A SOLID WASTE PLAN FOR SOUTHEASTERN OKLAHOMA

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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 [4]. 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. Some large towns have collection and disposal systems, but many smaller towns have no service or partial service. A few are not in compliance with the law.

The counties of Oklahoma contained in the Kiamichi Economic Development District, hereafter referred to as KEDDO, have indicated the need for a solid waste management plan, Figure 1.[1] In view of the area's need, the goal of this research was to determine the least cost solid waste system utilizing the landfill disposal method. The KEDDO area was divided into two separate geographical study areas for the purpose of examining waste systems. The first area, consisting of Choctaw and McCurtain counties, was considered here. Both single and multicounty system alternatives were studied. Further, the analysis included unincorporated as well as incorporated areas.

METHODOLOGY

Linear programming was employed to develop the optimum solid waste collection and disposal system.[2] In particular, a cost-minimization algorithm was used to search for optimal numbers and location of landfill sites based on transportation costs between origins and landfills. Three active and five potential, but nonexistent, landfills were selected for consideration. Sites considered were those indicated by a ⊙ in Figure 2.

Letting $S_1, \ldots, S_{255}$ represent all possible combinations (nonempty subsets) of the eight potential site combinations, $255=\Sigma_{j=1}^{8} \binom{8}{j}$, a cost minimization problem was solved for each landfill combination. Each cost minimization problem was subject to both supply and demand restrictions. The problem was expressed as:

$$\min TC_k = C_o+R_k+FC_s+\sum_{j\epsilon S_k} C_j + \sum_{j\epsilon S_k} \sum_{i=1}^{o} x_{ij}c_{ij} \qquad (1)$$

Subject to

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

$$\sum_{i=1}^{o} x_{ij} \leq b_j, j\epsilon S_k \qquad (3)$$

$$x_{ij} \geq 0, i=1,\ldots,0;\ j\epsilon S_k \qquad (4)$$

where

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[1] The counties included in KEDDO are: Pittsburg, Pushmataha, McCurtain, LeFlore, Choctaw, Latimer and Haskell.

[2] The methodology employed is similar to that employed in Clayton [1].

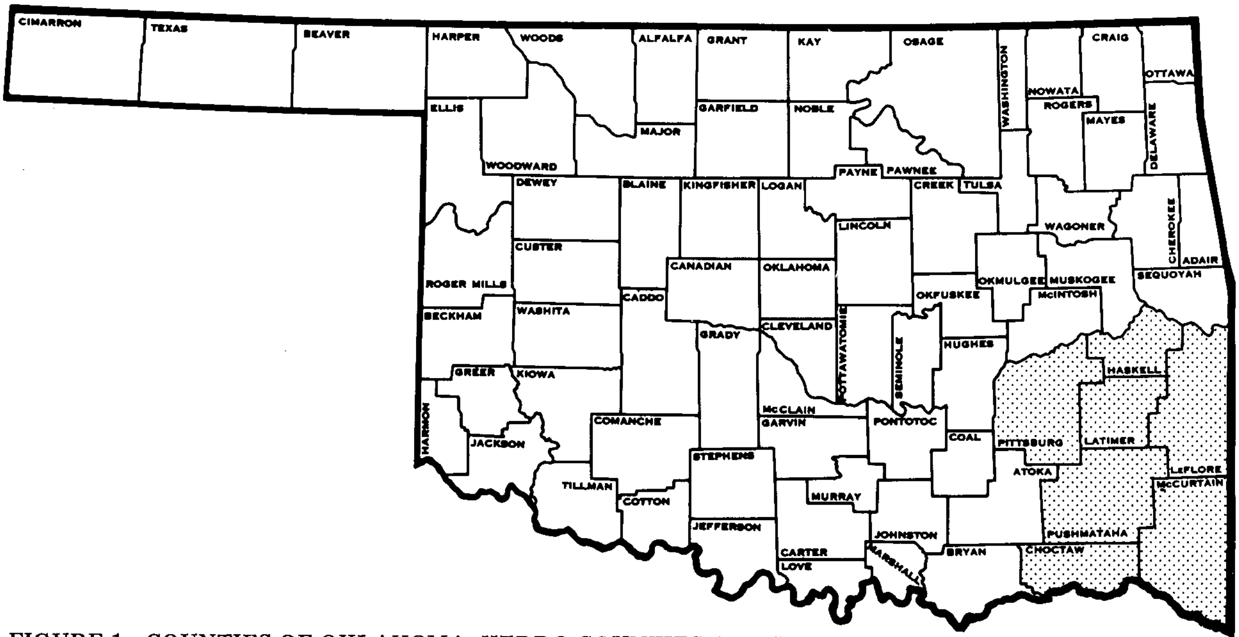

FIGURE 1. COUNTIES OF OKLAHOMA; KEDDO COUNTIES ARE SHADED

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

C_o = monthly collection costs of house-to-house residential pick-up

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 (salaries, boxes, buildings and capital expenses)

C_j = monthly cost of disposal at landfill j

x_{ij} = monthly quantity of solid waste transported from origin i to landfill j

b_j = maximum volume of waste per month disposed in landfill j (in terms of truck loads)

a_i = monthly volume of waste generated in origin i (in terms of truck loads)

c_{ij} = cost per ton transported from origin i to landfill j

o = number of origins.

In solving the above transportation problem C_o, FC_s, and C_j were ignored because they represented fixed values for each landfill alternative. Hence, for urban problems, where R_k=0, the function in (1) could be replaced by min $TC_k^* = \Sigma_{j\epsilon S_k} \Sigma_{i=1}^{o} x_{ij}c_{ij}$ subject to constraints in (2), (3) and (4). To determine the best landfill combination, the third right hand term in (1), $\Sigma_{j\epsilon S_k} C_j$, was estimated for each landfill alternative. The optimal waste system (landfill alternative) was then found by determining

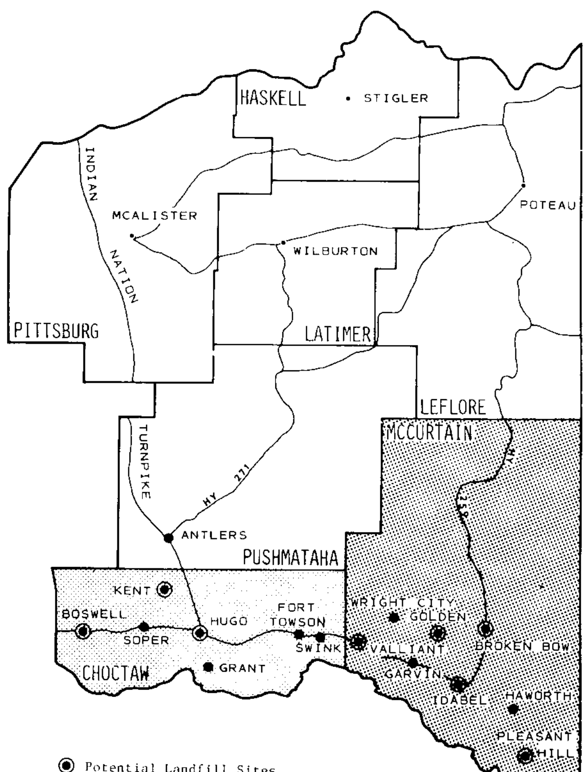

FIGURE 2. SOLID WASTE ORIGINS AND LANDFILL SITES IN CHOCTAW AND McCURTAIN COUNTIES, KEDDO, 1976

$$\overline{TC} = \min_k \overline{TC}_k^* + \sum_{j\epsilon S_k} C_j \quad (5)$$

where $\overline{TC}_k^*$ are the respective minimums for TC_k^* in the above transportation problems. Since C_o and FC_s were fixed over all landfill alternatives, they needed to be estimated only to establish user fees.

For rural problems, the $\Sigma_{j\epsilon S_k} \Sigma_{j=1} x_{ij} c_{ij}$ term of equation (1) remained equal to $\overline{TC}_k^*$ since collection costs in the rural system were based entirely on route mileage traveled by collection vehicles (reflected in R_k). The objective function for unincorporated areas was:

$$\min \overline{TC}_k = C_o + FC_s + R_k + \sum_{j\epsilon S_k} C_j + \overline{TC}_k^* \qquad (6)$$

THE COMPONENTS OF COST

To evaluate the objective functions in (1), (5) and (6) it was necessary to identify costs associated with their components. Four cost categories were identified: collection, transportation, landfill costs and shared costs.

Collection costs were directly associated with the physical collection of solid waste. These included truck operating costs (fuel, depreciation, maintenance and repairs), driver salaries and interest payments on collection vehicles. Collection costs were a function of number of vehicles required and distances traveled per month. Vehicle requirements were estimated on the basis of volume and miles driven in making collections. Assuming a \$.50 per mile operating cost [3, 5] and a monthly tonnage of 1500 tons, collection cost in incorporated areas was approximately \$4,500 per month.

Unincorporated areas were characterized by a wide dispersion of residences, making house-to-house collection prohibitively expensive; hence, the R_k component of equation (6) had to be estimated. The type of collection system planned in rural areas made use of steel containers placed at strategic locations, enabling rural residents to travel short distances to a container.

Container locations were at major highway intersections, in unincorporated towns, and along paved roads. The number of containers employed at each collection point was determined by number of residences served, where each container served 13 residences. Given a set of landfill alternatives, the routing problem consisted of devising routes to minimize total mileage.

Routes were established on the basis of truck capacity. Each was designed so that a 20 cubic yard truck could collect a week's solid waste production in one trip. Thus, each route was contrained to include no more than 182 homes or business equivalents; once-a-week collection was assumed and resulted in 40 routes.[3]

The major difference between the incorporated areas system and the rural one was inclusion of collection time. In the urban system, number of turcks required for use was determined on basis of volume. In the rural system, calculation of monthly driving time to collect solid waste on all routes was necessary because a significant amount of time was required in driving.[4] A practical method of route selection, called the lockset method, was used in this study [2].

Transportation costs consisted of vehicle operating costs between origins and landfills. Given the twelve origins and eight destinations, transportation costs were determined between each landfill combination and all origins. Although 255 landfill combinations were possible, many combinations were ruled out on the basis of unnecessary costs. With few exceptions, least cost combinations resulted when existing landfills (Hugo, Idabel, Broken Bow), opposed to potential ones were included.

Disposal costs included fixed and variable costs. Fixed costs included land, bulldozer and dozer operator, utilities and set-up expenses. Variable costs included the hourly operating costs of the equipment plus maintenance. Based on surveys of two Oklahoma landfill sites, these costs were approximately \$400 per site.[5] Landfill costs were estimated at \$3,006 per month.

The fourth cost component estimated was the shared system cost(s). These costs were spread over all system components. Major items of shared costs included acquisition and operations of a truckbarn, hiring of employees and maintenance of collection equipment. Other costs were salaries for a supervisor and secretary, insurance, utilities and office supplies. For the two-county system, shared costs were \$17,645 [5].

[3]Each household produced about 56 pounds of solid waste for disposal per week. Given this estimate, 182 households would produce about five tons of waste, which is 20 cubic yards, or one truck load.

[4]Each route contained 14 containers spaced an average of 2.85 miles apart. Assuming average speeds of 30 miles per hour along the routes and 45 miles per hour driving to the landfills, the total driving time per week was approximately 45 hours. In addition, almost 36 hours per week of truck time were required for loading, unloading and overhaul.

[5]The variable costs of operating a bulldozer were estimated at \$2.50 per hour. The machine consumes five gallons of fuel per hour at a cost of \$.40 per gallon. The cost of oil and maintenance was approximately \$.50 per hour.

EMPIRICAL RESULTS

Incorporated Area Analysis

Table 1 contains the results of the multicounty urban analysis. The least costly option was that in which landfills were located in Hugo, Idabel and Broken Bow. Total costs were $33,905 per month, with a fee of $2.58 per residence.[6] Other locations with differing numbers of landfills and other options resulted in higher monthly costs.

As a basis of comparing costs and corresponding user charges, a similar analysis was performed on an individual county basis to determine if the multicounty system resulted in economies of scale. Costs for single county systems and corresponding user charges are presented in Table 2.

The lowest cost Choctaw county system was $21,902, with a landfill located in Hugo. The least-cost solution in McCurtain County also resulted in a single landfill, located in Idabel.

Both single county systems resulted in user fees larger than multicounty systems. Cost reductions obtained through sharing of equipment and management resulted in economies to users. In fact, the total cost of operating the Choctaw and McCurtain county systems separately ($21,901 plus $22,658) was $44,560 which was $10,655 per month higher than the least-cost multicounty plan. An excess annual cost of $127,860 resulted if the single county systems were operated independently. The corresponding user fees for a single county system were lower in McCurtain County (with a greater population) than in Choctaw County, further supporting the economy of size hypothesis.

Combined Analysis

Since the average cost of waste collection and disposal fell as tonnage handled increased, costs were estimated when incorporated and unincorporated areas were combined (Table 3). In the unincorporated areas, house-to-house collection was not feasible because residences were scattered. Hence, a containerized collection system was utilized in rural areas and house-to-house collection in incorporated areas. As shown, the least-cost solution required landfills at Hugo and Idabel with a cost of $44,941 per month. User fees were estimated at $2.18 per month per residence, resulting in a $.40 per month savings.

To obtain a comparison with the single county result, presented in Table 2, single county analyses were again made, including unincorporated area collection. The least-cost system serving Choctaw county was $27,783 per month, with user fees of $3.02 per residence. For McCurtain county, the least cost was $29,621 per month with a $2.54 residence charge. Both counties incurred user costs lower than those reported in Table 2 but larger than those in Table 3, emphasizing advantages of including all potential customers. Both the single county least-cost system and single county combined system were obtained with single landfills in Hugo for the Choctaw analysis and Idabel for the McCurtain system.

CONCLUSIONS AND LIMITATIONS

The hypothesis that economies of scale can be achieved through the operation of large solid waste

TABLE 1. ESTIMATED MONTHLY SYSTEM COSTS FOR A MULTICOUNTY URBAN SYSTEM, VARIOUS LANDFILL COMBINATIONS, KEDDO, 1975

(1) LANDFILL LOCATIONS	(2) COLLECTION COSTS ($)	(3) TRANSPORTATION COSTS ($)	(4) DISPOSAL COSTS ($)	(5) SHARED COSTS ($)	(6) TOTAL COSTS ($)	(7) RESIDENCE CHARGE ($)
Hugo, Idabel, Broken Bow	4,500	2,742	9,018	17,645	33,905	2.58
Idabel, Broken Bow	4,500	10,669	6,012	17,645	38,826	2.95
Hugo, Antlers, Idabel, Broken Bow	4,500	1,973	12,024	17,645	36,142	2.75
Hugo, Antlers, Valliant, Idabel, Broken Bow	4,500	1,408	15,036	17,645	35,583	2.71
Hugo	4,500	9,778	3,006	17,645	34,929	2.66

[6] Residence fees were estimated by dividing total system costs by the number of residences being served. No attempt was made to calculate business fees because fees are traditionally based on the frequency of service provided and volume of waste per collection.

TABLE 2. ESTIMATED MONTHLY SYSTEM COSTS FOR TWO URBAN SYSTEMS IN CHOCTAW AND McCURTAIN COUNTIES, KEDDO, 1975

(1) LANDFILL LOCATIONS	(2) COLLECTION COSTS ($)	(3) TRANSPORTATION COSTS ($)	(4) DISPOSAL COSTS ($)	(5) SHARED COSTS ($)	(6) TOTAL COSTS ($)	(7) RESIDENCE CHARGE ($)
		Choctaw County				
Kent, Hugo	2,354	1,276	6,012	14,922	24,564	4.92
Kent	2,354	2,511	3,006	14,922	22,793	4.56
Hugo	2,354	1,620	3,006	14,922	21,902	4.39
		McCurtain County				
Broken Bow, Valliant, Golden	2,156	1,662	9,018	15,871	28,707	4.26
Broken Bow, Idabel	2,156	1,019	6,012	15,871	25,058	3.72
Idabel	2,156	1,628	3,003	15,871	22,658	3.36

systems was supported. Counties with large populations could operate a system at a lower per-resident cost than a small county. Multicounty systems result in less cost per residence than the lowest cost single-county system. Also, the operation of a multicounty system resulted in $127,000 less per year than separate county-wide systems.

First, Choctaw and McCurtain counties should plan to operate a multicounty system designed to serve both rural residents and those living in incorporated areas. If rural service were not possible, the second best solution was a multicounty system serving the 12 incorporated areas. If cooperation was not feasible, individual counties could minimize costs by operating a single landfill each, and offering urban as well as rural service. It was shown that incorporation of rural areas lowered user fees.

Assumptions in this analysis must be recognized and kept in proper perspective by system planners in other areas. Our conclusions were presented for a specific geographical area. We assumed house-to-house collection in urban locations and containerized collection in rural areas would take place. Certain specifications were made regarding size of trucks, containers, wages, size of facilities, etc. Changes in the method of collection or specifications of equipment would alter results.

Likewise, purchase of used machinery would alter not only initial outlays but also variable costs. These assumptions, to some extent, dictate the magnitude of system cost. Planners in any state, however, can adopt the methodology developed here to determine location and number(s) of landfill sites and the costs of single or multicommunity systems. Identification of prospective landfill sites, distances between origins and these sites, and cost estimates of needed equipment and personnel are required data to develop system alternatives for any area.

TABLE 3. ESTIMATED MONTHLY COSTS OF A MULTICOUNTY RURAL-URBAN SYSTEM IN CHOCTAW AND McCURTAIN COUNTIES, KEDDO, 1975

(1) LANDFILL LOCATIONS	(2) TRANSPORTATION AND COLLECTION COSTS ($)	(3) DISPOSAL COSTS ($)	(4) SHARED COSTS ($)	(5) TOTAL COSTS ($)	(6) RESIDENCE CHARGE ($)
Hugo, Idabel, Broken Bow	11,546	9,018	26,763	47,327	2.30
Hugo, Idabel	12,166	6,012	26,763	44,941	2.18
Hugo, Idabel, Broken Bow, Kent	8,690	12,024	26,763	47,477	2.31
Hugo, Idabel, Broken Bow, Valliant, Golden, Kent	10,009	18,038	26,763	54,810	2.67

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