A SOLID WASTE PLAN FOR SOUTHEASTERN OKLAHOMA

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. 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 mult county 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. 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 $S_1, \ldots, S_5$ represent all possible combinations (nonempty subsets) of the eight potential site combinations, $255 = \sum_{j=1}^{8} \binom{8}{j}$, 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:

$$\text{min } TC_k = C_o + R_k + FC_s + \sum_{j \in S_k} C_j$$

$$+ \sum_{j \in S_k} \sum_{i=1}^{1} x_{ij} c_{ij}$$

subject to

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

$$\sum_{i=1}^{n} x_{ij} \leq b_j, j \in S_k$$

$$x_{ij} \geq 0, i=1, \ldots, 0; j \in S_k$$

where

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].
TC<sub>k</sub> = total monthly cost of disposal, collection
and transportation of solid waste with
landfill alternative S<sub>k</sub>
C<sub>o</sub> = monthly collection costs of house-to-
house residential pick-up
R<sub>k</sub> = minimum monthly cost of containerized rural collection; and transportation of solid waste with landfill alternatives S<sub>k</sub>
FC<sub>s</sub> = fixed costs of the system (salaries, boxes, 
buildings and capital expenses)
C<sub>j</sub> = monthly cost of disposal at landfill j
x<sub>ij</sub> = monthly quantity of solid waste trans-
ported from origin i to landfill j
b<sub>j</sub> = maximum volume of waste per month
disposed in landfill j (in terms of truck
loads)
a<sub>i</sub> = monthly volume of waste generated in
origin i (in terms of truck loads)
c<sub>ij</sub> = cost per ton transported from origin i to
landfill j
o = number of origins.

In solving the above transportation problem C<sub>o</sub>, FC<sub>s</sub>, and C<sub>j</sub> were ignored because they represented
fixed values for each landfill alternative. Hence, for
urban problems, where R<sub>k</sub>=0, the function in (1)
could be replaced by min TC<sub>k</sub>=Σ<sub>j</sub>Σ<sub>i</sub> x<sub>ij</sub> C<sub>ij</sub>
subject to constraints in (2), (3) and (4). To
determine the best landfill combination, the third
right hand term in (1), Σ<sub>j</sub>Σ<sub>i</sub> C<sub>ij</sub>, was estimated for
each landfill alternative. The optimal waste system
(landfill alternative) was then found by determining

FIGURE 1. COUNTIES OF OKLAHOMA; KEDDO COUNTIES ARE SHADED

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

TC = min<sub>k</sub> TC<sub>k</sub> + Σ<sub>j</sub> C<sub>j</sub> (5)
where $TC_k^*$ are the respective minimums for $TC_k^*$ in the above transportation problems. Since $C_o$ and $FC_n$ were fixed over all landfill alternatives, they needed to be estimated only to establish user fees.

For rural problems, the $\sum_{k \in S_k} \sum_{j=1}^{x} c_{ij}$ term of equation (1) remained equal to $TC_k^*$ 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:

$$\min TC_k = C_o + FC_n + R_k + \sum_{j \in S_k} c_{ij} + TC_k^*$$ (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 constrained 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 trucks 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].

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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 30 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. 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.

<table>
<thead>
<tr>
<th>LANDFILL LOCATIONS</th>
<th>COLLECTION COSTS ($)</th>
<th>TRANSPORTATION COSTS ($)</th>
<th>DISPOSAL COSTS ($)</th>
<th>SHARED COSTS ($)</th>
<th>TOTAL COSTS ($)</th>
<th>RESIDENCE CHARGE ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hugo, Idabel, Broken Bow</td>
<td>4,500</td>
<td>2,742</td>
<td>9,018</td>
<td>17,645</td>
<td>33,905</td>
<td>2.58</td>
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<td>Idabel, Broken Bow</td>
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<td>10,669</td>
<td>6,012</td>
<td>17,645</td>
<td>38,826</td>
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<td>Hugo, Antlers, Idabel, Broken Bow</td>
<td>4,500</td>
<td>1,973</td>
<td>12,024</td>
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<td>35,583</td>
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<tr>
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<td>9,778</td>
<td>3,006</td>
<td>17,645</td>
<td>34,929</td>
<td>2.66</td>
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6Residence 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.
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 2. ESTIMATED MONTHLY SYSTEM COSTS FOR TWO URBAN SYSTEMS IN CHOCTAW AND McCURTAIN COUNTIES, KEDDO, 1975

<table>
<thead>
<tr>
<th>(1) LANDFILL LOCATIONS</th>
<th>(2) COLLECTION COSTS ($)</th>
<th>(3) TRANSPORTATION COSTS ($)</th>
<th>(4) DISPOSAL COSTS ($)</th>
<th>(5) SHARED COSTS ($)</th>
<th>(6) TOTAL COSTS ($)</th>
<th>(7) RESIDENCE CHARGE ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kent, Hugo</td>
<td>2,354</td>
<td>1,276</td>
<td>6,012</td>
<td>14,922</td>
<td>24,564</td>
<td>4.92</td>
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<tr>
<td>Kent</td>
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<td>22,793</td>
<td>4.56</td>
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<td>21,902</td>
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<tr>
<td>Broken Bow, Valliant, Golden</td>
<td>2,156</td>
<td>1,662</td>
<td>9,018</td>
<td>15,871</td>
<td>28,707</td>
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<td>6,012</td>
<td>15,871</td>
<td>25,058</td>
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<tr>
<td>Idabel</td>
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<td>3,003</td>
<td>15,871</td>
<td>22,658</td>
<td>3.36</td>
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### TABLE 3. ESTIMATED MONTHLY COSTS OF A MULTICOUNTY RURAL-URBAN SYSTEM IN CHOCTAW AND McCURTAIN COUNTIES, KEDDO, 1975

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


