Solid Waste Planning in the Northern Counties of the Kiamichi Economic Development District

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Introduction

Several Southeastern Oklahoma towns located in the Kiamichi Economic Development District (KEDDO) are not currently in compliance with the Oklahoma Solid Waste Management Act of 1970 [5]. The act requires that all incorporated cities and towns adequately dispose of solid wastes generated within incorporated limits. Most areas of the state were granted extensions until July, 1975 to operate landfill facilities in accordance with state requirements. Most large towns have collection and disposal systems but many smaller towns have no service or partial service, and a few are incorrectly disposing of their wastes.

The objective of this study is to explore the possibilities for designing and operating solid waste systems to serve counties—or towns within counties—not currently meeting the 1970 law. A central hypothesis of this research is that economies of scale exist in the formation and operation of multicounty solid waste systems. Cost reductions are assumed to be achieved through the sharing of facilities, equipment, management and the ability to obtain bulk and fleet discounts. To test this hypothesis four types of systems are analyzed. First, systems which serve the incorporated towns of each county in KEDDO are analyzed. Second, systems designed to serve residents and businesses scattered throughout the unincorporated areas of the counties are presented. Third, a joint rural-urban analysis is performed. Finally, multicounty systems designed to serve two or more counties will be evaluated.

As shown in Figure 1 the KEDDO planning area consists of seven counties. An earlier analysis [8] contains information on Choctaw, McCurtain and Pushmataha county systems. The work here will focus on Pittsburg, Latimer, Leflore and Haskell counties. The incorporated

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analysis will include the towns shown in the shaded portion of Figure 2; the unincorporated analysis will involve the remaining areas of the four study counties.

This report contains four sections. In the next section methodology will be discussed. Included will be a general discussion of the use of linear programming as a tool for solid waste system planning, and of "lockset" as a method for achieving minimum cost routing. The components of a waste management system will be presented, including estimates of fixed and variable costs in different systems.

The KEDDO area analysis and empirical results are presented in the third section. Results from the single county plans are given, including estimates of monthly operating costs, capital outlays and user fees for incorporated, unincorporated and incorporated-unincorporated (combined) systems. In addition, three multicounty systems will be evaluated on a cost and return basis. Section four contains conclusions and limitations of the study.

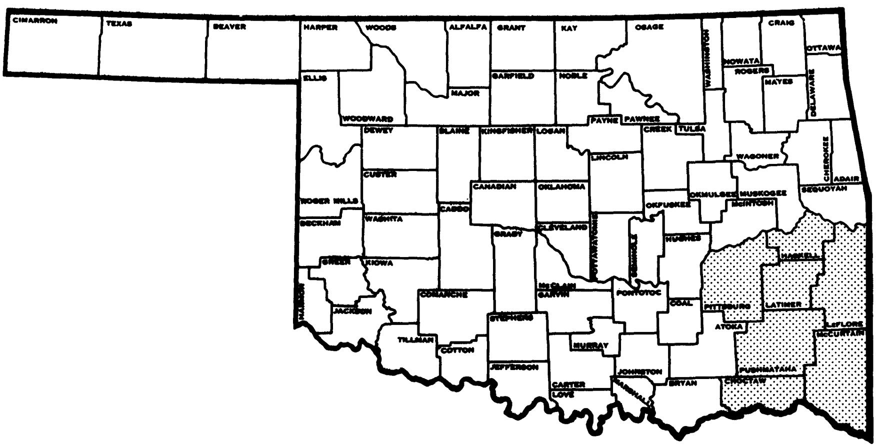

Figure 1. Counties of Oklahoma; KEDDO Counties are shaded.

Methodology

The Linear Programming Problem

Solid waste collection and disposal is viewed in a transportation framework and linear programming is employed to solve for the landfill number(s) and location(s) which minimize the costs of collection, trans-

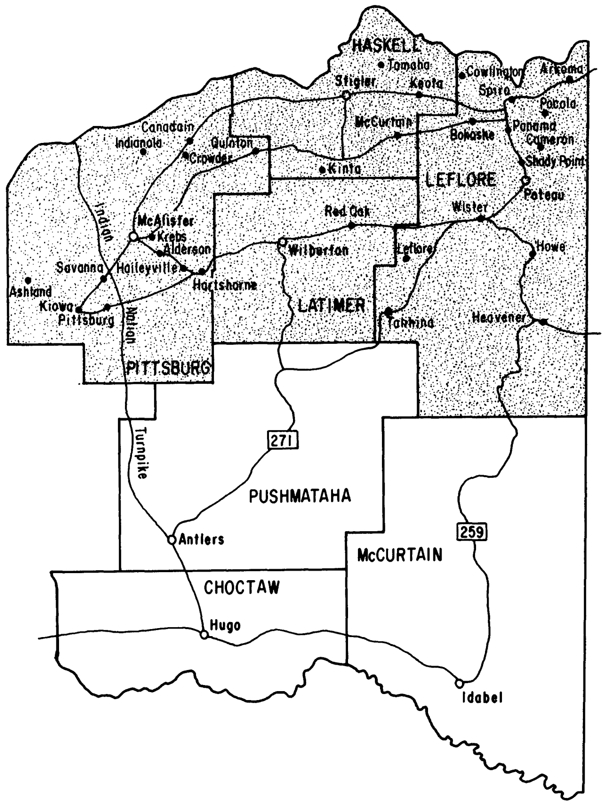

Figure 2. The incorporated towns of the KEDDO planning area.

portation and disposal. System costs are minimized when correct decisions regarding landfill sites are made.

The problem is solved by minimizing the costs of collection, transportation and disposal subject to supply and demand restrictions. The supply constraints insure that no landfill will process a volume in excess of its capacity, and the demand constraints insure that no customer will be left unserved. The problem is expressed in mathematical form as:

$$(1)\ \text{Min}\ TC_k = C_o + R_k + FC_s + \sum_{j \in S_k} C_j + c_t \sum_{j \in S_k} \sum_{i=1}^{o} x_{ij} d_{ij}$$

Subject to

$$(2)\ \sum_{j=1}^{n} x_{ij} = a_i,\ i = 1, \ldots, 0$$

$$(3)\ \sum_{i=1} x_{ij} \leq b_j,\ j \in S_k$$

$$(4)\ x_{ij} \geq 0,\ i = 1, \ldots, 0_j,\ j \in S_k$$

Where

TC_k = total monthly cost of disposal, collection and transportation of solid waste with landfill alternatives S_k;

C_o = monthly collection cost of containerized residential pickup in the incorporated areas;

R_k = minimum monthly cost of containerized rural collection and transportation of solid waste with landfill alternatives S_k;

FC_s = fixed costs of the system (boxes, salaries, buildings and capital expenses);

C_j = cost of disposal at landfill j;

x_{ij} = monthly quantity of waste transported from origin i to landfill j, imputed as number of truckloads required to transport waste from origin i;[1]

b_j = maximum volume of waste per month disposed in landfill j (in terms of truckloads);

a_i = monthly volume of waste generated at origin i (in terms of truckloads);

d_{ij} = round trip mileage between origin i and landfill j;

c_t = truck operating charge per mile (assumed constant);

o = number of origins (towns, cities).

Solution of equation (1) is performed in three stages. First, the costs of transporting solid waste from all origins to all potential landfills are calculated. To obtain these costs, C_o, FC_s, and C_j are ignored because they are assumed constant for each landfill alternative(s). For the urban situation where $R_k = 0$, the function in (1) can be replaced by

$$(5)\ \text{Min}\ TC_k^* = c_t \sum_{j \in S_k} \sum_{i=1} x_{ij} d_{ij}$$

[1] Number of truckloads are obtained by dividing origin tonnage by truck capacity.

subject to the constraints in (2), (3) and (4), in order to solve the transportation problem for each landfill alternative. To determine the cost of various landfill combinations the fourth right hand term in (1),

$$\sum_{j \in S_k} C_j$$

is estimated for each combination of landfills. The least cost waste system is then found by minimization of

$$(6)\ \overline{TC} = \underset{k}{\mathrm{Min}}\ \overline{TC}^*_k + \sum_{j \in S_k} C_j$$

where $\overline{TC}^*_k$ are the respective minimums for TC^*_k in (5). The combination of landfills (S_k) attaining minimum cost is the optimum landfill combination. Finally, to calculate total cost of the optimum system and determine user fees, the C_o and FC_s terms must be added to (5). For analysis of the rural (unincorporated) areas in KEDDO the R_k term is obtained by establishing a containerized collection system in the rural areas then minimizing the total mileage of collection routes. The R_k term is included in the objective function only in the analysis of systems serving unincorporated areas; similarly, the $c_t \sum_{j \in S_k} \sum_{i=1} x_{ij}d_{ij}$ term is relevant only for those systems serving incorporated areas. Hence, in those combined systems serving incorporated and unincorporated areas jointly, both terms are present in the objective function. For the three types of systems analyzed in this study, their associated objective functions are:

Systems for incorporated areas;

$$(7)\ \mathrm{Min}\ TC_k = C_o + FC_s + \sum_{j \in S_k} C_j + c_t \sum_{j \in S_k} \sum_{i=1} x_{ij}d_{ij}.$$

Systems for unincorporated areas;

$$(8)\ \mathrm{Min}\ TC_k = R_k + FC_s + \sum_{j \in S_k} C_j.$$

Systems for incorporated-unincorporated (urban-rural) areas;

$$(9)\ \mathrm{Min}\ TC_k = C_o + R_k + FC_s + \sum_{j \in S_k} C_j + c_t \sum_{j \in S_k} \sum_{i=1} x_{ij}d_{ij}$$

The Components of Cost

In order to evaluate the objective functions in (7), (8), and (9), it is necessary to specify the costs associated with their components. Four major cost components are identified: collection, transportation, landfill costs and shared costs.[2] Collection costs are those costs directly associated with the physical collection of solid waste within the incorporated areas. These costs include truck operating costs (fuel, depreciation, maintenance, and repairs), driver salaries, and interest payments on collection vehicles.[3] Transportation cost consists of vehicle operating costs between origins and landfills. Landfill set-up and operating costs are assumed constant because most landfills are assumed to process approximately the same volume of waste each month, and because most landfill operating costs are fixed. Fixed landfill costs include a bulldozer and operator, rent on the land, set-up costs and insurance. Variable operating costs of fuel and maintenance are assumed constant.[4]

The fourth cost component to be estimated is the shared system cost(s). These costs are shared because they are spread over all system components. The major shared costs of any system are the costs of purchasing and operating a truckbarn, hiring of truckbarn employees, and maintaining collection containers. Other costs include salaries for a supervisor and secretary, insurance, utilities and office supplies.[5]

Unincorporated areas are characterized by wide dispersion of residences making house to house collection prohibitively expensive; hence, the R_k component of equation (8) must be estimated. The type of collection system planned in rural areas makes use of steel containers placed at strategic locations. Residents would be required to deposit their refuse in these containers for weekly collection. Location of the containers involves a tradeoff between cost and service. Grouping the containers at only a few widely separated points results in low collection cost since the trucks have only a few distinct points to visit, although such a system implies a high cost incurred by the residents who must travel long distances to deposit their refuse. At the other extreme, a high level of service will be provided by evenly distributing the containers throughout the rural areas. While residents will have to travel only a short distance to the nearest container, collection cost would rise dramatically as trucks visit more points. In this study an arbitrary compromise is employed, whereby containers are placed at major highway intersections,

[2] In the objective function for systems serving the incorporated areas, these correspond to the C_o, $c_t \sum_{j \in S_k} \sum_{i=1} x_{ij} d_{ij}$, $\sum_{j \in S_k} C_j$, FC_s terms respectively.

In the unincorporated area system objective function the collection and transportation costs are combined in the R_k term.

[3] Appendix A contains additional information on collection costs.

[4] Appendix B contains additional information about landfill costs.

[5] Appendix C contains budgets detailing shared costs.

in unincorporated towns, and along paved roads such that a maximum distance of any residence from a container is approximately four miles. The number of containers needed at each collection point is determined by the number of residences served, where each container serves 13 residences.

Given any particular set of alternative landfills, the routing problem consists of devising truck routes such that total mileage is minimized subject to the condition that all waste is collected weekly. Since more than one container location may be on a single route, the number of activities to be considered is much greater than in the urban situation. A practical method of route design called the lockset method is used in this study to limit the alternatives to a manageable number. The computer program developed by Hallberg and Kriebel [4] for this method is used to develop the routes for each set of alternative landfills.[6]

Besides the estimation of components necessary to solve for the total costs of equations (7), (8), and (9), all system planners are faced with initial capital outlays to "set up" a system. Appendix D contains tables providing estimates of both a single county's capital requirements and possible required multicounty outlays.

Empirical Results

The Single County Systems

Table 1 contains the results of the single county analysis for the four counties.[7] The first seven rows contain the results from the incorporated areas' analysis. The *most expensive* (largest user fees) is the one in the smallest county (Haskell). The *least costly* (smallest user fees) is the large Pittsburg county system. Clearly, the larger the population served the cheaper the per-resident costs. The Pittsburg-Latimer system does not result in the lowest user fees because Latimer has too few incorporated residents to pay for the costs of service. Note in each county the least cost system contains only one landfill.[8]

In section II of Table 1 the results of the unincorporated analysis are presented. All user fees are larger for unincorporated than incorporated system alternatives except for Haskell county. Incorporated systems are cheaper because of the larger populations available to share operating costs. The reason for the Haskell county exception is that Haskell has fewer urban than rural residents making low cost urban service im-

[6] Appendix D contains additional information on the calculations of the rural routes.

[7] Budgets detailing the costs of collection, transportation, shared costs, and disposal costs for these systems are presented in Table A_1, B_1, and C_1.

[8] In the single county analysis a Latimer county study is not undertaken because of its small size (1761 incorporated dwellers). We found it uneconomical for a county of this size to operate a collection and disposal system. Combinations with Pittsburg county is a lower cost option.

Table 1 Monthly Costs of Single County Systems Serving Incorporated, Unincorporated and Combined Areas of Leflore, Pittsburg, Haskell and Pittsburg-Latimer Counties, KEDDO, 1975

County	Combination of Landfill Sites	(1) Collection and Transportation $c_t\Sigma\Sigma x_{ij}d_{ij}+C_o$ ($)	(2) Disposal Costs ΣC_j ($)	(3) Fixed Costs FC_s ($)	(4) Total Costs TC_k ($)	(5) Cost per Residence ($)
		I. Incorporated Area Analysis				
Leflore	Poteau	11,887	3,006	11,264	26,157	2.82
	Poteau, Talihina	11,008	6,012	11,264	28,284	3.05
Pittsburg	McAlester	17,357	3,006	15,073	35,463	2.42
	McAlester, Kiowa	16,511	6,012	15,073	37,596	2.57
Haskell	Stigler	3,085	2,169	3,659	8,913	3.82
Pittsburg and	McAlester	21,848	3,006	16,334	41,188	2.51
Latimer	McAlester, Wilburton	19,589	6,012	16,334	41,935	2.56
		II. Unincorporated Area Analysis				
Leflore	Poteau	7,287	3,006	5,813	16,106	2.99
	Poteau, Talihina	5,030	6,012	5,813	16,855	3.13
Pittsburg	McAlester	4,553	3,006	5,527	13,086	3.20
	McAlester, Kiowa	4,349	6,012	5,527	15,888	3.88
Haskell	Stigler	1,747	2,169	2,985	6,901	3.42
Pittsburg and	McAlester	8,104	3,006	5,088	16,198	2.62
Latimer	McAlester, Wilburton	7,500	6,012	5,088	18,600	3.04
		III. Combined Analysis				
Leflore	Poteau	19,174	3,006	12,450	34,690	2.36
	Poteau, Talihina	16,038	6,012	12,450	33,314	2.27
Pittsburg	McAlester	21,910	3,006	26,771	51,687	2.76
	McAlester, Kiowa	20,860	6,012	26,771	53,643	2.87
Haskell	Stigler	4,832	3,006	6,192	14,030	3.22
Pittsburg and	McAlester	29,952	3,006	18,362	51,320	2.27
Latimer	McAlester, Wilburton	27,693	6,012	18,362	52,067	2.31

possible. The relatively large numbers of unincorporated dwellers result in lower costs in rural areas. The least cost system among unincorporated areas is the one serving the Pittsburg-Latimer area because Latimer county has a large number of rural residents and the ratio of total system costs to total numbers of residents (Latimer plus Pittsburg) is smaller than for the other three counties. Again the economies of scale hypothesis cannot be rejected.

In the third section of Table 1 the results of the combined analysis are presented. Combined systems can be operated cheaper than the other two options resulting in lower user fees for all counties and all landfill combinations except for the Pittsburg County incorporated area system. The Pittsburg-Latimer and Leflore county systems are the lowest cost of all alternatives analyzed. The $2.27 residential charge cannot be matched by any incorporated or unincorporated area system.

Multicounty Systems

To further illustrate the economies of scale hypothesis, three multicounty systems—each composed of the four counties under study—are compared. Table 2 contains the costs of components and estimates of user fees necessary to operate each of the alternative systems.[9] Column 1 of Table 2 shows transportation costs between all origins and six potential landfill combinations.[10] Column 2 contains collection costs, and in column 3 the costs of disposal are presented. Rising disposal costs indicate additional landfills. Shared costs are presented in column 4. They are needed to calculate user fees and total system costs but do not influence selection of the least cost landfill combinations within a given system, (incorporated, unincorporated, combined). Shared costs differ between the three systems, however, because of container depreciation. The incorporated and combined systems require more containers than other systems, and hence incur larger shared costs thus affecting comparisons of alternative system costs. Column 5 contains total system costs. The least cost systems range from $69,459 for the incorporated system to $90,211 for the combined system.

Section I of Table 2 contains the results from the incorporated system multicounty analysis. The least cost option specifies three landfills to be located in McAlester, Poteau, and Quinton at a cost of $69,459, with user fees of $2.49 per residence. Comparing this outcome with section 1, Table 1, we see that no individual county system approaches this cost. The lowest monthly cost and corresponding user fee is found in

[9] Tables A_2 and C_2 contain the collection, transportation and shared cost estimates for the three systems.

[10] The combinations presented include the minimum cost options as well as combinations likely to be considered on geographical, institutional and political grounds. Additional combinations are available upon request.

Table 2 Monthly Costs of Multicounty Systems Serving A Four County Area, KEDDO, 1975

Landfill Locations	(1) Transportation Costs $c_t\Sigma\Sigma x_{ij}d_{ij}$ ($)	(2) Collection Costs C_o ($)	(3) Disposal Costs ΣC_j ($)	(4) Shared Costs FC_s ($)	(5) Total Costs TC_k ($)	(6) Estimated User Fees ($)
		I. Incorporated Analysis				
McAlester	34,075	23,884	3,006	24,799	85,764	3.06
McAlester and Poteau	15,328	23,884	6,012	24,799	70,077	2.50
McAlester, Ft. Smith	19,735	23,884	6,012	24,799	74,440	2.66
Crowder, Poteau	19,341	23,884	6,012	24,799	74,036	2.66
McAlester, Quinton, Poteau	11,758	23,884	9,018	24,799	69,459	2.49
McAlester, Stigler, Poteau	11,974	23,884	9,018	24,799	69,675	2.49
		II. Unincorporatd Analysis				
Poteau, McAlester		20,327	6,012	8,548	34,887	2.56
Poteau, McAlester, Talihina		17,257	9,018	8,548	34,823	2.56
Poteau, McAlester, Talihina, Stigler		15,463	12,024	8,548	36,035	2.65
Poteau, McAlester, Talihina, Stigler and Wilburton		13,758	15,030	8,548	37,336	2.75
		III. Combined Analysis				
Poteau, McAlester		59,593	6,012	27,481	93,085	2.21
Poteau, McAlester, Stigler		53,712	9,018	27,481	90,211	2.14
Poteau, McAlester, Talihina		56,577	9,018	27,481	93,076	2.21

Pittsburg County. If we add up the least costs of the three single county incorporated systems (assuming independent operations) the total cost per month is $76,258, and user fees average $2.71. This large multicounty cost, compared to the cost of $69,459 results in wasted resources, high user fees and wasted county revenues. By operating a multicounty system, opposed to three separate county systems, $6,799 ($76,258-$69,459) can be saved each month; the yearly savings is $81,588.

Comparing section 2 of Table 2 with section 2 of Table 1 yields similar results. Section 2 of Table 2 contains results of the multicounty unincorporated analysis. Four landfill combinations are presented and the least cost is $34,823, with corresponding user charges of $2.56. No single county incorporated system has user fees of $2.56 or lower. Pittsburg and Latimer together could collect and dispose of solid waste products for $16,198 a month and $2.62 per resident. Again, if the costs of the individual county systems are added the multicounty cost would be $39, 205, and annual revenue waste of $52,584 would result.

Finally, section 3 of Table 2 and section 3 of Table 1 are compared. The least cost option from the multicounty analysis is $90,211 with user fees estimated to be $2.14 per residence. Landfill locations are Poteau, McAlester and Stigler. The lowest cost, single county shared systems are in Leflore County with landfills located in Poteau and Talihina, and in Pittsburg-Latimer counties with a landfill located in McAlester. Although the total costs of these systems differ, the user fees are equal ($2.27). If the single county combined systems are added, the total cost is $98,664, and the lost annual revenue is $101,436.

Clearly, there are advantages to cooperation. The cost reductions obtained from operating a multicounty system rather than single county systems average 15% and similar cost reductions result from joining rural with urban collection within a county. Finally, it is shown that the larger the population of a county the lower the per capita user costs. Figure 3 is an estimated long run average cost curve representing the cost per ton of collecting, transporting and disposing solid waste from the incorporated areas in the study area. As shown, costs are minimized when approximately 1750 tons per month are handled. To achieve this tonnage approximately 38,000 people must be served, which approximates the combined incorporated populations of three of the four study counties (or of Pittsburg county alone). As indicated by the flattening of average cost beyond 1750 tons, additional service (tonnage handled) can be provided for practically the same low cost. System planners anticipating fu-

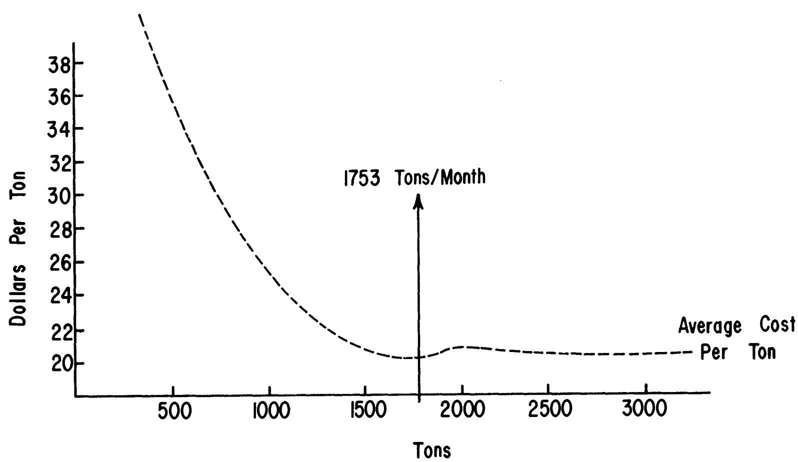

Figure 3. Average cost of collecting, transporting and disposing of solid waste from incorporated areas.

ture population growth will be able to increase the volume of waste collected and disposed for approximately $20 per ton, assuming the costs of components remain fixed. Hence, solid waste systems designed to handle current volume will be able to absorb rising future increases.

Inflation

At the present time there is concern over the rising costs of equipment, fuel and other variable inputs needed in system operation. The rising cost of fuel, oil and parts concerns system planners because these cost increases affect system planning. As indicated in a previous section the costs of these items are absorbed into operating costs immediately while the costs of machinery and the like can be postponed until new equipment is needed.

To evaluate the effects of rising costs we doubled the operating costs of collection vehicles to $1.50 per vehicle mile. The incorporated area analyses performed earlier were recomputed using this higher cost. In all cases, except the single county system in Haskell county, the costs of fuel and vehicle maintenance are estimated to be about 25% of total system cost.[11] As shown in Table 3, doubling of transport and repair costs results in a 25% average increase in both operating costs and user fees.

Rising costs not only increase user fees, but can alter the number of landfills in an optimal system. In Table 3 it is shown that the optimal landfill numbers in the Pittsburg-Latimer system have increased along with operating costs. At $.75 per mile the optimal locations called for a single landfill at McAlester. When costs increased to $1.50 per mile, landfills substituted for vehicle mileage and the least cost solution suggested landfill facilities at McAlester and Wilburton. The savings resulting from reduced transportation costs are large enough to pay for the added landfill. Almost 2500 miles of travel per month have to be eliminated before an added landfill becomes profitable.

Conclusions and Limitations

The maintained hypothesis tested in this paper is that economies of scale can be achieved through the operation of "large" solid waste systems. We found that, for the study area, counties with large populations can operate a system cheaper, on a per-resident basis, than a small county and that multicounty systems are less expensive, per resident, than the lowest cost single-county system. In addition, the operation of a multicounty system would save approximately $100,000 per year compared to the cost of operating separate county wide systems.

[11]In Haskell county, the figure is about 12%. Haskell county is quite small (total number of residents is 2331) and vehicle mileage driven per month is low.

Table 3 Estimated Monthly Costs and User Fees of Optimal Solutions From Multi and Single County Incorporated Systems Assuming $.75 and $1.50 per mile Operating Costs, KEDDO, 1975

County	Landfill Locations	$.75 Total Cost	$.75 User Fees	Landfill Locations	$1.50 Total Cost	$1.50 User Fees
4 County System	McAlester, Quinton, Poteau	$69,459	$ 2.49	McAlester, Quinton, Poteau	$95,175	$3.40
LeFlore	Poteau	26,157	2.82	Poteau	34,499	3.72
Pittsburg	McAlester	35,436	2.42	McAlester	47,121	3.23
Haskell	Stigler	8,913	3.82	Stigler	10,580	4.54
Pittsburg and Latimer	McAlester	41,188	2.51	McAlester, Wilburton	54,434	3.32

In view of these results the following conclusions can be made for the study areas. Clearly, the most economically efficient way to provide solid waste disposal service to LeFlore, Pittsburg, Latimer and Haskell counties would be with a multicounty system capable of serving all residents. Landfills located in Poteau, McAlester and Stigler would insure cost minimization. Second, if unincorporated service is to be postponed until required by state law the second least costly alternative is a multicounty plan serving only incorporated areas. Optimal operation of such a system occurs with landfills operating in McAlester and Poteau and a third near Stigler or Quinton. Finally, if county cooperation is not feasible, the individual counties can minimize costs by operating single landfills. Section 1, Table 1, identifies the least cost sites. As shown Pittsburg county can operate a system serving its own urban customers cheaper than if it combines in a multicounty venture. If Pittsburg county operates alone however, the cost of serving the remaining three counties would result in wasted revenue in the aggregate. As shown previously, a joint system can save $100,000 or more in yearly revenue for the KEDDO counties.

The assumptions in this analysis must be recognized and kept in proper perspective by system planners. First, we assumed that containerized collection would take place in urban areas rather than house-to-house pickup. Second, certain specifications are made regarding the size of trucks, containers, wages, size of facilities, etc. All costs and specifications about equipment were obtained, as documented, from reliable sources. However, changed specifications (i.e., 16 cu. yd. trucks or 1 cu. yd. boxes) would alter the costs obtained here. Likewise, the purchase of used machinery instead of new would alter not only initial outlay costs but also variable operating costs.

The analysis performed here included all incorporated cities and towns in the four county area into the analysis. In reality it may well occur that a county or multicounty system may only serve a subset of these towns. Again, the costs and corresponding user fees would be changed. What will not change, however, are the economic conclusions that bigger is less expensive per capita and that three landfill sites serving the four study counties is the least cost way to achieve waste collection and disposal.

Appendix A

Tables A_1 and A_2 contain the costs of collecting solid waste in single and multicounty systems, respectively. Collection costs are composed of residential collection costs, salaries of vehicle operators, depreciation on equipment and interest charges on borrowed capital.

The first entry on both tables represents the cost of residential collection in urban areas and the cost of route collection (R_k) in the unincorporated analysis. Transport costs are a function of the number of vehicles required, the distances traveled and variable operating costs. Vehicle numbers are determined by volume of waste production, and operating costs depend on per mile operating charges times total mileage driven.

Data on the number of homes and businesses located in each of the incorporated areas were obtained and the street miles driven by collection vehicles were estimated using a coefficient of 0.08 miles driven per collection. This coefficient is based on data from the Stillwater, Oklahoma, system. Even through the KEDDO and Stillwater residential areas are not identical the coefficient is the best available. Total transport cost per truck is found by multiplying operating cost per mile, estimated to be $.75, by total mileage driven.

Given monthly volumes of waste production in the incorporated areas, the required number of trucks and the corresponding costs of drivers, depreciation and interest can be determined. Each truck is operated by one man whose salary is $500 per month. Truck depreciation and interest expenses are based on an initial cost of $20,000 and a ten-year vehicle life. Interest calculations are based on a 5% rate of interest on the average investment over the ten year life. Table A_1 contains a budget detailing the costs of collection for all single county systems. Table A_2 contains this information for the multicounty analyses.

Table A_1 Monthly Collection Costs for the Incorporated Systems Serving Haskell, Leflore, Pittsburg and Pittsburg-Latimer, KEDDO, 1975

	Haskell	LeFlore	Pittsburg	Pittsburg-Latimer
		DOLLARS		
Residential Collection Cost				
Truck fuel, repairs, maintenance $.75 per mile	1,196	4,760	7,528	8,433
Salaries				
1 man/truck, $500/man	1,000	2,500	4,000	5,000
Depreciation Expenses				
$20,000 purchase price, 10 yr. life $167/truck	334	835	1,336	1,670
Interest Expense				
5% interest on average investment $42/truck	84	210	336	420
Total Collection Cost	2,614	8,305	13,200	15,523

Table A_2 Monthly Collection and Transportation Cost for Multicounty Systems Serving Pittsburg, Latimer, Leflore and Haskell Counties, KEDDO, 1975—Landfills located at Poteau, McAlester, Talihina

	Unincorporated Costs	Incorporated Costs	Combined Costs
Residential Collection Cost		DOLLARS	
Truck fuel, repairs and maintenance, $.75 per mile	12,294	13,958	41,688[1]
Salaries:			
1 man per truck, $500 per man	3,500	7,000	10,500
Depreciation Expense:			
$20,000 purchase price of trucks, 10 yr. life, $167 per truck,	1,169	2,338	3,507
Interest Expense:			
5% interest on average investment $42 per truck	294	588	882
Total Collection and Transportation Cost	17,257	23,884	56,577[1]

[1] This total cost includes a $15,436 charge for transporting solid waste from incorporated areas to the landfills.

Appendix B

Table B_1 contains the estimated cost of a landfill operation. Fixed costs include 30 acres of land, the bulldozer, the dozer operator, utilities, and set-up expenses. Variable costs are the hourly operating costs of the equipment plus maintenance. Based on surveys of two Oklahoma landfill sites these costs are assumed constant at $800 per site.

In the four-county area, seven landfills are considered for entry into the least cost solution. Four landfills are currently in operation and three potential sites have been selected. Landfills exist in Poteau, Stigler, Quinton, and McAlester. Potential sites were identified in Fort Smith, Arkansas, Talihina and Wilburton, Oklahoma. These were selected on the basis of geographical location to large population centers.

The potential number of site combinations (S_k) is 127, obtained by solution of $S_k = \sum_{j=1} \binom{7}{j} = 127$. Since seven landfills have been chosen as potential sites it is possible that a multicounty system could be operated using 1, 2, 3, or all 7 landfills. Likewise any combination of the 7 landfills could prove to be least cost. For the individual county analyses potential site combinations are, of course, fewer. In both the single and multicounty analyses presented in this paper only the lowest cost combinations are presented.

Table B_1 Monthly Cost Budget For a Single Landfill Operation KEDDO, 1975[1]

		Dollars
Land Expense:		
30 acres, $500 per acre amortized over 10 years plus 5% interest payment		156
Dozer Operator Salary:		583
Dozer Expense:[2]		
Fuel	300	
Maintenance, repairs each estimated at $3.00 per hr., 10,000 hr. life	500	
Depreciation $135,000 purchas price, 10 yr. life	1,125	
Interest	281	
Total Dozer Expense		2,206
Utilities:		30
Set-up Expense:		
Landfill site preparation — $3700 amortized over 10 years plus 5% interest payment		31
Total Monthly Landfill Cost		3,006

[1] Equipment costs are based on 1974-75 retail costs, obtained from Oklahoma equipment dealers. Operating costs were obtained from existing systems in Oklahoma.

[2] Bulldozer expense for the landfill alternative at Stigler in Haskell County is less than shown due to the use of a smaller (25,000 lb.) dozer. Fuel expense is estimated at $150 and depreciation and interest expenses are based on a purchase cost of $69,000. Total landfill expense for a landfill at Stigler is $2,169 per month. This figure is used in the analysis of single county systems for Haskell County.

Appendix C

Tables C_1 and C_2 contain the monthly shared costs of single county systems and multicounty systems, respectively. Shared costs consist of salary expenses for supervisors, mechanics, and clerical help. It is assumed that labor expenses are equal for both single county systems (except Haskell) and multicounty systems. Likewise, the costs of insurance, utilities and supplies are assumed equal with Haskell County the exception. Because Haskell County has a significantly smaller population, a system serving this county would not need to incur all of the expenses of a full-time supervisor, two mechanics, etc.

Depreciation expense is the largest fixed cost in the system. The items depreciated are trucks, containers and the truckbarn facility. The cost of the multicounty system is more expensive than the single county system due to the large number of containers required. In the combined multicounty analysis approximately 7900 containers are required. Containers are assumed to serve four residents in incorporated areas and thirteen residents in unincorporated areas.

Table C_1 Monthly Shared Costs for the Incorporated Systems Serving Haskell, Leflore, Pittsburg, Pittsburg-Latimer, KEDDO, 1975

	Haskell	LeFlore	Pittsburg	Pittsburg-Latimer
Salary Expense:		DOLLARS		
Supervisor	600	1,200	1,200	1,200
Truckbarn mechanic	400	1,100	1,100	1,100
Secretary		400	400	400
Total Salary Expense	1,000	2,700	2,700	2,700
Insurance:	700	1,300	1,300	1,300
Utilities:	100	100	100	100
Office Supplies:	150	150	150	150
Total	950	1,550	1,550	1,500
Depreciation:				
1 truckbarn ($60,000 cost, 30 yr. life)		167	167	167
Pickup trucks ($3000 each, 10 yr. life)	30	30	30	30
1 welding truck ($4500, 10 yr. life)		38	38	38
Containers ($275 each, 10 yr. life)	1,338	5,310	8,358	9,366
Total	1,368	5,545	8,592	9,601
Interest Expense:	341	1,469	2,231	2,483
Total	3,659	11,264	15,073	16,334

Table C_2 Monthly Shared Costs for Multicounty Systems Serving Pittsburg, Latimer, Haskell and Leflore Counties

	Incorporated Costs	Unincorporated Costs	Combined Costs
Salary Expense:		DOLLARS	
Supervisor	1,200	1,200	1,200
Truckbarn mechanics (2)	1,100	1,100	1,100
Secretary	400	400	400
Total Expenses	2,700	2,700	2,700
Insurance:	1,300	1,300	1,300
Utilities:	100	100	100
Office Supplies:	150	150	150
Depreciation Expense:			
Truckbarn ($60,000 cost, 30 yr. life)	167	167	167
Pickup trucks ($3000 each, 10 yr. life)	120	120	120
Welding trucks ($4000 each, 10 yr. life)	76	76	76
Containers ($275 each, 10 yr. life)	16,011	2,392	18,156
Total Depreciation	16,374	2,755	18,519
Interest Expense:	4,175	1,543	4,712
Total Monthly Fixed Cost	24,799	8,548	27,481

Appendix D

Use of the lockset program requires estimation of several variables. First, the volume of waste to be picked up at each location and truck capacity are needed. Only one type of truck was studied: a side-loading packer with capacity of 20 cubic yards (5 tons). Such a truck is capable of holding the weekly solid waste from 182 residences. The number of containers required depends solely upon the total number of residences served by the system. A 4 cubic yard container is capable of holding the solid waste from approximately 13 residences per 7-day period. It is assumed that an average residence consists of 2.67 persons and each person produces three pounds of solid waste per day. A second type of information needed is the distances between every pair of locations and the distance between each location and the landfill. It is assumed that trucks drive at an average speed of 40 mph, and that three minutes loading time are required. Given these inputs, the program selects the routes, the sequence of location pickups, the mileage driven and total time required for collection and uploading.

Since the lockset method is able to consider only one landfill at a time it is assumed that each location would be picked up by a truck from the closest landfill. Thus for a set with two landfills, the program was run twice—once for the first landfill to obtain the routes for the locations nearest it, and again for the second landfill. The total mileage and time required by the system is the sum of route mileage traveled. These two outputs—total mileage and total time—are used to develop the R_k term in the rural objective function.

Appendix E

Tables E_1 and E_2 below contain budgets detailing the capital requirements of a single county waste management system and a multi-county system respectively. In both cases the total outlay will vary with population density and amount of equipment required but the budgets provide good approximations of the costs of setting up waste management systems in the study counties.

Table E_1 Estimated Capital Outlay Requirements for a Single County System in Southeast Oklahoma—Population 9,374 KEDDO, 1975

Item	Number	Purchase Price (per unit $)	Total Outlay ($)
Collection Vehicles	3	20,000	60,000
Land Purchase	30 Acres	500	15,000
Land Preparation	–	3,700	3,700
Bulldozer (50,000 lbs. or larger)[1]	1	135,000	135,000
Truckbarn[2]	1	30,000	30,000
Pickup Truck	1	3,500	3,500
Welding Truck	1	4,500	4,500
Container[3]	584	275	160,600
Legal Costs		11,000	11,000
Office Equipment		3,000	3,000
Total Capital Outlay			426,300
Monthly Principle Payments (10 yr. loan) on the $426,300 debt		3,552	
Average monthly interest expense on $426,300 assuming 5% interest on average balance. (Current FHA loan rates are approximately 5%)		888	

[1] Three leading crawler tractor companies gave estimates on tractors weighing 50,000 or more at prices from $120,000 to $135,000.
[2] Truckbarn facilities may already exist or be constructed at lower costs than indicated here. The $30,000 price is a liberal estimate which provides for a barn large enough to handle four or five trucks.
[3] Container requirements will vary depending on the population of a county. One container is assumed to serve four households.

Table E_2 Capital Outlay for a Multicounty Incorporated System Designed Serve Pittsburg, Leflore, Haskell and Latimer Counties, KEDDO, 1975

Item	DOLLARS Number	Purchase	Amount
Collction Truck	14	20,000	280,000
Land	90 Acres	500 per Acre	45,000
Land Preparation			11,100
Bulldozer	3	135,000	405,000
Truckbarn	1	60,000	60,000
Pickup truck	4	3,500	14,000
Welding truck	1	4,500	4,500
Containers (4 cu. yd.)	6987	275 each	1,921,425
Total Capital Expenditures		2,741,026	
Monthly Principle (10 year loan)		22,841	
Monthly Interest (5% on average balance)		5,710	

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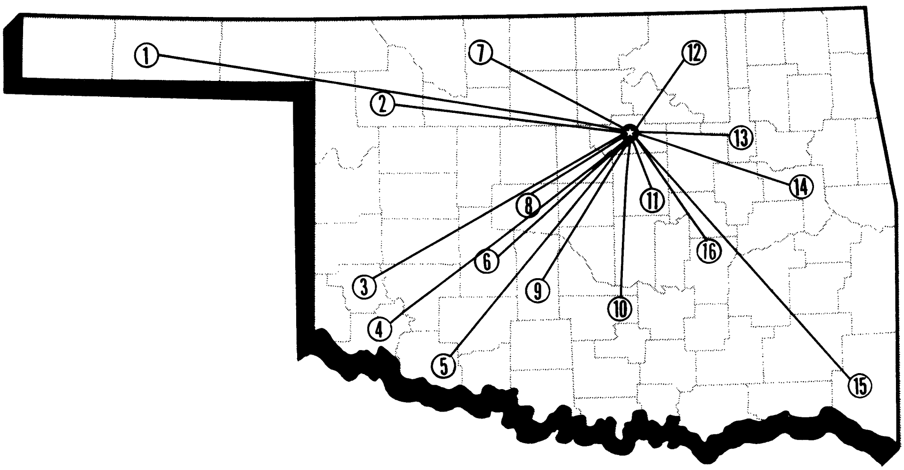
OKLAHOMA

Agricultural Experiment Station

System Covers the State



Main Station — *Stillwater, Perkins and Lake Carl Blackwell*

1. **Panhandle Research Station — *Goodwell***
2. **Southern Great Plains Field Station — *Woodward***
3. **Sandyland Research Station — *Mangum***
4. **Irrigation Research Station — *Altus***
5. **Southwest Agronomy Research Station — *Tipton***
6. **Caddo Research Station — *Ft. Cobb***
7. **North Central Research Station — *Lahoma***
8. **Southwestern Livestock and Forage Research Station — *El Reno***
9. **South Central Research Station — *Chickasha***
10. **Agronomy Research Station — *Stratford***
11. **Pecan Research Station — *Sparks***
12. **Veterinary Research Station — *Pawhuska***
13. **Vegetable Research Station — *Bixby***
14. **Eastern Pasture Research Station — *Muskogee***
15. **Kiamichi Field Station — *Idabel***
16. **Sarkeys Research and Demonstration Project—*Lamar***

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