneously or at least recursively in a single model in order to determine the most economical management plan for the county as a whole.[8]

Operationalizing the Model

The model used is simplistic in design, as is the procedure used to operationalize the model. The limited number of subsets or activities, the emphasis of the model as a local planning tool, and the use of known technologies suggest a general simulation procedure. In this context, simulation is defined as the running of many experiments using some model, while changing the values of variables in the model for different runs or experiments.

Information on each subset is inputted into the model. Given a landfill (or resource recovery) location, average distances of haul, waste generation or throughput, and all unit cost estimates, it is possible to determine the cost of each subset. The costs of subsets 1 and 2 are both calculated by assuming certain time and capacity constraints. The cost of subset 1 is determined from an iterative computer program which selects the minimum cost rural collection system, and determines the service pickups per week, the number of collection vehicles, and the number of boxes. Appendix A describes the development and characteristics of this computer program. The cost of subset 3 is calculated by using total waste generation or throughput in subsets 1 and 2 to determine the unit disposal (or recovery) cost. The total disposal (or recovery) cost can then be calculated.

The Scenario i cost, as shown in Figure 2, is the minimum cost alternative of subset 1 plus the costs of subsets 2 and 3. The interdependencies of the subsets, described in the previous section, are addressed in this simulation procedure by recursively considering different combinations of alternatives for each subset. Different values for the exogeneous variables of distance and throughput are inputted into the model to describe and calculate the costs of other alternatives. If the waste is transferred to an adjacent county, the owning and operating cost of a solid waste transfer station is included in the cost for that alternative. The simulation procedure is repeated to determine the Scenario i cost for all alternatives being considered, and the Most Economical Management Plan (MEMP) is selected. A generalized form of the Scenario i cost is shown by the following equation:

$$\text{Scenario i cost} = \text{ARCSC} + \text{ATUWC} + \text{AOOCTS} + \text{ALFRRC} \qquad (1)$$

where:

ARCSC = annual rural collection system cost
ATUWC = annual transportation of urban waste cost
AOOCTS = annual owning and operating cost for a transfer station
ALFRRC = annual landfilling or resource recovery cost

Method of Analysis

This analysis uses budgeting to compare alternatives within the model subsets. Budgeting is a straightforward method of analysis which presents the community or county with an annual cost estimate for solid waste services. All costs are converted to annual costs in 1978 dollars to make the comparisons. Each cost component—motor vehicles, labor, equipment, buildings, land, fuel, tires, and maintenance—has been classified into one of three cost categories. This was done to illustrate the proportions of total cost in each category and also to facilitate later sensitivity analysis. For example, fuel costs tend to change much more than taxes and insurance rates over time. Categorizing the costs allows the model to more easily test the significance of relatively unstable costs.

The cost categories as defined by King and Wall are fixed overhead costs, fixed operating costs, constant unit operating costs, and variable operating costs (15). Fixed overhead costs are a function of size and can be eliminated only through the sale of the project. Fixed operating costs are those which are independent of the number of units produced. They are a function of the size of the project and length of operating period, but can be eliminated if the project is shut down. Constant unit operating costs include all items which vary directly with the number of units produced. Variable operating costs include all other costs that arise only when the plant is operating and that are influenced by the volume of output (15).

[8]Other management considerations are important in nonmetro counties, especially urban areas. The type of collection service provided in an urban area (curb, back yard, or alley) implies much different collection costs, but is essentially independent of other nonmetro solid waste management considerations. As a result, it is not included in this model.

Some costs such as annual amortization cost are clearly fixed overhead costs. Most costs do not seem to fit exclusively into one category. Costs which did not clearly fit into one category were classified in the category most closely approximating the nature of that cost. Classification of all costs resulted in only three categories: fixed overhead, fixed operating, and constant unit operating costs.

The fixed overhead cost is the annual amortization cost. All principal and interest payments for a capital item are amortized over the expected useful life of the investment.[4] The primary interest rate used in this study is 9%. Fixed operating cost is composed of labor, certain maintenance costs, base utility costs, insurance, taxes, and licenses.

Constant unit operating costs are composed of fuel, tires, oil, preventive maintenance, and equipment repair. For motor vehicles, constant unit operating costs can be expressed in cost/mile or cost/hour. The preference in expressing constant unit operating costs should be based upon the general operating pattern of the vehicle and the expression which can most closely approximate the actual costs. For the collection vehicles, landfill equipment and the front-end loader used in the transfer station, cost/hour is the more appropriate measurement because the number of miles traveled is not as critical as the amount of time the machine is operating. For the transfer trailer associated with the transfer station and the truck used for bulk goods pickup, the number of miles traveled (cost/mile) is a good measure of the cost of operation.

Rural Collection Subset

In this analysis, it is assumed that all rural residents are evenly distributed throughout the county. The box systems are analyzed assuming there is one box site per township. This allows all rural residents to be within approximately 3 miles of a box site. The number of boxes required per site is dependent upon waste generation, the weekday vs. weekend variation in the inflow of waste at the box site, and the frequency of pickup. The time required to service the study area must be determined for each alternative rural system. The estimated time required, or the total vehicle hours of operation, is dependent upon the waste generation, spatial orientation of waste generation source points and distance characteristics of the service area, and upon the individual time and capacity characteristics of the alternative collection systems. The annual vehicle hours of operation are determined by multiplying the cycle time/load by the total number of loads required to service the county each year. The cycle time/load is determined by the following equation:

$$CTPLD_s = TLD_s + TUNLD_s + TBWNBS_s + WD_t \cdot 2/ASPMPH \quad (2)$$

where:

- CTPLD = cycle time per load
- TLD = the time required to load waste into the vehicle
- TUNLD = the time at the transfer, disposal, or recovery site
- TBWNBS = the time traveling between box sites (or households)
- WD = the average weighted distance from box sites (or households) to transfer, disposal, or resource recovery site[5]
- ASPMPH = average speed in miles per hour from last pickup to transfer, disposal, or recovery site
- $_s$ = the alternative collection system—mailbox, green box, open-top box, compaction box, or bulk goods pickup system
- $_t$ = the type of waste—rural, urban residential, commercial, or industrial

Equation 3 shows the determination of annual vehicle hours required to service the study area:

$$ANSYHR_s = CTPLD_s \times NUMLDS_s \quad (3)$$

where:

- $ANSYHR_s$ = the annual system hours required to service the study area
- $NUMLDS_s$ = the annual number of loads required to service the study area

All comparisons (except where indicated) of rural collection systems assume that the rural system is privately operated. It is assumed that the private hauler can fully utilize his packer trucks by servicing accounts in urban areas or in neighboring counties. Therefore, the annual fixed cost which is attributable to the rural collection system for a packer truck is determined by multiplying the packer truck total annual fixed cost by the ratio of the annual vehicle hours available. The following equation shows the calculation of the annual owning and operating costs of the alternative collection vehicles:

$$ANCVC_s = (ANSYHR_s/ANHRAV) \cdot (FXOVCV_s + FXOPCV_s) + ANSYHR_s \cdot CUOCV_s \quad (4)$$

where:

- ANCVC = the annual owning and operating collection vehicle cost
- ANHRAV = the annual hours available for use per vehicle
- FXOVCV = the annual fixed overhead for the collection vehicle

[4] Land, engineering investigations, planning costs, etc. are amortized over the expected life of the project. For example, these items would be amortized over a 20-year period for a transfer station.

[5] The concept of weighted distance, which controls for variation in waste generation by source point and spatial orientation of source points, is more fully explained in the section on County Data Collection.

FXOPCV = the annual fixed operating cost for the collection vehicle

CUOCV = the constant unit operating costs per hour

Figure 2 shows that the costs for the green box, compaction box, and mailbox systems include bulk goods pickup. Large items such as refrigerators, stoves, furniture, etc. must be picked up with another vehicle. Determination of the cost for bulk goods pickup is very similar to the procedure used for the collection vehicle cost. First of all, the cycle time per load is calculated using equation 2 and this is multiplied by the total annual number of loads required to service the county (equation 3). The annual number of miles traveled is determined by multiplying the miles traveled per load by the annual number of loads. The total annual costs for bulk goods pickup can be expressed by the following:

$$ANCTBP = (ANSYHR_s/ANHRAV) \cdot (FXOVBP + FXOPBP) + ANMLBP \cdot CUOCV_s \quad (5)$$

where:

ANCTBP = the annual costs for bulk goods pickup

FXOVBP = the annual fixed overhead costs for a bulk goods pickup vehicle

FXOPBP = the annual fixed operating costs for a bulk goods pickup vehicle

ANMLBP = the annual miles required for bulk goods pickup

The cost of each alternative rural box system includes the cost of cleanup around the boxes at each box site. The compaction box system includes a labor cost for operating each stationary compactor unit. Unit costs for each rural collection system are shown in Appendix B and have been determined from conversations with private haulers, manufacturers, and previous research (3, 11, 19, 22, 23). The total annual cost, including all vehicle owning and operating costs, labor, rural system boxes, rural box system sites, and stationary compactors, is represented in the following expression:

$$ARCSC_s = ANCVC_s + NUMBX_s (FXOVBX_s + CUOBX_s + FXOVSC_s + CUOSC_s) + NUMBS_s (FXOVBS_s + FXOPBS_s) + ANCTBP_s + ANCLUP_s \quad (6)$$

where:

NUMBX = the number of rural system boxes required

FXOVBX = the annual fixed overhead cost per box

CUOBX = the annual constant unit operating cost per box

FXOVSC = the annual fixed overhead cost per stationary compactor

CUOSC = the annual constant unit operating cost per stationary compactor

$NUMBS_s$ = the number of rural system box sites

FXOVBS = the annual fixed overhead cost per box site

FXOPBS = the annual fixed operating cost per box site

ANCLUP = the annual cleanup costs around the box sites

Some of the terms of the equation would have a value of zero for particular rural systems. The annual owning and operating cost of the collection vehicles ($ANCVC_s$) would be the only cost component of the mailbox system. All terms in the equation would have a positive value in reference to the compaction box system.

Because they provide different levels of service, comparison of mailbox pickup with the alternative box systems must include the private cost of taking the waste to the box site. First, the travel costs and the hours required for the rural residents to haul their waste to a box site are estimated. The difference between the cost of mailbox pickup and the cost of the sum of the most economical box system and associated private costs is divided by the hours required for traveling to the box sites. This quotient is the break-even hourly labor rate for rural residents. The following equation illustrates this procedure:

$$BEHRLR = (ARCSC_1 - (ARCSC_{2,3,4} + TATCBS)) / (NUMTBS \cdot (2 \cdot DSTBS/AVSPBS + TLDUN)) \quad (7)$$

where:

BEHRLR = the break-even hourly labor rate

$ARCSC_1$ = the annual rural system collection cost for mailbox pickup

$ARCSC_{2,3,4}$ = the minimum annual cost rural "box" system alternative cost—green box, open-top, or compaction box system

TATCBS = total annual private travel costs for all rural households to take their solid waste to a box site

NUMTBS = annual number of trips to the box sites for all rural households

DSTBS = the average distance from each rural household to a box site in miles

AVSPBS = the average speed traveled to a box site in miles per hour

TLDUN = the time loading waste into a vehicle and unloading at the box site

If the residents' opportunity costs are equal to the break-even hourly rate, they would be indifferent between mailbox pickup and the most economical box system. If the rural residents' opportunity costs are higher than the break-even hourly rate, mailbox pickup would be the most economical alternative.

The rural collection alternatives are also analyzed assuming that the system is publicly operated. This variation assumes that vehicles used in the rural system will not be used in any urban area or in any other county. The entire annual fixed cost of the vehicle is charged to the rural system regardless of the hours of use. Based on a study in Utah which is consistent with a national study by Columbia University, it is also assumed that the efficiency of the publicly operated system is 14% less than that of the privately operated system (17, 18). The publicly operated systems are analyzed at a 5% interest rate since government entities are often able to secure money at less than the opportunity cost of capital in the private sector.

Transportation of Urban Waste Subset

The transfer mode for each type urban waste—residential, commercial, and industrial—must be defined in order to determine transportation costs. Private haulers in Columbus, Ohio, have indicated that the size of urban area is a fairly good indication of the amount of waste hauled by different modes. At one extreme, small urban areas, it is assumed that all urban waste is hauled by rear-loaders. As the size of the urban area increases, the amount of waste hauled by front-loaders and the compaction box would be expected to increase. These proportions would increase until approximately 80% of residential waste is hauled by rear-loaders, 20% of residential and 50% of commercial waste is hauled by front-loaders, and the compaction box hauls 50% of the commercial and 100% of the industrial waste.[6]

The cost of the transportation of urban waste is determined very similarly to the determination of rural collection costs. The cycle time per load is calculated as in equation 2, except the value for TBWNBS (time traveling between box sites) is zero in these circumstances. The annual system hours required and the annual owning and operating collection vehicle costs are calculated using equations 3 and 4, respectively, for each type of waste (t) found in the urban area (residential, commercial, and industrial waste). Transportation costs for each type of urban waste are added to determine the annual total urban waste transportation costs (ATUWC).

In scenarios involving transfer to an adjacent county, transfer stations are considered as a possible alternative. It has been assumed that all waste in the county is brought to the transfer station before being transferred to an adjacent county. Four alternative transfer station sizes have been designed in this study. The costs which are shown in Appendix C, *i.e.,* the building, excavation, engineering, labor, transfer trailer and tractor, and all operating costs, are based on manufacturers' estimates (1) and previous research by Poling (19). Equation 8 shows the components of the transfer station costs.

$$AOOCTS = FXOVTS + FXOPTS + TAWGTS \cdot CUOTST + NUMTT\,(FXOVTT + FXOPTT) + NUMTR\,(FXOVTR + FXOPTR) + NUMLDS \cdot 2 \cdot DLFRR \cdot CUOTTR \qquad (8)$$

where:

AOOCTS = the annual owning and operating cost for a transfer station alternative
FXOVTS = the annual fixed overhead costs for the transfer station
FXOPTS = the annual fixed operating costs for a transfer station
TAWGTS = the total annual waste generation throughput at the transfer station, in tons
CUOTST = the constant unit operating costs per ton for the transfer station
NUMTT = the number of transfer trailers
FXOVTT = the annual fixed overhead cost for a transfer trailer
FXOPTT = the annual fixed operating cost for a transfer trailer
NUMTR = the number of transfer tractors
FXOVTR = the annual fixed overhead cost for a transfer tractor
FXOPTR = the annual fixed operating cost for a transfer tractor
NUMLDS = the total annual number of transfer trailer loads hauled from the transfer station
DLFRR = the distance from the transfer station to the landfill or resource recovery facility
CUOTTR = the constant unit operating costs per mile for the transfer tractor and trailer

Disposal and Recovery Subset

Cost estimates for sanitary landfilling are usually extremely variable and subject to local conditions. Landfilling costs for this study have been budgeted using a methodology similar to that of Clayton (5). Variables which were *a priori* expected to cause variation in landfilling costs and were controlled in this budgeting methodology include the type of landfill operation (*e.g.,* trench, area, trench-area), distance to cover material, depth of the landfill, land cost, and the size of the landfill operation. The size of the landfill operation is the only variable which could be identified as causing substantial variation in the landfilling cost per ton. Appendix D shows the estimated landfilling costs per ton.

Resource recovery is a very broad category which can include recycling, composting, methane

[6]In the analysis, these percentages are used when referring to "urban waste is transported by three modes." These estimates were obtained from conversations with private haulers.

recovery from landfills, or energy recovery from combustion of garbage. Most of these systems have not been analyzed on an economic basis and, as a result, very limited data exist in some cases. Materials and energy recovery of solid waste through boiler combustion has been economically examined in studies by Clayton (4), Luttner (16). and Hitzhusen (14) and is used in this study. Resource recovery costs in this study are based on the experience in Ames, Iowa, and reflect the cost of converting an existing steam-electric power plant so that solid waste can be used as a fuel supplement to coal. As shown in Appendix D, resource recovery facilities show considerable economies of scale. The following expression has been used to determine the annual landfilling or recovery costs:

$$ALFRRC = TCWG \cdot LFRRCT \quad (9)$$

where:

ALFRRC = the annual landfilling or resource recovery cost

TCWG = the total county annual waste generation

LFRRCT = the landfilling or resource recovery cost per ton

County Data Collection

Secondary data were collected for the 75 Ohio nonmetro counties in order to provide information for the simulation procedure.[7] The secondary data are used to describe the range in costs for the subsets of the model and to determine the most dominant solid waste scenarios in nonmetro counties. Determination of the most dominant scenarios is done to facilitate comparison of alternatives and to simulate actual situations found in Ohio nonmetro counties.

After examining the secondary data, the most distinguishing characteristics found among counties involved the number of landfills. The determination of the most dominant solid waste scenarios is therefore based upon the number of operating landfills within a county and the site suitability for landfilling. According to 1978 Ohio EPA data, approximately one-half of the nonmetro counties in Ohio have one landfill or no landfills. The remaining counties all have two or more operating landfills. Based on Ohio EPA reports, several counties, especially in northwestern Ohio, have very poor hydrogeologic characteristics for landfilling which indicates a need for alternatives to landfilling in the counties. The most dominant solid waste scenarios in nonmetropolitan Ohio are defined as: 1) a county with two landfills (*Scenario 2* LF), 2) a county with a single landfill or resource recovery facility (*Scenario S* LF or RR), and 3) a county transferring its waste to an adjacent county (multi-county) landfill or resource recovery facility (*Scenario M* LF or RR). The resource recovery alternative is more feasible in counties which have limited landfilling site suitability.

Each solid waste scenario is further described by variations in waste generation and weighted distance. The range and frequency distribution for each subdivision of total waste generation (rural, urban residential, commercial, and industrial) was determined by estimating these waste generation amounts for each nonmetro Ohio county. Figure 4 shows the frequency distribution of nonmetro Ohio counties for total county waste generation. (See Appendix E for description of the waste generation methodology used in this study.)

The concept of weighted distances is used in this study instead of individual distances from each waste generation source point to a transfer, disposal, or recovery site. Within the study area or county, the distance from each waste generation source point to a transfer, disposal, or recovery site is "weighted" by the solid waste generated at that particular source point. The result is a single, average, weighted distance for rural and urban solid waste for the nonmetro county as a whole. This is expressed as follows:

$$WD_t = \frac{\sum_{i=1}^{n} WG_{it} \cdot D_{it}}{TCWG_t} \quad (10)$$

where:

WD_t = the weighted distance for type of waste t

WG_{it} = waste generation (in tons) at source point i for type of waste t

D_{it} = distance from source point i to transfer, disposal, or recovery site for type of waste t

TCWG = total county waste generation for type of waste t

n = the number of source points

The use of weighted distance facilitates simulating a range of distances and spatial orientations of waste generation source points by changing a single number.

Alternative weighted distances were determined by selecting five Ohio counties which represent variations in waste generation, physical size, and spatial distribution of waste generation source points. Weighted distances to various locations within each county and to adjacent counties were calculated for these five counties to determine a range. The counties selected include Wayne, Guernsey, Auglaize, Gallia, and Morrow. Recent preliminary case study type analyses

[7]In this study, the nonmetro county is defined as any county with total population less than 150,000 people. Examination of counties in Ohio indicated that counties with populations less than 150,000 exhibited both rural and urban areas. Counties with populations more than 150,000 seem to be primarily urban oriented.

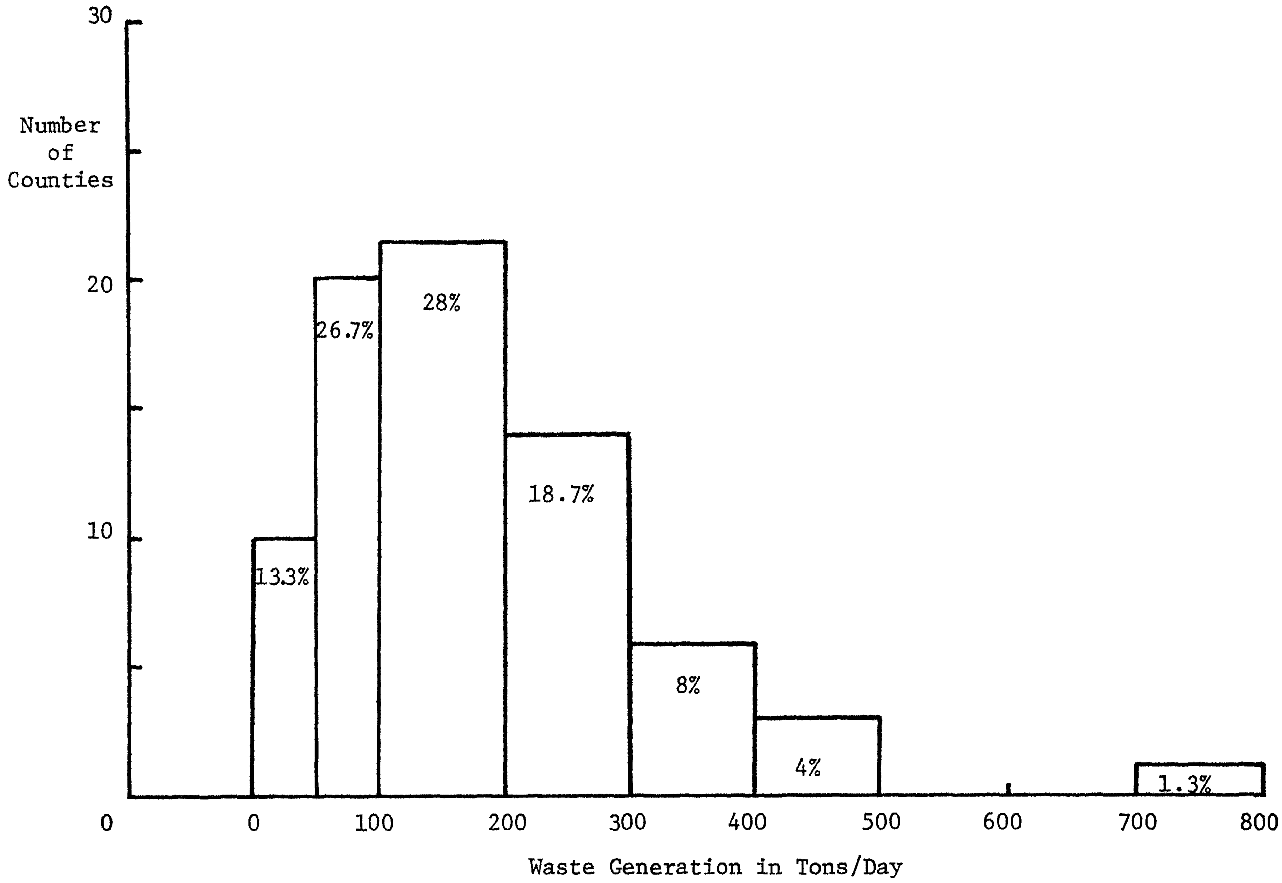


FIG. 4.—Frequency distribution of total waste generation for nonmetro Ohio counties.

have also been conducted in three nonmetro Ohio counties (Fulton, Vinton, and Wayne) to further test some of the model assumptions and parameter estimates.

ANALYSIS OF THE SCENARIO COMPARISONS

In the previous section, the most dominant solid waste scenarios in nonmetropolitan Ohio were defined as: 1) a county with two landfills, *Scenario 2* LF (the "2" referring to the number of landfills in the county and "LF" referring to landfilling or the method of disposal); 2) a county with a single landfill, *Scenario S* LF, or resource recovery facility, *Scenario S* RR (the "S" referring to a single landfill in the county and "RR" resource recovery); and 3) a county transferring its waste to an adjacent county landfill, *Scenario M* LF, or resource recovery facility, *Scenario M* RR (the "M" indicating that waste is being transferred to an adjacent county, or a multi-county system).

The combination of economic comparisons made in this simulation analysis has been determined from the scenarios defined above and the ability to deduce the relative economic feasibility of one scenario by knowing the costs of two others. For example, given the assumptions made in this research, if *Scenario 2* LF is more economical than *Scenario S* LF, *Scenario 2* LF must also be more economical than *Scenario M* LF. The economic comparisons simulated in the following analysis are:

1) *Scenario 2* LF vs. *Scenario S* LF
2) *Scenario S* LF vs. *Scenario M* LF
3) *Scenario S* LF vs. *Scenario M* RR
4) *Scenario M* LF vs. *Scenario S* RR

Data describing these scenarios are input into the model as shown in Figure 2 and the minimum cost scenario is selected. Comparison of alternatives within each scenario is possible by allowing key factors such as throughput and average weighted distance to vary. Allowing these key factors to vary often results in a relative change in the most economical scenario.

For *Scenario 2* LF, values are entered into the model for waste throughput and weighted distance, which assume that one-half of the county's waste is transferred to each of two landfills located at opposite ends of the county. For *Scenario S*, values included for waste throughput and weighted distance indicate all the waste is transferred to a single county landfill or resource recovery facility. For *Scenario M,* values incorporated for waste throughput and weighted distance indicate that the total county waste generation is transferred to a landfill or resource recovery facility in an adjacent county.

The first comparison simulation results are shown in Table 1. This indicates that the single county landfill scenario is more economical for low, medium, and high weighted distances for counties in which the total county waste generation is less than or equal to 40 tons per day. The single landfill per county scenario is more economical at all throughputs below 180 tons/day when the low value for weighted distance is used. The weighted distance to the single county landfill is seen to be an important factor in determining the most economical scenario. Additional sensitivity analysis indicates that if urban waste is transported by the three modes instead of all being transported by rear-loader, the economic feasibility of *Scenario S* LF increases. The economic feasibility of *Scenario S* LF also increases somewhat as the proportion of rural waste generation relative to urban waste generation increases within the county.

As shown in Figure 2, for all multi-county alternatives, the transfer station is considered as a possible alternative to direct transfer to the adjacent county. Table 2 shows the comparison of the transfer station alternative and direct haul, assuming all urban waste is transported by rear-loader. Throughput and distance are both shown to be important in determining the feasibility of the transfer station. At a distance of 20 miles, direct haul is more economical for all throughputs less than or equal to 100 tons/day. For throughputs of 20 tons/day or less, direct haul is the most economical for all distances shown. As the throughput and distance increase, the transfer station becomes more economical. Additional analysis has also shown that the economic feasibility of the transfer station is reduced considerably when the urban waste is transported by all three modes.

The simulation results of comparing *Scenario S* LF with *Scenario M* LF are shown in Table 3. The throughput of the single county alternative and distance to the multi-county alternative are both important determinants of economic feasibility. If the urban waste is transported by three modes, the economic feasibility of the multi-county alternative increases slightly. Unit transportation costs for urban waste transported by three modes are lower than those costs for rear-loader transfer.

Table 4 indicates the simulation results of comparing *Scenario S* LF with *Scenario M* RR. If the actual cost of landfilling is greater than the break-even cost/ton for a particular throughput and distance, the resource recovery alternative is more economical. For example, if the single county throughput is 60 tons/day, if the multi-county alternative resource recovery facility is located 40 miles from the single county alternative, and if the multi-county throughput is 200 tons/day, the single county landfill alternative will

TABLE 1.—Two vs. One Landfill per County (Scenario 2 LF vs. Scenario S LF): Urban Waste Transported by Rear-Loader.

Total County Throughput (in tons/day)	Weighted Distance for Single Landfill Alternative (in miles)		
	High	Medium	Low
40 and less	1	1	1
50-80	2	1	1
90-170	2	2	1
180 and more	2	2	2

Note: High—rural waste 20 miles, urban waste 20 miles; medium—rural waste 15 miles, urban waste 12 miles; low—rural waste 12 miles, urban waste 7 miles.

The number "1" indicates that one landfill is more economical; "2" indicates that two landfills per county are more economical.

TABLE 2.—Direct Haul vs. Transfer Station for Multi-County Alternatives.

Throughput (tons/day)	Distance (in miles)						
	20	25	30	35	40	45	50
20	DH*	DH	DH	DH	DH	DH	DH
30	DH	DH	DH	DH	TS	TS	TS
40	DH	DH	DH	TS	TS	TS	TS
50	DH	DH	TS	TS	TS	TS	TS
60-90	DH	TS	TS	TS	TS	TS	TS
100	DH	TS	TS	TS	TS	TS	TS
110 and more	TS	TS	TS	TS	TS	TS	TS

*"DH" indicates direct haul is more economical and "TS" indicates the transfer station alternative is more economical.

Note: All the urban waste is transported by rear-loaders.

TABLE 3.—Single County vs. Multi-County Landfill Alternatives (Scenario S LF vs. Scenario M LF).

Throughput of Single County Alternative (in tons/day)	Distance to Multi-County Alternative Landfill (in miles)						
	20	25	30	35	40	45	50
20	50*	50	50	50	75	100	350
30	50	75	100	350	—	—	—
40	75	100	375	400	—	—	—
50	100	400	—	—	—	—	—
60	150	—	—	—	—	—	—
70	425	—	—	—	—	—	—
80 and more	—	—	—	—	—	—	—

*These numbers indicate the throughput of a multi-county alternative in tons/day based on a 365-day year. Any multi-county alternative with throughput equal to or greater than the values shown for a particular "cell" is more economical than the single county alternative. Empty cells, denoted by a dash, indicate that the single county alternative is more economical.

Note: All urban waste is assumed to be transported by rear-loader.

TABLE 4.—Break-Even Cost/Ton for Single County Landfill vs. Multi-County Resource Recovery (RR) Alternative (Scenario *S* LF vs. Scenario *M* RR).

Single County Throughput (tons/day)	Multi-County Resource Recovery Throughput (in tons/day): 100 — Distance to RR Facility: 20	30	40	50	200 — 20	30	40	50	300 — 20	30	40	50	400 — 20	30	40	50
20	26.75	29.76	32.76	35.77	12.65	15.66	18.66	21.67	7.95	10.96	13.96	16.97	5.75	8.76	11.76	14.76
40	27.05	29.78	30.12	31.86	12.95	15.68	16.02	17.76	8.25	10.98	11.32	13.06	6.05	8.78	9.12	10.86
60	26.89	28.89	29.26	29.62	12.79	14.79	15.16	15.52	8.09	10.09	10.46	10.82	5.89	7.89	8.26	8.62
80	26.92	28.14	28.50	30.11	12.82	14.04	14.40	16.01	8.12	9.34	9.70	11.31	5.92	7.14	7.50	9.11
100	26.90	27.36	28.72	29.08	12.80	13.26	14.62	14.98	8.10	8.56	9.92	10.28	5.90	6.36	7.72	8.08
120					12.36	13.55	13.91	15.10	7.66	8.85	9.21	10.40	5.46	6.65	7.01	8.20
140					11.99	13.06	13.42	14.50	7.29	8.36	8.72	9.80	5.09	6.16	6.52	7.60
160					12.48	12.82	13.77	14.72	7.78	8.12	9.07	10.02	5.58	5.92	6.87	7.82
180					12.13	13.01	13.36	14.24	7.43	8.31	8.66	9.54	5.23	6.11	6.46	7.34
200					11.91	12.73	13.56	14.39	7.21	8.03	8.86	9.69	5.01	5.83	6.66	7.49
220									7.02	7.81	8.59	9.38	4.82	5.61	6.39	7.18
240									7.25	8.00	8.74	9.49	5.05	5.80	5.64	7.29
260									7.09	7.81	8.53	9.24	4.89	5.61	6.33	7.04
280									6.94	7.62	8.31	9.35	4.74	5.42	6.11	7.15
300									6.78	7.77	8.43	9.10	4.58	5.57	6.23	6.90

Note: The figures in the table represent landfilling costs/ton at which the cost of the indicated single county landfill alternative will break even with the cost of the multi-county resource recovery alternative.

break even with the multi-county resource recovery facility at a landfilling cost of $15.16/ton.

The multi-county resource recovery alternative becomes more favorable as the size of the resource recovery facility increases. The distance to the multi-county facility or the single county throughput do not seem to be as important as the size of the multi-county facility in determining the economic feasibility.

The results of comparing *Scenario S* RR with *Scenario M* LF are shown in Table 5. For example, if the single county resource recovery alternative has a throughput of 200 tons/day and if the multi-county landfill is located 40 miles from the resource recovery alternative, the cost of the single county resource recovery alternative will break even with the cost of the multi-county alternative at a landfilling cost of $5.73/ton. The single county throughput is relatively more important than the distance to the multi-county landfill in determining the economic feasibility of resource recovery.

Analysis of Rural Collection Systems

The endogenously determined results for the rural collection subset have been incorporated in the analysis of the scenario comparisons. However, the results of the rural collection systems simulation are presented separately to allow additional focus on this subset. Table 6 shows the comparison of the three box systems, assuming 13 box sites per county for all three systems. The green box system is the most economical for the majority of throughputs and distances. The open-top box system shows limited feasibility at relatively low throughputs and distances. The compaction box system is most economical at relatively high throughputs.

Sensitivity analysis revealed that several variables caused substantial variation in the results. As the number of box sites per county is decreased and increased, the economic feasibility of the compaction box system increases and decreases, respectively. When the percentage of bulk goods is increased, the open-top box system becomes the most economical system over a wider range of throughput and distance. The variability of the rural waste stream from weekday to weekend is also important. As the percentage of rural waste deposited at the box site on the weekend increases relative to the amount of waste deposited during the week, the economic feasibility of the compaction box system increases. (The results of these comparisons are in tabular form in Appendix F.)

If the rural system is publicly operated, both the open-top and compaction box systems increase in economic feasibility relative to the green box system. The open-top and compaction box systems are relatively more economical because of the decreased produc-

TABLE 5.—Break-Even Cost/Ton for Multi-County Landfill vs. Single County Resource Recovery (RR) Alternative (Scenario M LF vs. Scenario S RR).

Single County Throughput (in tons/day)	Distance to Multi-County Landfill (in miles)						
	20	25	30	35	40	45	50
100	20.69	20.28	20.14	19.92	18.79	18.57	18.42
125	15.14	14.92	13.98	13.76	13.62	13.00	12.46
150	11.87	11.01	10.88	10.67	9.89	9.68	9.54
175	9.06	8.85	8.44	7.95	7.82	7.06	6.92
200	7.38	6.69	6.56	6.35	5.73	5.52	4.90
225	6.14	5.50	5.37	4.73	4.59	3.95	3.82
250	4.65	4.45	3.92	3.72	3.19	2.99	2.46
275	3.84	3.28	3.15	2.59	2.45	1.89	1.58
300	3.14	2.61	2.15	1.94	1.48	0.95	0.82

Note: The figures in the table represent the landfilling cost/ton at which the cost of the multi-county landfill alternative will break even with the cost of the single county resource recovery alternative.

TABLE 6.—Economic Comparison of Rural Collection Alternatives Assuming 13 Box Sites per County.

Throughput (tons/day)	Weighted Distance (in miles)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5-10	G*																				G
12	O	O	G																		G
14-18	O	G																			G
20-26	G																				G
28	G																		G	C	C
30	G													G	C						C
32	G										G	C									C
34-66	C																				C

*Most economical system: "G"—Green Box System
"O"—Open-Top Box System
"C"—Compaction Box System

TABLE 7.—Break-Even Hourly Rates for Private Cost, Mailbox Pickup vs. Most Economical Box System.

Tons per Day	Weighted Distance to Disposal or Recovery Alternative (in miles)								
	5			15			25		
	Average Distance of Households from Box Site (in miles)			Average Distance of Households from Box Site (in miles)			Average Distance of Households from Box Site (in miles)		
	1	2	3	1	2	3	1	2	3
5	3.56	3.18	2.43	3.62	3.25	2.49	3.69	3.31	2.55
8	2.50	2.12	1.36	2.56	2.18	1.43	2.62	2.25	1.49
12	1.76	1.38	0.62	1.77	1.39	0.63	1.83	1.45	0.70
16	1.46	1.09	0.33	1.51	1.13	0.37	1.57	1.19	0.44
20	1.26	0.88	0.12	1.32	0.94	0.19	1.39	1.01	0.25
24	1.08	0.70	—*	1.15	0.77	0.01	1.21	0.83	0.08
28	1.04	0.66	—	1.06	0.69	—	1.12	0.74	—
32	0.96	0.59	—	1.02	0.65	—	1.15	0.77	0.02
36	0.93	0.55	—	1.05	0.67	—	1.18	0.80	0.04
40	0.95	0.57	—	1.07	0.69	—	1.20	0.82	0.06
44	0.97	0.59	—	1.09	0.71	—	1.21	0.83	0.08
48	0.98	0.60	—	1.10	0.72	—	1.23	0.85	0.09
66	1.02	0.64	—	1.14	0.77	0.01	0.88	0.50	—

*Net private travel costs are greater than the difference between the cost of mailbox pickup and the most economical box system.

tivity assumption (the green box system generally requires more operating hours) and because the assumption of full-utilization of vehicles is relaxed under public operation.[8] The collection vehicle for the green box system is considerably more expensive than the vehicle used for the other two systems. Assuming public operation of the system, the entire cost of this more expensive vehicle is charged to the cost of the single county rural system. Given thc methodology used in this research, public operation of the rural system is more costly than private operation. (See Appendix F for tabular results of public operation of rural collection alternatives.)

The comparison of the most economical box system and mailbox pickup is shown in Table 7. In situations in which the rural residents perceive their opportunity cost to be greater than the value given for the appropriate throughput and distance, mailbox pickup would be the most economical alternative. For example, in a county with 20 tons/day of throughput, if the weighted distance to the disposal or recovery site is 15 miles, and the average distance of rural households from the box site is 2 miles, the break-even hourly opportunity cost is $0.94. Therefore, if the residents value their time at more than $0.94/hour, they would prefer mailbox pickup. The total county rural waste generation and the average distance of rural households from the nearest box site cause the greatest variation in the break-even hourly rate.

SUMMARY AND CONCLUSIONS

Considerable planning resources have been expended for metropolitan solid waste management, but little has been spent for nonmetropolitan areas. This was not a problem in nonmetropolitan areas until solid waste began to be associated with environmental pollution, health concerns, and community aesthetics. More stringent state and federal environmental legislation followed and resulted in the closing of many open dumps. Fewer disposal sites, more difficulty in finding acceptable landfill sites, increasing transportation costs, and an associated increase in roadside dumping and littering have made integrated solid waste management planning much more important.

The model developed in this research addresses the solid waste problems found in nonmetro areas and determines the most economical alternative or scenario for a given situation. The model consists of three subsets: 1) rural collection, storage, and transfer; 2) transportation of urban waste; and 3) landfilling or resource recovery. Dominant solid waste scenarios found in nonmetropolitan Ohio counties are simulated by inputting values for waste generation, distance, time and capacity parameters, and unit cost estimates into the planning model.

Several important findings and variables have been identified through the simulation and comparison of the scenarios. In each scenario comparison, it is evident that the cost of landfilling and the economies of scale associated with landfilling are very important. The economies of scale associated with resource recovery are also seen to be very important. Waste generation, throughput, distance, and the transportation mode for urban waste are all important variables in determining the most economical scenario.

The results of the rural collection analysis are sensitive to changes in the values of several variables including throughput, the percent of bulk goods, the number of box sites, and the required weekend box site storage. The results seem to be rather insensitive to the weighted distance, relative to the other variables. The green box system is the most economical system in a majority of situations. Eliminating the required weekend storage increases the green box system feasibility tremendously. As the percent of bulk goods increases, the open-top box system becomes more feasible. As the number of box sites decreases, and as the required weekend box site storage increases, the compaction box system becomes more feasible relative to the green box system. The feasibility of mailbox pickup, relative to the most economical box system, is most sensitive to the throughput and the average distance of rural households from the box sites. As the values of these two variables increase, the mailbox pickup system becomes more attractive.

The results of the analysis indicate conditions under which counties could more efficiently utilize resources for solid waste management. For example, if total county waste generation is less than or equal to 40 tons/day and the county operates two landfills, total solid waste management costs could probably be reduced by operating only one landfill. The feasibility of multi-county landfill alternatives for counties generating less than 30 tons/day looks very promising.

The simulation results suggest that several nonmetro counties in Ohio could reduce total solid waste management costs by operating only one landfill. Depending upon the local costs for landfilling, some counties could save money by transporting their waste to an adjacent county. The feasibility of resource recovery appears to be very dependent upon the al-

[8] Under public operation, it seems less likely that collection vehicles would be used in urban areas or in adjacent counties in order to utilize any vehicle time which would not be needed for the rural collection system operation.

ternative cost of landfilling. The green box system appears to be the most economical rural *box* system for the majority of situations in nonmetro Ohio.[9]

This research has focused on nonmetro Ohio. All of the values for the exogeneous variables have been developed from Ohio EPA data, Department of Commerce, Ohio Department of Economic and Community Development, and Ohio Bureau of Employment Services information for counties in Ohio. Each component of the model was developed based on Ohio regulations, political structure, and climate. Even so, the simulation results should be applicable to other states, particularly the North Central and Northeast regions because of similarities to Ohio (primarily climate) regarding the necessary solid waste management practices. The model itself should be applicable over a wider range of states. Certain unit costs will change from state to state, most notably labor costs and landfilling costs, but it is not expected that the basic conceptualization of the model would need to change.

More research is needed to generate primary data and/or better utilize available secondary information as proxies for specific variables. This would make the simulation results much more powerful. The most important example is landfilling costs. These costs tend to be subject to a wide range of local variation but yet are extremely important in determining the economic feasibility of a particular scenario. Further research would also be helpful in determining residents' demand for solid waste services and their willingness to pay for these services. Estimating residents' willingness to pay for mailbox pickup versus the green box system would enable a more direct economic comparison between the two systems.

Research presently underway is examining the model results when some of the assumptions made in the simulation analysis are relaxed. The assumptions being relaxed include allowing more than one rural collection system to be used per county, examining the effect of seasonal variation in waste generation, and assuming that not all solid waste in a county must be directly hauled to a transfer station when analyzing the feasibility of a transfer station. Additional county and multi-county case studies are anticipated to further refine the model.

Nonmetropolitan solid waste management planning will likely become more important as disposal sites in metropolitan areas become scarce and as desire for a better quality of life continues to grow. In order to meet a growing demand for solid waste services with a limited amount of resources, planning for the nonmetropolitan area as a whole, both urban and rural, becomes vitally important.

[9]In order to determine the most economical rural **collection** system, the opportunity cost for rural residents delivering waste to rural box sites must be estimated.

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APPENDIX A

A computer program written in FORTRAN language was developed in the Department of Agricultural Economics and Rural Sociology at The Ohio State University to analyze nonmetropolitan solid waste management alternatives. The program addresses all subsets of nonmetro solid waste management, with particular emphasis on rural collection alternatives.

The program is relatively simple in terms of resources required to use it. The total time required to compile, execute, and print the results will rarely exceed 1 minute. The compile and execution time is normally less than 5 seconds. A minimal amount of memory is required to run the program.

The program is designed so that it is relatively easy to change the values of variables in the model. Variable values which must be included for the rural collection systems analysis are:

- capital costs for equipment and motor vehicles
- capital costs for box site development
- labor costs for drivers and helpers
- average distance between the box sites
- percent of waste generation spilled at box sites
- cleanup rate around box sites in cubic yards per hour
- annual license fee for collection vehicles
- annual insurance premium for collection vehicles
- salvage value of capital items
- expected life of capital items
- maximum available annual hours of use for collection vehicles
- average speed for collection vehicles in miles per hour
- time required to load and unload collection vehicles in hours
- fuel, oil, tire, maintenance, and repair costs per hour for collection vehicles
- maintenance costs for boxes and box sites
- percent of waste generation considered to be bulk goods

- bulk goods pickup frequency
- capacity of collection vehicles in tons
- number of collection vehicles restriction (maximum number which would not invalidate assumption of full utilization of collection vehicles)
- percent of week's total rural waste generation deposited on Saturday and on Sunday
- hours in the day during which solid waste is collected
- productivity factor for labor
- capacity of boxes in tons
- maximum number of boxes allowed per site
- maximum and minimum number of pickups per day

Variables included for urban waste transfer and the solid waste transfer station include:

- all capital costs for motor vehicles, equipment, buildings
- salvage values for all capital items
- expected life of all capital items
- labor costs for drivers, supervisors, and laborers
- average speed for collection vehicles and transfer trailers
- fuel, oil, tire, maintenance, and repair costs per hour for collection vehicles
- time unloading collection vehicles
- maximum available annual hours of use of collection vehicles
- annual license and insurance fees for motor vehicles
- capacities in tons of collection and transfer vehicles
- time required to load and unload transfer trailers
- cost of land for the transfer station
- maintenance cost for all equipment required in transfer station
- base utility costs and unit utility rates for the transfer station
- number of days in the week and hours in the day during which the transfer station is operating

A single variable included for landfilling or resource recovery is the cost of landfilling (or resource recovery) per ton. An annual amortized cost for each capital cost item is calculated within the program. Therefore, an interest rate must be included as another variable. The effect of changing the values of the variables stated above can be determined by making independent computer runs.

Additional variables in the program include weighted distances from waste generation source points to transfer, disposal, or recovery sites; direct distances from transfer stations to disposal or recovery sites; and estimates for rural, urban residential, commercial, and industrial waste generation. The program is designed so that all of these variables can be varied within the same computer run. (With minor modifications in the program, variables listed in the preceding paragraphs could also be varied within the same computer run.)

The analysis of the rural collection alternatives is the most involved part of the program. Restrictions in the program include the maximum and minimum number of pickups per day, the maximum number of boxes per site, and the maximum number of collection vehicles used for rural collection. The annual cost, which includes all amortized capital costs, fixed operating costs, and constant unit operating costs, is calculated for each system and the most economical alternative is selected.

The annual urban waste transportation costs and the disposal (or recovery) costs are calculated and added to the annual cost of the most economical rural collection system. The program prints the following results for each rural system:

- annual cost
- cleanup around box sites
- annual cost for bulk goods pickup
- number of boxes per site
- pickups per month
- total annual rural collection cost
- total annual rural collection cost plus disposal (or recovery) costs
- weighted distance to transfer, disposal, or recovery site
- quantity of rural waste generation

Information printed for the urban transfer of waste includes the annual cost for urban transfer by rear-loader, front-loader, and compaction box, and the total cost for urban transfer plus the disposal (or recovery) cost. A total annual cost for rural collection, urban transfer of waste, and disposal (or recovery) alternatives is also included.

The program allows the solid waste transfer station to be included as a possible alternative in the solid waste management plan. Information printed for transfer station alternatives includes:

- the number of transfer trailers
- the annual operating costs for the transfer vehicles
- the annual owning and operating costs of the transfer station
- the total annual cost associated with the transfer station alternative

The total annual cost for solid waste management with and without the transfer station alternative is calculated and printed in the results.

APPENDIX B
RURAL COLLECTION UNIT COSTS

TABLE B-I.—Annual Fixed and Variable Costs for the Rural Collection Systems.

System	Fixed Overhead	Fixed Operating	Constant Unit Operating	Totals
Green Box				
Collection Vehicle	$18,810		$5.607/hr	
Driver		$16,900		
Insurance		1,000		
License		1,390		
Subtotals	$18,810	$19,290		
Total Annual Fixed Cost for Collection Vehicle				$38,100
8 cu yd Box	$104		$21/yr	
Total Annual Cost for 8 cu yd Box				$125
Open-Top Box				
Collection Vehicle	$15,400		$5.600/hr	
Driver		$16,900		
Insurance		1,000		
License		930		
Subtotals	$15,400	$18,830		
Total Annual Fixed Cost for Collection Vehicle				$34,230
40 cu yd Box	$490		$180/yr	
Total Annual Cost for 40 cu yd Box				$670
Compaction Box				
Collection Vehicle	$15,400		$5.600/hr	
Driver		$16,900		
Insurance		1,000		
License		930		
Subtotals	$15,400	$18,830		
Total Annual Fixed Cost for Collection Vehicle				$34,230
42 cu yd Box	$1,340		$260/yr	
Total Annual Cost for 42 cu yd Box				$1,600
Stationary Compactor	$1,690		$260/yr	
Supervision		$1,200		
Total Annual Costs for Stationary Compactor				$3,790
Mailbox Pickup				
Collection Vehicle	$13,820		$3.801/hr	
Driver		$16,900		
Helper		$14,300		
Insurance		1,000		
License		1,200		
Subtotals	$13,820	$33,400		
Total Annual Fixed Cost for Collection Vehicle				$47,220
Bulk Goods Pickup				
Collection Vehicle	$4,113		$0.187/mile	
Driver		$ 8,320		
Helper		8,320		
Insurance		250		
License		250		
Subtotals	$4,113	$17,140		
Total Annual Fixed Cost for Collection Vehicle				$21,253
Box Site Cleanup Labor			$4.00/hr	

Sources: (2, 3, 7, 8, 9, 11, 19, 21, 22, 23, and conversations with manufacturers and private haulers.)

Note: All costs are in 1978 dollars.

APPENDIX C
TRANSFER STATION UNIT COSTS

TABLE C-I.—Annual Fixed Costs for Transfer Trailer and Tractor.

	Transfer Station Size (tons/day)			
	0-100	100-180	180-325	325 and More
Fixed Overhead				
Transfer Trailer	$ 8,970	$ 8,970	$ 7,070	$ 7,070
Tractor	8,950	8,950	10,280	10,280
Fixed Operating				
Transfer Trailer License	730	730	730	730
Trailer License and Insurance	1,450	1,450	1,450	1,450
Driver	16,000	16,000	16,000	16,000

Sources: (2, 19, and manufacturers.)
Note: All costs are in 1978 dollars.

TABLE C-II.—Annual Fixed Costs for Transfer Stations.

	Transfer Station Size (tons/day)			
	0-100	100-180	180-325	325 and More
Fixed Overhead*	$ 9,900	$11,200	$28,800	$28,800
Fixed Operating				
Insurance	1,500	2,000	2,500	3,000
Building Maintenance	800	1,000	1,500	2,000
Utilities†	1,360	1,450	1,850	1,950
Office Supplies, Material, Misc.	1,200	1,500	2,400	2,900
Labor				
Supervisor	11,500	11,500	11,500	11,500
Operator	10,400	20,800	20,800	20,800
Total Fixed Operating Costs	$26,760	$38,250	$40,550	$42,150
Total Annual Fixed Costs	$36,660	$49,450	$69,350	$70,950

*Includes the building, all associated equipment, engineering, and site excavation.
†Includes electricity for lighting, heat, water, and telephone.
Sources: (1, 19, 26, and manufacturers.)
Note: All costs are in 1978 dollars.

TABLE C-III.—Constant Unit Operating Costs for Transfer Station Alternatives.

	Transfer Station Size (tons/day)			
	0-100	100-180	180-325	325 and More
Fuel and Electricity*	$0.161/ton	$0.161/ton	$0.138/ton	$0.138/ton
Equipment Maintenance	0.126/ton	0.126/ton	0.068/ton	0.068/ton
Totals	$0.287/ton	$0.287/ton	$0.206/ton	$0.206/ton

*Fuel costs cover the operation of the front-end loader. Electricity costs include the operation of all transfer station equipment.
Sources: (19, 21)

TABLE C-IV.—Constant Unit Operating Costs for Transfer Trailer and Tractor.

	Cost/Mile
Fuel	$0.13
Oil (including Hydraulic Oil)	0.02
Tires	0.07
Maintenance	0.08
Road Tax	0.02
Total	$0.32

Source: (1).
Note: All costs are in 1978 dollars.

APPENDIX D
DISPOSAL AND RECOVERY COSTS

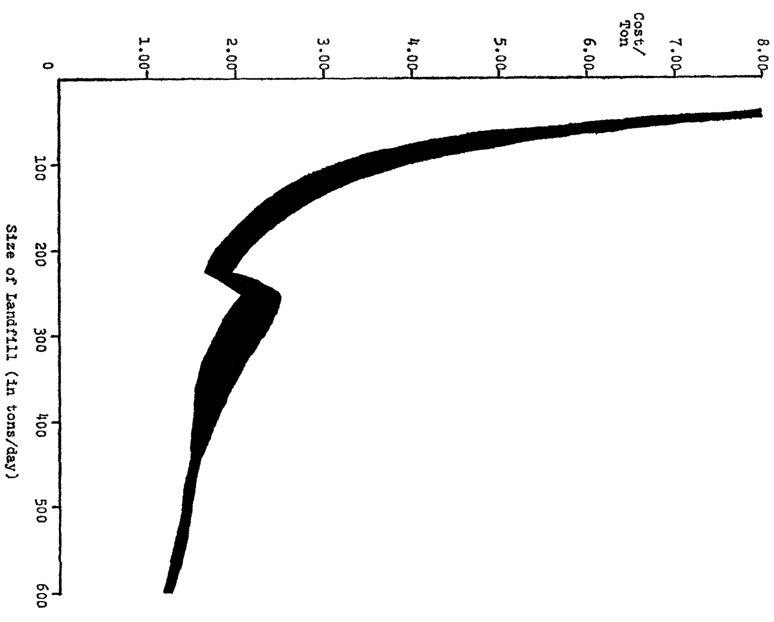

FIG. D-1.—Average annual costs per ton for sanitary landfilling.
Source: Adapted from Clayton and Huie (5).
Note: All costs are based on 1978 dollars.

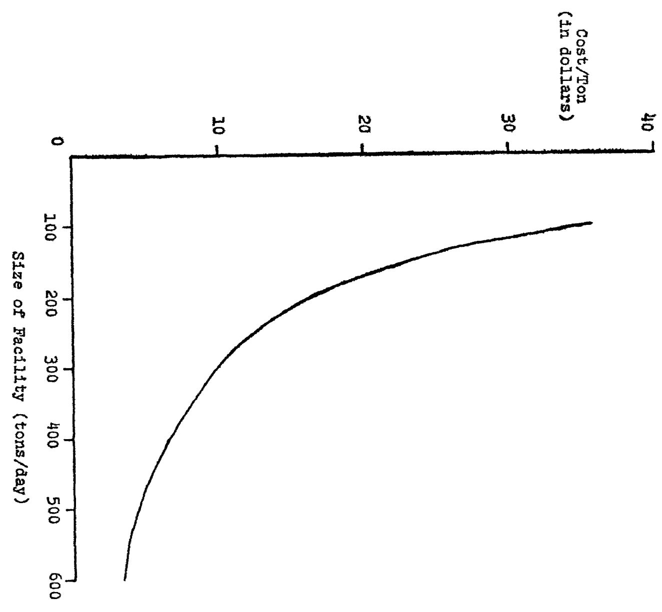

FIG. D-2.—Cost per ton for resource recovery facilities (based on a 254-day operating year).
Source: Adapted from Hitzhusen et al. (14).
Note: All costs are based on 1978 dollars.

TABLE D-I.—Estimated Cost Components of a Trench Type Sanitary Landfill.

Size of Landfill (tons/day)	Annual Costs								
	Planning and Designing*	Initial Site Development†	Land Expense	Equipment	Personnel‡	Site Maintenance and Development	Administration and Overhead	Total	Cost/Ton
100	$ 880	$ 9,250	$1,170	$ 56,590	$13,960	$7,530	$1,000	$ 90,380	$3.160
200	1,750	9,250	1,640	66,100	13,960	7,530	2,000	102,230	1.787
300	2,630	9,250	2,140	97,190	53,260	7,530	3,000	175,200	2.040
400	3,500	9,250	2,170	113,880	53,260	7,530	4,000	193,590	1.692
500	4,380	10,320	2,580	117,670	61,840	8,510	5,000	210,300	1.471
600	$5,260	$10,320	$2,970	$122,130	$61,840	$8,510	$6,000	$217,030	$1.265

Source: Adapted from Clayton (5).
Note: All costs are based on 1978 dollars.
*Updated from Clayton and Huie (5) with the GNP price deflator (8).
†Updated from Clayton and Huie (5) with a construction cost index (7).
‡Salaries obtained from an occupational wage survey (2) for jobs which correspond closely with the personnel requirements of a landfill, as described by Clayton (4).

APPENDIX E
WASTE GENERATION METHODOLOGY

Residential waste generation can be estimated using population. A previous study by Poling (19) has shown that a coefficient of 2.3 lb/person/day is a good approximation of urban residential waste generation. The same study by Poling indicated that the rural residential waste generation coefficient is approximately 1.5 lb/person/day. In this study, the urban population is defined as all residents living in incorporated and unincorporated cities and villages. The rural population is defined as the total population minus the urban population. Multiplying the above coefficients by the corresponding populations estimates the residential waste generation.

Commercial and industrial waste generation is approximated by multiplying the number of employees within a particular standard industrial classification (SIC) category by the waste generation coefficient for that category. Waste generation coefficients for commercial categories and industrial SIC categories 00-21, 23-25, and 38-39 are shown in Table E-1 and are based on Poling (20).

Coefficients for SIC categories 22 and 26-37 have been estimated based on primary data collected by the Ohio Environmental Protection Agency. The amount of landfilled waste was regressed against the number of employees for each observation within each SIC category. Based on a study by the Ohio Environmental Protection Agency (27), reliable waste generation estimates are those in which the simple correlation coefficient between employees and landfilled waste is greater than 0.5. In addition, there must be five or more observations in that particular category. The estimates and reliability of the estimates are shown in Table E-II.

TABLE E-I.—Commercial and Industrial Waste Generation Coefficients for SIC Categories: 00-21, 23-25, and 38-99.

SIC Category	Description	Waste Generation Coefficient* (tons/employee/day)
	Commercial	
40-49	Transportation and Utilities	0.001
50-51	Wholesale Trade	0.0021
52-59	Retail Trade	0.0034
60-67	Finance, Insurance, Real Estate	0.0015
70-89	Services	0.0025
90-99	Government	0.0015
	Industrial	
00-09	Agriculture, Fishing, Forestry	0.0004
15-17	Construction	0.0632
20	Food and Kindred Products	0.0096
21	Tobacco and Tobacco Products	0.0075
23	Apparel and Finished Products Made from Fabric	0.0009
24-25	Furniture, Lumber and Wood	0.0027
38-39	Other Durables	0.0044

*Based on a 365-day year.

TABLE E-II.—Industrial Waste Generation Coefficients for SIC Categories 22 and 26-37.

Description	SIC	Observations	Correlation	Waste Generation Coefficient* (tons/employee/day)
Textiles	222	1		0.07327
	225	1		0.00033
	229	4	—0.7645	0.22679
Paper and Allied Products	262	2		0.0
	264	13	—0.0412	0.00017
	265	5	—0.0118	0.00010
Printing and Publishing	271	9	0.6319	0.00016†
	275	23	0.0452	0.00002
	276	4		0.0
	279	4		0.0
Chemicals	281	14	0.5921	0.10823†
	282	17	0.6911	0.09596†
	283	2	1.0	0.00011
	284	11	—0.0720	0.00001
	285	18	0.3990	0.00096
	287	4	—0.1850	0.00276
	289	30	0.5068	0.0083†
Petroleum Refining and Related Industries	291	6	0.9206	0.04783†
	295	3	—0.5721	0.00322
	299	8	0.9601	0.01805†
Rubber and Miscellaneous Plastics	30	112	0.8258	0.0162†
Leather and Leather Products	31	4	—0.6414	0.00095
Stone, Clay, Glass, and Concrete Products	321	2		0.0
	322	15	0.1816	0.00021
	323	2	—1.0	0.01151
	325	5	0.5208	0.00003†
	326	8	0.0100	0.00009
	327	8	—0.1636	0.03738
	328	3	—0.1860	0.02309
	329	14	0.6753	0.07152†
Primary Metals	331	25	0.7896	0.04027†
	332	12	—0.0820	0.00178
	333	1		0.0
	334	3	—0.4216	0.00835
	335	8	0.9990	0.00496†
	336	9	—0.2155	0.00042
	339	10	0.9035	0.02766†
Fabricated Metals	341	3	0.1348	0.00418
	342	11	0.823	0.00566†
	343	3	0.0356	0.000002
	344	25	0.1738	0.00027
	345	9	0.1562	0.00008
	346	13	0.8237	0.00127†
	347	38	0.184	0.00593
	348	3		0.0
	349	27	0.8545	0.00002†
Machinery, except Electrical	351	2	—1.0	0.00319
	352	4	0.999	0.00004
	353	10	0.00065	0.00002
	354	39	0.0834	0.00006
	355	12	0.0838	0.00001
	356	15	0.3077	0.00003
	357	3	0.500	0.02168
	358	2	1.0	0.01941
	359	16	—0.1713	0.00002
Electrical Machinery	361	5	—0.4586	0.000002
	362	19	0.2770	0.00021
	363	6	—0.014	0.00001
	364	11	—0.1733	0.00003
	366	3	0.9999	0.00009
	367	6	—0.348	0.00025
	369	5	—0.0597	0.00047
Transportation Equipment	37	40	0.8388	0.00393†

*Based on a 365-day year.
†Statistically reliable coefficients.

APPENDIX F

TABLE F-I.—Economic Comparison of Rural Collection Alternatives with Seven Box Sites per County.

Throughput (tons/day)	Weighted Distance (in miles)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5- 8	G*																				G
10	O	G																			G
12	G																				G
14	G																				G
16	G																		G	C	C
18	G								G	C											C
20-34	C																				

*Most economical system: "G"—Green Box System
"O"—Open-Top Box System
"C"—Compaction Box System

TABLE F-II.—Economic Comparison of Rural Collection Alternatives with 25 Box Sites per County.

Throughput (tons/day)	Weighted Distance (in miles)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5-20	G*																				G
22	O	—	O	G																	G
24	O	O	G																		G
26	O	G																			G
28-46	G																				G
48	G							G	C												C
50	G							G	C												C
66	C																				C

*Most economical system: "G"—Green Box System
"O"—Open-Top Box System
"C"—Compaction Box System

TABLE F-III.—Economic Comparison of Rural Collection Alternatives with Bulk Goods at 1%.

Throughput (tons/day)	Weighted Distance (in miles)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5-26	G*																				G
28	G																	G	C	—	C
30	G											G	C								C
32	G				G	C															C
34-66	C																				C

*Most economical system: "G"—Green Box System
"O"—Open-Top Box System
"C"—Compaction Box System

TABLE F-IV.—Economic Comparison of Rural Collection Alternatives with Bulk Goods at 10%.

Throughput (tons/day)	Weighted Distance (in miles)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5-10	G*																				G
12	O						O	G													G
14	O					O	G														G
16	O					O	G														G
18	O			O	G																G
20-28	G																				G
30	G																	G	C	—	C
32	G												G	C							C
34	G										G	C									C
36-66	C																				C

*Most economical system: ' G '—Green Box System
"O"—Open-Top Box System
' C"—Compaction Box System

TABLE F-V.—Economic Comparison of Rural Collection Alternatives with High Weekend Waste Deposits (Sunday Storage Requirement at 30%).

Throughput (tons/day)	Weighted Distance (in miles)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	G*																				G
6	|																				|
8	G																				G
10	O		O	G																	G
12	O		O	G																	G
14	O		O	G																	G
16-22	G																				G
24	G		G	C																	C
26	G	G	C																		C
28-66	C																				C

*Most economical system: "G"—Green Box System
"O"—Open-Top Box System
' C —Compaction Box System

TABLE F-VI.—Economic Comparison of Rural Collection Alternatives with Public Operation of the Systems.

Throughput (tons/day)	Weighted Distance (in miles)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	O*				O	G															G
6	O			O	G																G
8	O	O	G																		G
10	O				O	G										G	O	—		O	G
12	G									G	O	O	G								G
14	G																				G
16	G																				G
18	G						G	C													C
20	G	C																			C
22-66	C																				C

*Most economical system: ' G' —Green Box System
"O"—Open-Top Box System
"C"—Compaction Box System

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of research at the Ohio Agricultural Research and Development Center. All Ohioans benefit from this product.

Ohio's farm families benefit from the results of agricultural research translated into increased earnings and improved living conditions. So do the families of the thousands of workers employed in the firms making up the state's agribusiness complex.

But the greatest benefits of agricultural research flow to the millions of Ohio consumers. They enjoy the end products of agricultural science—the world's most wholesome and nutritious food, attractive lawns, beautiful ornamental plants, and hundreds of consumer products containing ingredients originating on the farm, in the greenhouse and nursery, or in the forest.

The Ohio Agricultural Experiment Station, as the Center was called for 83 years, was established at The Ohio State University, Columbus, in 1882. Ten years later, the Station was moved to its present location in Wayne County. In 1965, the Ohio General Assembly passed legislation changing the name to Ohio Agricultural Research and Development Center—a name which more accurately reflects the nature and scope of the Center's research program today.

Research at OARDC deals with the improvement of all agricultural production and marketing practices. It is concerned with the development of an agricultural product from germination of a seed or development of an embryo through to the consumer's dinner table. It is directed at improved human nutrition, family and child development, home management, and all other aspects of family life. It is geared to enhancing and preserving the quality of our environment.

Individuals and groups are welcome to visit the OARDC, to enjoy the attractive buildings, grounds, and arboretum, and to observe first hand research aimed at the goal of Better Living for All Ohioans!

The State Is the Campus for Agricultural Research and Development

Ohio's major soil types and climatic conditions are represented at the Research Center's 12 locations.

Research is conducted by 15 departments on more than 7000 acres at Center headquarters in Wooster, eight branches, Pomerene Forest Laboratory, North Appalachian Experimental Watershed, and The Ohio State University.

Center Headquarters, Wooster, Wayne County: 1953 acres

Eastern Ohio Resource Development Center, Caldwell, Noble County: 2053 acres

Jackson Branch, Jackson, Jackson County: 502 acres

Mahoning County Farm, Canfield: 275 acres

Muck Crops Branch, Willard, Huron County: 15 acres

North Appalachian Experimental Watershed, Coshocton, Coshocton County: 1047 acres (Cooperative with Science and Education Administration/Agricultural Research, U. S. Dept. of Agriculture)

Northwestern Branch, Hoytville, Wood County: 247 acres

Pomerene Forest Laboratory, Coshocton County: 227 acres

Southern Branch, Ripley, Brown County: 275 acres

Vegetable Crops Branch, Fremont, Sandusky County: 105 acres

Western Branch, South Charleston, Clark County: 428 acres