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Analysis of Cost for Solid Waste Management in Nonmetropolitan Oklahoma

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Contents

ANALYSIS OF COSTS FOR SOLID WASTE MANAGEMENT IN NONMETROPOLITAN OKLAHOMA

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Solid waste management is fast becoming a major service function of local government jurisdictions. National annual public outlay for refuse collection and disposal is exceeded at the local level only by expenditures for schools and roads. The total national public and private refuse collection and disposal bill currently exceeds $3 billion annually [16, p. 6]. For Oklahoma, public expenditures for solid waste services were $5 million in 1962 $8.6 million in 1967 [32].

To plan efficient nonmetropolitan[1] solid waste systems, it has become apparent that more detailed information is needed on service requirements and factors affecting costs of solid waste collection and disposal for rural environments. Metropolitan plans for collection and disposal of solid waste are of little help since their problems are significantly different than those faced in rural areas. Availability of landfill sites, location and size of transfer stations, and meeting air quality standards for incinerators are major problems of the metropolitan centers. Rural areas in general have a minimum of these problems but are faced with small or poorly organized systems and high costs for collection and disposal services.

Objectives and Procedures

The objectives of this study are to:

(1) estimate costs related to the collection and transfer processes of solid waste systems in nonmetropolitan areas,

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[1] Nonmetropolitan is defined as rural areas and cities up to 50,000.

(2) estimate costs associated with solid waste disposal employing the sanitary landfill and
(3) provide an application in comprehensive planning of solid waste collection and disposal services to a multi-community planning region.

Procedures used to estimate collection and transfer costs are based on observed budget data. Disposal costs are based on cross sectional and budget data. Individual procedures are more fully explained in later sections.

Analysis of Solid Waste Collection Systems

A system for solid waste collection consists of the facilities, equipment, personnel, and operating procedures used to remove solid waste from points of origin such as commercial, industrial, residential, and public establishments to a disposal site. Present technology consists of collection vehicles (usually closed compactors) and crews who pick up the waste. This study analyzes two systems in general usage: (1) a rear loading closed compactor, the most common system used in residential areas and (2) a front loading closed compactor frequently employed in commercial, industrial, and multi-family complex areas (Figure 1). The front loading

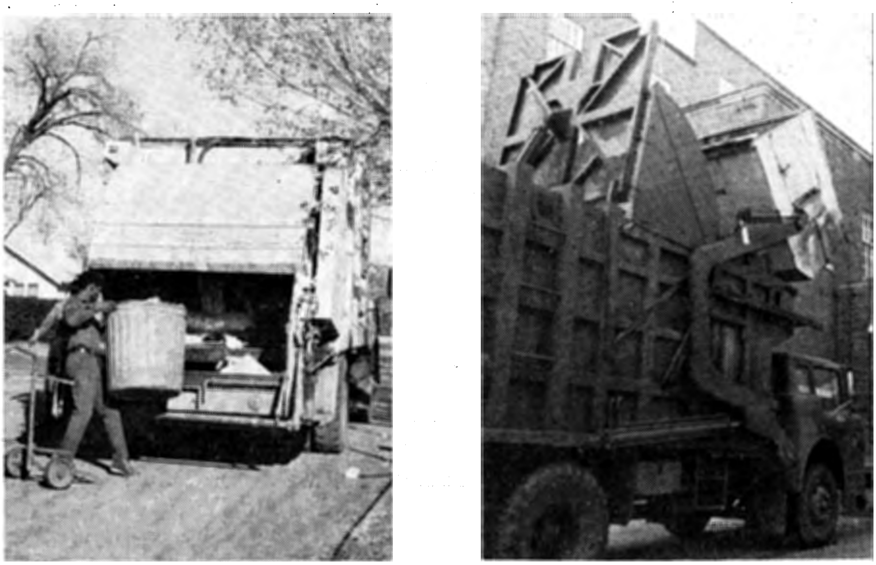

Figure 1. Typical solid waste collection compactor equipment, (left) rear loading and (right) front loading.

system requires a completely containerized collection unit whereas the rear loading system can facilitate both containers and residential cans. The task of both systems is to provide a specified frequency and quality of service over some planning period for all entities of the community receiving the service.

Factors Affecting Collection Costs

A number of factors must be considered in determining the total costs of a collection system. Total collection costs are influenced by certain spatial factors, quality characteristics of the collection system, and efficiency of system operations. For a specific type of collection service, whether residential or commercial, total costs are more sensitive to number of collections than to any quantity or volume measurement of solid waste collected.

Important spatial factors affecting collection costs are density of residential and commercial service areas and distance from collection areas to disposal sites. Quality characteristics affecting cost of collection in rural communities include such things as collection frequency, pickup location, and nature of pickup. Efficiency of operation is a function of management and includes such factors as optimum routing of collection vehicles, optimum combinations of resources for given resource prices, and overall management ability.

Total costs represent the summation of fixed and variable costs. Fixed costs represent a relatively small part of the total costs of providing a collection service. They are comprised of administrative costs, building costs, general overhead expenses, equipment and facility costs, and interest on investment. Variable costs are a function of the quantity of service output. In the case of solid waste collection, the qauntity of service output is measured by the number of collection units served. Variable costs in this case represent labor, vehicle operation and maintenance, and container costs.

Total variable costs distributed over a specified time period are a function of (1) the quantity of refuse generated for disposal by production source, (2) frequency with which the waste must be handled, (3) location and density arrangement of the producing units, (4) nature of the process used to facilitate collection, (5) type of equipment utilized, (6) quantity and efficiency of the labor input, and (7) hauling distance of a specified route.

The service area included in the collection process influences costs in the sense that density of collection points and volume of waste generated by residential and commercial sectors govern the time required to load a collection vehicle and the number of trips necessary for disposal. These factors also determine the number of collections which can be made per week and, hence, the number of collection vehicles required to service a municipality or areawide economy. When these variables are known, labor and other variable inputs required to facilitate the process can be determined and costs of the collection system are calculated.

Estimating Collection Costs by Means of Budget Data

Budget data were used to calculate cost per collection and per ton of waste collected for each of two systems. These data were supplemented with time and motion observations on individual routes of each system to determine the effects of pickup density and nonroute miles on collection costs; both factors are important for rural communities. Data were collected pertaining to the number of collections per route; time involved in the collection, transfer, and disposal processes; percent of the total collections classified as commercial pickups; and miles traveled in the collection and transfer processes. Results of the analysis were used to explain differences in collection rates which are measured as the number of collections made per hour of collection time.

Solid Waste Collection Budgets

Budgets for a municipality of approximately 25,000 persons using rear loading technology and a large institutional system using front loading technology were observed and the results given in Tables 1 and 2.[2] An examination of the cost budgets for the two collection systems reveals information concerning the amount of resources that must be committed by local communities to provide for solid waste collection.

The annual cost per collection crew, including vehicle and container costs but excluding fixed overhead cost, is $23,657 for the three-man crew, rear loading system versus $25,549 for the two-man crew, front loading system. The rear loading system requires $2,062 annual fixed vehicle costs per crew, as compared with $4,279 for the front loading system. This represents the annual cost of capital alone. The annual vehicle fixed costs represent about 9 percent and 7 percent of the total collection crew costs of the rear loading and front loading systems, respectively. Of the remaining outlays, labor comprises 69 percent of the

[2] The original budgets were for 1971 and are given in [8b, Davis]. The budgets as they appear here have been updated to 1974 using the following information and assumptions:

(1) Administrative costs and labor costs have been increased by one-half the change in the index of average hourly earnings for service employees given in [Survey of Current Business]. It is assumed that labor productivity accounts for 50 percent of the change in average hourly earnings.

(2) Building costs have increased from $7.39 per square foot to $9.00.

(3) Vehicle and container costs are assumed at present replacement values and obtained from equipment dealers. It appears that efficiency of equipment has not changed significantly from 1971.

(4) Vehicle and operation costs have changed in the following manner: (a) gas and oil costs have increased 40 percent (b) remaining vehicle and operation costs are assumed to have increased at the same rate as equipment costs. The percentage increase for both budgets is equal to about 34 percent.

Table 1—Solid Waste Collection Budget for Municipality of 25,000, Rear Loading Technology, 1974

		Dollars	Dollars
Fixed Administrative and Building Costs			
Annual administrative costs			
Supervisory personnel		14,759	
City overhead billing costs		19,348	
Building costs			
General warehouse construction cost for 5,600 sq. ft. at $9.00 sq. ft.	$50,400		
Annual building cost assuming 30 year life and 6% interest on average annual investment		3,192	
Annual maintenance (1% average value)		252	
Annual insurance (0.8% average value)		202	
Total annual fixed costs			37,753
Cost per Collection Crew			
Fixed vehicle and misc. cost			
Purchase price (20 cubic yard compactor)	$50,400		
Annual cost assuming 12,000 hour life, 6% interest, 12.5% salvage value and 1,232 hours annual use		1,857	
Annual insurance (2% average value)		155	
Misc. fixed cost per crew		50	
Container cost per crew			
Average purchase price per container (67% 3 cubic yd. and 33% 2 cubic yd.)	$ 218		
Average no. containers per crew	62		
Annual container cost per crew assuming 10 year life and 6% interest		1,757	
Variable cost per crew			
Annual labor cost per 3 man crew		16,329	
Annual vehicle operation and maintenance cost		3,509	
Total annual cost per collection crew			23,657
Annual Municipal Fixed Costs and Collection Crew Costs with Nine Crews			250,666

annual collection crew costs for the municipality and 47 percent for the institutional system. Hence, labor becomes an important factor when the rear loading system is utilized.

Cost Per Collection and Per Ton of Solid Waste

Cost per collection was estimated using the previously described budgets along with information from the time and motion analysis of the collection processes. The purpose of the analysis in this section is to distinguish between collection rates for residential areas and rates for commercial areas in the municipal system. A following section will utilize the analysis of both systems for purposes of distinguishing spatial effects upon collection rates.

Table 2—Solid Waste Collection Budget for Institutional Facility, Front Loading Technology, 1974

		Dollars	Dollars
Fixed Administrative and Building Costs			
(Assumed 15% of total budget per results of municipal budget)			9,017
Cost per Collection Crew			
Fixed vehicle and misc. cost			
Purchase price (24 cubic yard)	$28,000		
Annual cost assuming 12,000 hour life, 6% interest, 12.5% salvage value, and 1,523 hours annual use		3,949	
Annual insurance (2% average value)		280	
Misc. fixed cost per crew		50	
Container cost per crew			
Average purchase price per container	$ 335		
Average no. containers per crew	82		
Annual container cost per crew assuming 10 year life and 6% interest		2,827	
Variable cost per crew			
Annual labor cost per 2 man crew		11,959	
Annual vehicle operation and maintenance cost[1]		6,484	
Total annual cost per collection crew			25,549
Annual Fixed Costs and Collection Crew Costs with Two Crews			60,115

[1] Repairs and maintenance computed from engineering formulas [5].

Collection rates, expressed as the number of collections made per collection and transfer hour, were estimated as a function of density of collections per route mile, number of nonroute miles and, for the municipal system, percent commercial collections. The hypothesis tested was that the collection rate would increase as the density of the household and commercial establishments increased. This is due to less time required by the crew and compaction vehicle to move between collection points. Further, it was expected that the collection rate would decrease as the number of nonroute miles increased for any service area. Nonroute miles were a proxy for size of community and subsequent distance to the solid waste disposal site. At this stage of the analysis, the disposal site was assumed to be located at the edge of the city.

Collection rate was also expected to decrease as the percentage of commercial collections increases for any given service area of the municipal system. Commercial collections require more time for connection of the containers to the hydraulic system and more frequent trips to the disposal site because of larger waste volumes per collection.

Regression analysis was used to estimate the functional relationship between collection rate and the three explanatory factors. Observations on the municipal system included data on each of the 23 biweekly routes plus a daily commercial route. For the institutional system, two collection crews cover several route combinations over a two week cycle and hence daily observations for the cycle were recorded. The results of the regression equations were the following:

Municipal system

$$\underset{}{COLR=66.5028-\underset{(0.6779)^{*}}{1.2247\ NRM}+\underset{(0.166)^{***}}{0.788\ DEN}-\underset{(0.2031)}{0.1684\ PCOM}} \quad (3.1)$$

$$R=.71 \qquad n=24$$

Institutional system

$$COLR=4.0954-\underset{(0.0400)}{0.0391\ NRM}+\underset{(0.2356)^{***}}{1.9156\ DEN} \quad (3.2)$$

$$R=.85 \qquad n=15$$

where,

COLR = *COL*lection *R*ate, number per hour
NRM = *N*on-*R*oute *M*iles
DEN = *DEN*sity, number of collections per route mile
PCOM = *P*ercent *COM*mercial (by number of collections)
* = Students t test significant at the 10 percent level
*** = Students t test significant at the 1 percent level

Results of the regression analysis indicated density of collections were highly significant in explaining collection rate for both systems. Non-route miles appeared significant in the municipal system but not in the institutional system.

Cost per collection. Total cost per collection was estimated for residential and commercial service areas for the municipal system using rear loading technology and for the institutional system using front loading technology. Estimation of total cost per collection was expressed in the following model:

$$\begin{aligned} TCPCOL &= FCPCOL + CRCCOL + COCCOL \\ FCPCOL &= TAFC \div NACOL \\ CRCCOL &= CRCPHR \div COLR \\ CRCPHR &= [COLCRC - COCPCR] \div NACRHR \\ COCCOL &= COCPCR \div [NCOPCR \bullet NCOLCO] \end{aligned} \quad (3.3)$$

where,

TCPCOL = *T*otal *C*ost *P*er *COL*lection, ($)
FCPCOL = *F*ixed *C*ost *P*er *COL*lection, ($)
CRCCOL = *CR*ew *C*ost per *COL*lection, ($)
COCCOL = *CO*ntainer *C*ost per *COL*lection, ($)
TAFC = *T*otal *A*nnual *F*ixed *C*ost, ($)

NACOL = *N*umber *A*nnual *COL*lections
CRCPHR = *CR*ew *C*ost *P*er *H*ou*R*, ($)
COLR = *COL*lection *R*ate, number per hour
COLCRC = annual *COL*lection *CR*ew *C*ost, ($)
COCPCR = annual *CO*ntainer *C*ost *P*er *CR*ew, ($)
NACRHR = *N*umber of *A*nnual *CR*ew *H*ou*R*s
NCOPCR = *N*umber of *CO*ntainers *P*er *CR*ew
NCOLCO = *N*umber annual *COL*lections per *CO*ntainer

Tables 3 and 4 indicate the results of the cost per collection model for the municipal and institutional systems. Cost per collection varied from about 27 cents for residential collections to 74 cents for commercial collections where the municipality provides the container. For the institutional system, cost per collection varied from $1.54 where a one man crew is employed to $1.92 for a two man crew, assuming the same collection rate in both instances. Collection rates were evaluated at average conditions for density and non-route miles in both systems.

Cost per ton of solid waste. A frequent measurement of solid waste entering a disposal facility is in volume or tonnage units. Total cost of the solid waste system is then calculated on a cost per ton basis. There-

Table 3—Solid Waste Collection Rate, Cost Per Collection, Volume Per Collection, Cost Per Ton Collected, and Other Data: Municipal System, Rear Loading, 1974

	Variable Name[1]	Residential Service Areas	Commercial Service Areas with Containers
Number of Collections (annual)	NACOL	777,089	71,447
Fixed Cost per Collection ($)	FCPCOL	0.0445	0.0445
Crew Cost per Collection			
Crew Cost per Hour ($)	CRCPHR	17.78	17.78
Collection Rate (# per hr.)	COLR	78[2]	37[3]
Cost per Collection ($)	CRCCOL	0.2279	0.4805
Container Cost per Collection ($)	COCCOL	---	0.2480[4]
Total Cost per Collection ($)	TCPCOL	0.2724	0.7430
Monthly Cost ($)		2.36[5]	8.05[4]
Volume per Collection (cu. yds.)	VPCOL	0.0546[6]	0.3537[7]
Quantity per Collection (tons)[8]	QSWCOL	0.0098	0.0637
Collection Cost per Ton ($)	COLCTN	27.72	11.67

[1] See text for model formulation.
[2] Average of 40 pickups per route mile, 16.5 non-route miles and zero percent commercial.
[3] Average of 10 pickups per route mile, 16.5 non-route miles and 100 percent commercial.
[4] Average of 2.5 pickups per container weekly.
[5] Two pickups weekly.
[6] Evaluated at zero percent commercial and 40 pickups per route mile.
[7] Evaluated at 100 percent commercial and 10 pickups per route mile.
[8] Assumed 360 lbs. per cubic yard of compacted (3:1) refuse following data in [11, p. 26].

Table 4—Solid Waste Collection Rate, Cost Per Collection, Volume Per Collection Cost Per Ton Collected and Other Data: Institutional System, Front Loading, 1974.

	Variable Name[1]	Two Man Crew	One Man Crew
Number of Collections (annual)	NACOL	31,772	31,772
Fixed Cost per Collection ($)	FCPCOL	0.2838	0.2838
Crew Cost per Collection			
Crew Cost per Hour ($)	CRCPHR	14.92	10.99[2]
Collection Rate (# per hr.)	COLR	10.23[3]	10.23[4]
Cost per Collection ($)	CRCCOL	1.4585	1.0743
Container Cost per Collection ($)	COCCOL	0.1792	0.1792
Total Cost per Collection ($)	TCPCOL	1.9215	1.5373
Monthly Cost ($)[5]		30.81	26.65
Volume per Collection (cu. yd.)[6]	VPCOL	0.7317	0.7317
Quantity per Collection (tons)[7]	QSWCOL	0.1317	0.1317
Collection Cost per Ton ($)	COLCTN	14.59	11.67

[1] See text for model information.
[2] Assumed 50 percent labor cost of two man crew.
[3] Evaluated at sample means of 13.4 non-route miles and 3.477 collections per route mile.
[4] Assumed equal productivity for one man crew as with two man crew.
[5] Average of 3.7 pickups per container per week.
[6] Computed as the average compacted volume per collection over a two week period.
[7] Assumed 360 lbs. per cubic yard of compacted (3:1) refuse following data in [11, p. 26].

fore, cost per ton of solid waste was estimated for residential collections and commercial collections in the municipal system and on the basis of a one man crew and a two man crew in the institutional system.

Volume per collection was estimated in the municipal system as a function of percent of commercial collections and density of collections. Individual route data were used as observations in a regression analysis. It was hypothesized that routes with a higher percentage of commercial collections would show a higher volume per collection. Density of residential areas is used as a proxy variable indicating low income neighborhoods or service areas.

From a cursory inspection of collection routes in the observed municipal system, housing density would be positively correlated with low family incomes. Other studies show that the amount of solid waste generated per family is somewhat positively correlated with income levels. Therefore, for this system it was expected that increased housing density would negatively influence volume of solid waste per collection.

Results of the regression for 30 observations in the municipal system were the following:

$$\begin{aligned} VPCOL = 0.0574 &+ 0.00297\ PCOM - 0.00007\ DEN \\ &\quad (0.00026)^{***} \qquad (0.00006) \qquad (3.4) \\ R^2 = .84 &\qquad n = 30 \end{aligned}$$

where,

VPCOL = *V*olume *P*er *COL*lection (cubic yards at a 3:1 compaction ratio)
PCOM = *P*ercent *COM*mercial (by number of collections)
DEN = *DEN*sity, number of collections per route mile
*** = Student t test significant at the 1 percent level

Percentage commercial collections was highly significant in explaining volume per collection. Density was negatively correlated with volume per collection but was not significant.

Volume per collection for the institutional system was computed as the average compacted volume (3:1) per collection over a two week period.

Cost per ton of solid waste collected is expressed in the following model:

$$COLCTN = TCPCOL \div QSWCOL$$
$$QSWCOL = VPCOL \bullet WPCUBY \quad (3.5)$$

where,

COLCTN = *COL*lection *C*ost per *T*o*N*, ($)
TCPCOL = *T*otal *C*ost *P*er *COL*lection, ($)
QSWCOL = *Q*uantity of *S*olid *W*aste per *COL*lection, tons
VPCOL = *V*olume *P*er *COL*lection (cubic yards at a 3:1 compaction ratio)
WPCUBY = *W*eight *P*er *CUB*ic *Y*ard, tons

Weight per cubic yard of solid waste is highly variable and depends upon many factors. The average weight of a number of samples of solid waste from typical residential areas was 360 pounds per cubic yard of compacted refuse at a 3:1 compaction ratio [11, p. 26]. Those data were used for the analysis of cost of solid waste collection per ton.

The results of the model on cost per ton of solid waste collected for the municipal and institutional systems are presented in Tables 3 and 4. Cost per ton varied from $27.72 for residential solid waste to $11.67 for commercial solid waste in the municipal system. For the institutional system, cost per ton varied from $14.59 for a two man crew to $11.67 for a one man crew. Volume per collection was evaluated at average density for residential and commercial service areas in the municipal system.

Spatial Effects on Collection Costs

Density becomes a significant variable when collection services are being planned for rural communities and rural areas. Rural communities are frequently less densely settled than residential areas in larger cities.

Subsequently, according to the cost models formulated in the previous section collection costs are expected to be higher. Reducing unit costs of operating solid waste disposal facilities[3] by means of combining several communities and service areas for purposes of utilizing common disposal sites must be compared against increased costs of longer transfer distances in the collection-transfer process. These two factors are described in the following models with the empirical results given in subsequent sections for the municipal and institutional collection systems.

Collection cost as a function of density is described in the following relationship:

$$TCPCOL(DEN) = FCPCOL + COCCOL + CRCPHR \div [COLR(DEN)] \qquad (3.6)$$

All variables have been previously defined in equations 3.1, 3.2 and 3.3. Density of collection was allowed to vary in equation 3.6 which has a subsequent effect on variable costs in the total cost per collection function.

Collection cost as a function of transfer miles to a disposal site from the edge of a community or service area was determined by the following model:

$$TCPCOL(TRM) = TCPCOL(DEN) + [CPTNM \bullet QSWCOL]TRM$$
$$CPTNM = CTRM \div TKCAPQ \qquad (3.7)$$
$$CTRM = CPCRHR \div VEL$$

where,

TCPCOL(TRM) = *T*otal *C*ost *P*er *COL*lection as a function of *TR*ansfer *M*iles ($)
TCPCOL(DEN) = *T*otal *C*ost *P*er *COL*lection as a function of *DEN*sity with zero transfer miles, ($)
CPTNM = *C*ost *P*er *T*o*N* *M*ile, ($)
QSWCOL = *Q*uantity of *S*olid *W*aste per *COL*lection, tons
TRM = *TR*ansfer *M*iles
CTRM = *C*ost per *TR*ansfer *M*ile, ($)
TKCAPQ = *T*ruc*K* *CAP*acity in solid waste *Q*uantity, tons
CPCRHR = *C*ost *P*er *CR*ew *H*ou*R*, ($)
VEL = *VEL*ocity, miles per hour

Spatial Effects on Residential Collection Costs

Parameter data for the residential portion of the municipal rear loading system was applied to equation 3.6 to determine density effects on collection costs. Utilizing average values for nonroute miles of the

[3] See the following section on solid waste disposal costs.

municipal system, the following results:

$$\text{TCPCOL (DEN)} = 0.0445 + 17.78 \div [66.5028 - 1.2247\ (16.5) + 0.788\ \text{DEN}]$$
$$= 0.0445 + 17.78 \div [46.30 + 0.788\ \text{DEN}] \qquad (3.8)$$

The results of equation 3.8 are presented graphically in Figure 2. Cost per residential collection varies from about 33.1 cents for a density of 20 collections per route mile to about 23.4 cents for a density of 60. On a monthly basis with two collections per week the cost variation is $2.87 versus $2.03.

The effect on collection costs of increasing transfer distance is given for the same residential system assuming a compaction truck capacity of 20 cubic yards and fully loaded, 360 pounds per compacted cubic yard, a transfer velocity of 40 miles per hour, and results of the density function evaluated at 40 collections per route mile:

$$\text{TCPCOL(TRM)} = 0.2730 + [0.12347 \bullet 0.00983]\ \text{TRM}$$
$$= 0.2730 + 0.001214\ \text{TRM} \qquad (3.9)$$

The effect of transfer miles on residential cost per collection is presented in Figure 3.

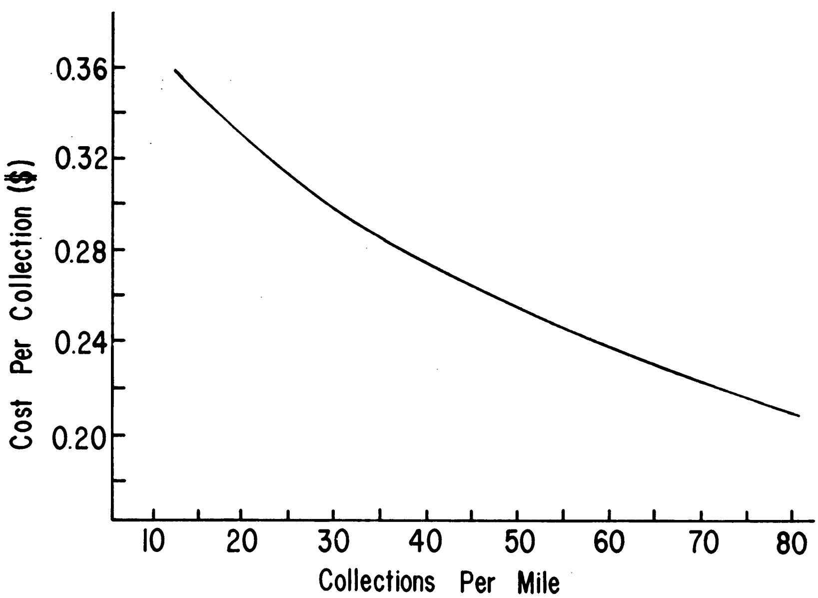

Figure 2. Average Cost Per Residential Collection Under Different Densities

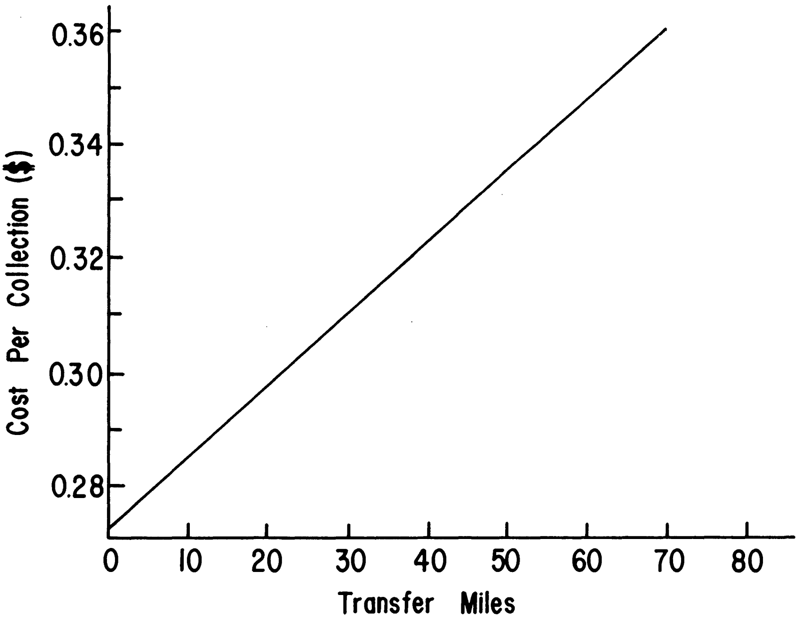

Figure 3. Average Cost Per Residential Collection Under Different Transfer Distances and Density of 40 Collections Per Route Mile

Since equation 3.9 is linear, each additional transfer mile adds about .12 cents to each residential collection. A disposal site located 10 miles from the edge of the city adds 20 transfer miles and a cost of about 2.4 cents per collection. Assuming the above relationship, monthly costs for the collection and transfer process with two collections per week is $2.57 for a disposal site 10 miles from the edge of the city and $2.89 when the disposal site is 25 miles out.

Spatial Effects on Commercial Collection Costs

A similar spatial analysis is given for commercial collections utilizing the parameter date for the front loading system. Incorporating average values for nonroute miles of the front loading system into equation 3.6 gives the following results:

$$\begin{aligned} \text{TCPCOL(DEN)} &= 0.2838 + 0.1792 + 14.92 \div [4.0954 - 0.0391 \\ &\quad (13.4) + 1.1956\ \text{DEN}] \\ &= 0.463 + 14.92 \div [3.5715 + 1.9156\ \text{DEN}] \quad (3.10) \end{aligned}$$

Cost per commercial collection varies from about $2.48 for a density of 2 collections per mile to about $1.12 for a density of 10 collections per mile (Figure 4). On a monthly basis, assuming transfer miles to be fixed, the cost of two collections per week ranges from $21.49 to $9.71.

The effect of transfer miles on collection costs when a front loading system was employed was determined by equation 3.7, assuming the total costs per collection from Table 4.[4] As illustrated in Figure 5, the cost per collection utilizing a one man crew ranged from $2.17 to $4.72 (10 versus 50 transfer miles). A two man crew ranged from $2.78 to $6.24 per collection.

For both technologies examined in this analysis, increasing transfer miles and holding density constant did not contribute as much to total collection costs as did decreasing density. This consideration takes on significant importance when disposal facilities must be located some distance from the solid waste production source. However, the paradox of providing rural collection service is that density is sparse and transfer

[4] The equations, assuming a velocity of 40 miles per hour and 24 cubic yard truck capacity, are:
Two Man Crew
TCPCOL(TRM) = 1.9215 + 0.08634 TRM
One Man Crew
TCPCOL(TRM) = 1.5373 + 0.06360 TRM

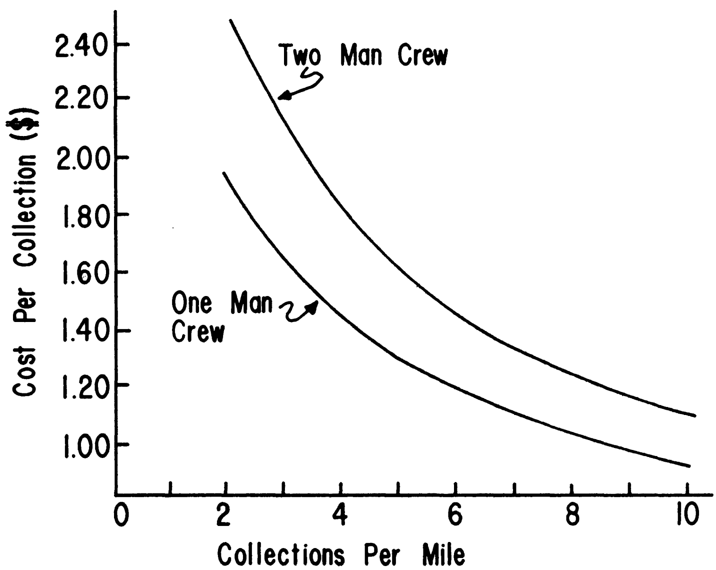

Figure 4. Average Cost Per Collection of Solid Waste Using Front-Loading Equipment With Different Densities

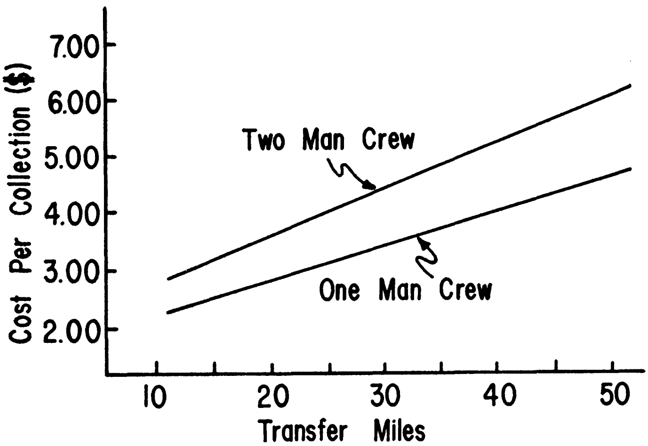

Figure 5. Average Cost Per Collection of Solid Waste Using Front Loading Equipment With Different Transfer Miles

distance is normally substantial; both factors contributing to higher per unit costs.

In summarizing the two systems analyzed for factors effecting collection costs, it appears that area-wide solid waste collection is faced with higher per unit costs. The provision of solid waste collection from several combined service areas increases costs mainly because of the increased cost associated with transfer miles. For rural areas, where residential patterns are usually less concentrated, transfer and density have a compounding affect on collection costs. However, it should be pointed out that local intergovernmental cooperation may compensate for higher collection costs to some degree because of investment sharing on collection and landfill equipment and facilities.

Limitations and Conclusions

The collection systems considered in this study represent two alternatives by which planners can base their decisions when implementing solid waste management strategies. The procedures employed provide a detailed description of the factors which must be evaluated before a financial commitment is made when a particular strategy is being proposed. Its effectiveness and usefulness largely depends on the decision-maker's ability to identify variables that relate to the impact area.

The cost analysis for the two collection systems identifies the basic components of a solid waste management system and has the benefit of isolating the structure necessary for planning the collection system design. The analysis clearly defines the nature of rural area solid waste collection in the sense that low production source density and relatively high transfer miles contribute to high collection costs.

The analysis is limited by the inability to define operational changes resulting from seasonal variations in solid waste generation. The observations taken from the time and motion study were derived over a relatively short period of time. However, an attempt was made to include any changes that may affect costs as a result of climatic conditions.

Another possible error built into the procedure involves the routing schedule of the collection vehicles. Routing patterns may change over time and any efficiencies resulting from such changes are not incorporated into the analysis. No attempt was made to determine if optimum routing patterns were employed. However, the factors that influence costs are included in the analysis. Any operating efficiency from routing would affect the magnitude by which these factors are associated with collection costs.

Analysis of Solid Waste Disposal Systems

The disposal process must be planned as an integrated part of the total solid waste management system. Location of the disposal site determines transfer distance, and, in some cases, capital requirements for the collection process, i.e., transfer stations may require additional collection-transfer vehicles. Trade offs between site operating costs, transfer costs, and fixed or capital costs are considered only after total process selection has been determined. The existence of economies of size related to disposal may produce some impetus for area-wide cooperation and may produce a technically feasible disposal system for sparsely populated areas.

Alternative Solid Waste Disposal Methods

Several disposal methods currently are employed in solid waste management systems: sanitary landfills, incineration, recycling, composting, grinding and pyrolysis. These methods are designed to either reduce the volume of solid waste for ease of handling or to dispose the total quantity of solid waste. With the exception of the sanitary landfill method, the other alternatives still require some means of disposing specific types of remaining wastes or refuse. Also, most methods of disposal require high volume service areas to be economically feasible. A brief discussion of each of the major disposal methods is presented below.

The incineration method involves reduction of combustible wastes to inert residue by high temperature burning. While cost varies greatly with a number of factors, it is estimated that the total cost of operating an incinerator ranges from about $4 to as high as $18 per ton of refuse [11, p. 8].

Grinding cannot technically be considered a disposal process since its objective is to reduce the volume of waste. This alternative is largely a processing method used by households or business establishments. The wastes are frequently disposed into the sewage system and, hence, non-digestible residue must be handled in some other fashion. The costs are reported to vary from $0.25 to $3.00 per ton of solid waste processed [11, p. 9].

Composting involves the biochemical reduction of organic materials to sanitary, humus-like material. Costs are normally higher than for incineration and its feasibility is dependent on the market for the composted material.

Pyrolysis is basically the same disposal method as incineration with the exception that low oxygen, high temperature burning eliminates problems of air pollution associated with incineration. The costs of the pyrolysis method range from $7 to $12 per ton. This method offers some advantages over conventional incineration in that smaller units can be employed, with total construction being underground [11, p. 9]. However, it should be noted that residue disposal processes are required and should be considered in total costs of solid waste disposal.

For small municipalities and rural areas the least cost method for disposing solid waste is by means of landfill. Several research studies indicate that the average cost for a sanitary landfill is about $1.13 per ton of solid waste disposed with a range from $0.50 to $4.00 per ton [11, 6, 2, 28]. For rural areas where disposal site location is generally not a limiting factor, landfill operations can be economically employed and have the added advantage of being a total solid waste disposal system.

The ultimate landfill location is governed by local policy and economic constraints. Land values and/or the willingness of land-owners to cooperate in site provision are factors to be considered. While selection of a site depends on the evaluation of the site itself and the community acceptance of the site for solid waste disposal purposes, the costs associated with disposal are more dependent on volume of solid waste entering the landfill. The intention of linking transfer costs with collection costs was to allow disposal costs to be analyzed separately so that site location can remain a variable until implementation is achieved for any given service area.

Estimating Landfill Disposal Costs

Sanitary landfill costs include fixed costs of equipment, access road construction and site development; and variable costs of equipment operation and maintenance. Amount of equipment is not completely invariant with the size of landfill operation although a sizeable crawler type vehicle is necessary for compaction of refuse. Data on landfill operations of 138 cities, with populations of 15,000 or less, indicated that all but 3 operated their landfill with only one piece of equipment [11]. Other data indicate that one piece of equipment can handle landfills serving populations up to 50,000 [8a]. Because daily covering of solid waste in landfills is required, compaction equipment must remain at the site. Other site development costs in addition to all-weather access roads, include a shelter, water and sanitation facilities and fencing.

Variable costs are a function of the amount of solid waste to be disposed, requirements of the landfill operation, and geological characteristics of the disposal site. Requirements of the landfill operation refer to such things as the depth of the landfill, amount of compaction, and amount of cover material required. Geological characteristics include such things as the nature of the soil which has a bearing on the efficiency of equipment operation.

Land costs are frequently not included in determining total landfill costs. Such costs vary substantially by location and by expected use of the sites once the landfill has been terminated. It is argued that increased value of reclaimed land reduces land and site modification costs to near zero, particularly if landfills are short-lived.

Two approaches have been used to estimate landfill disposal costs: (1) observe a landfill operation which meets all of the requirements of the Oklahoma Solid Waste Management Act and the Oklahoma Clean Air Act and to construct a budget for the system; (2) utilize cross section data from a number of landfill operations and determine costs per ton of solid waste disposed.

Budget for Observed Landfill

Data on total estimated quantity of solid waste disposed for the observed system are presented in Table 5. The landfill served a municipality composed of residential and commercial collection service areas, a large institutional system, and an estimated quantity deposited directly by private individuals and establishments. The estimated annual quantity of solid waste entering the landfill was 21,830 tons.

A budget for the observed landfill is presented in Table 6. Annual fixed site development costs are an estimate of what is required to meet minimum conditions of the Oklahoma law and with an expected life

Table 5—Estimated Quantity of Solid Waste Disposed Annually in the Observed Landfill Serving A Population of About 25,000

	Estimated Number of Collections	Estimated Lbs./Collection	Estimated Tons/Year
Municipality			
Residential	777,089	19.66	7,639
Commercial	71,447	127.33	4,549
Institution	31,772	263.41	4,185
Direct Disposal			5,457
Total			21,830

Table 6—Solid Waste Landfill Disposal Budget for Municipality of About 25,000, (1974 Dollars)

		Dollars	Dollars
Site Development			
Annual Fixed site development cost			3,507
Fixed Equipment Costs			
Purchase price (DC6 Crawler Tractor)	$65,000		
Annual cost assuming 12,000 hour life, 6% interest, 12.5% salvage value, and 1,100 hours annual use		7,164	
Annual insurance (2% average value)		650	
Total annual fixed equipment cost			7,814
Variable Costs			
Annual labor costs including insurance and fringe benefits		13,210	
Annual vehicle operation and maintenance costs on the basis of 1,100 hours annual use[1]		8,534	
Total annual variable costs			21,744
Annual Fixed and Variable Cost			33,065
Total Quantity of Solid Waste Disposed, Tons	21,830		
Cost Per Ton Disposed			1.51

[1]Computed from the *Caterpiller Performance Handbook* [2].

of the landfill of about 10 years. Marginal increases (decreases) in site development cost due to larger (smaller) landfills are nominal and only relate to additional fencing and perhaps extensions of access roads. The remainder of the budget is composed of fixed equipment costs and variable labor and equipment operation costs.

Equipment depreciation is computed on a per hour basis for a 12,000 hour life of the crawler tractor. Hence, such costs can be considered variable relative to hours used and quantity of solid waste disposed. For the observed landfill, tractor usage averaged about 3.5 hours per day for 313 days a year. The 12,000 hours of tractor life in this case is used up in about 11 years. For smaller size landfills, the equipment cost should be considered a fixed cost. Annual insurance and interest costs are also considered fixed costs.

Labor and vehicle operation and maintenance are considered to be variable costs and can be adjusted in accordance with the amount of solid waste to be disposed. Vehicle operation and maintenance costs were computed using the *Caterpillar Performance Handbook* [2]. Local fuel prices were used and normal conditions for dozing in clays, sands or gravels with intermittant full throttle operation and idling time was assumed.

A model describing total costs of solid waste disposed and costs per ton was estimated using the budget data:

$$\begin{aligned} \text{TCDP} &= \text{FCDP} + \text{VCDPTN} \bullet \text{TQSWDP} \\ \text{ACDPTN} &= \text{TCDP} \div \text{TQSWDP} \\ &= \text{VCDPTN} + \text{FCDP} \div \text{TQSWDP} \end{aligned} \tag{4.1}$$

where,

TCDP = *T*o*t*al *C*ost of *D*is*P*osal, ($)
FCDP = *F*ixed *C*ost of *D*is*P*osal, ($)
VCDPTN = *V*ariable *C*ost of *D*is*P*osal per *T*o*N*, ($)
TQSWDP = *T*otal *Q*uantity of *S*olid *W*aste for *D*is*P*osal, tons
ACDPTN = *A*verage *C*ost of *D*is*P*osal per *T*o*N*, ($)

Utilizing budget data presented in Table 6, average cost per ton of solid waste disposed in the observed landfill was determined as follows:

$$\text{ACDPTN} = 0.8634 + 8{,}508 \div \text{TQSWDP} \tag{4.2}$$

For the observed landfill with an annual disposal of 21,830 tons, cost per ton was estimated at $1.51. For smaller quantities, cost per ton will be greater since fixed costs are spread over fewer tons. For greater quantities, cost per ton will decrease only slightly since equipment depreciation becomes a variable cost and only fixed site development costs are spread over more tons.

The budgeting technique of estimating disposal costs offers some advantages in terms of simplicity but it is not without limitations. Costs of labor and fuels were based on local conditions. Productivity of labor in terms of amount of solid waste disposed per hour is based on one observation which may not be typical for other communities. No attempt was made to analyze cost differences for different complements of equipment, including used equipment. Vehicle operation and maintenance costs were based on averages both in terms of machine efficiency and soil conditions. Results of the budget technique were compared with results of a cross-sectional analysis of several landfill sites where costs of operation and quantities of solid waste disposed were recorded.

Cross-Section Approach

Survey data reported in [11] were used to estimate cost per ton of solid waste disposed by means of landfill. Forty-one landfill sites in California were surveyed with data recorded on yearly waste disposed, annual wage payments, long term capital expenditures (site modification), short term capital expenditures (equipment depreciation), annual maintenance and equipment operation costs, and a series of qualitative characteristics. Land costs were not reported and are excluded in this analysis in accordance with the earlier discussion.

Cost per ton of solid waste disposed was regressed against annual quantity of solid waste using thirty observations of complete data from the California study:

$$\begin{aligned} ACDPTN &= 0.6479 + \underset{(4{,}973)^{***}}{28{,}380}\ (1/TQSWDP) \\ R^2 &= .54 \qquad n = 30 \end{aligned} \tag{4.3}$$

The inverse relationship of quantity of solid waste disposed annually is highly significant (1 percent level) although the total amount of variation in cost per ton accounted for is only 54 percent. Differences in quality characteristics of the landfills likely account for part of the cost variation.

The cost per ton estimate of equation (4.3) was corrected for differences in costs between California and Oklahoma using a construction cost index for major U.S. cities [10] and was updated to the 1974 level from the 1968-69 observed data using the Department of Commerce composite construction cost index [33]. These corrections amounted to a 15 percent increase in cost per ton as reported in equation (4.3) Results of equation (4.3) with the above adjustments are presented graphically in Figure 6.

Capacities of over one million tons annually tend towards a cost of $0.745 a ton, but such capacities are unrealistic for rural areas.[5] Cost per ton almost doubles for capacities of 50 thousand tons over the minimum cost and equals $4.00 per ton for capacities of only 10 thousand tons.

Using the quantity of solid waste disposed in the observed landfill (Table 5) the estimated cost per ton is equal to $1.95, which is in the rapidly decreasing range of the average cost curve. This estimate of dis-

[5] Observations on annual quantities of solid waste disposed by landfills in the California study ranged from 12 thousand tons to over one million tons.

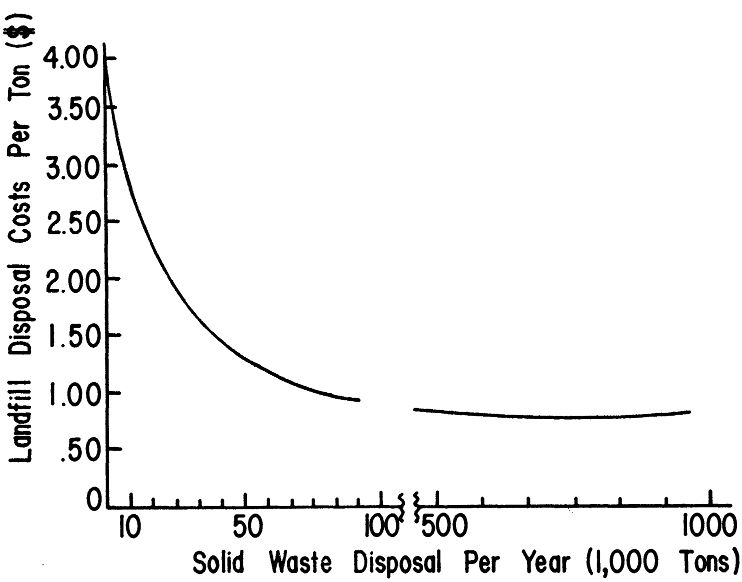

Figure 6. Average Landfill Disposal Costs Per Ton of Solid Wastes (1974 Dollars)

posal cost is about 29 percent more than the $1.51 estimate derived from the budget data.

The budget analysis assumes a given management level and a rather standard procedure in landfill operations. It is expected that this type of management and method of landfill operation could easily be duplicated at other sites in Oklahoma. Minor adjustments in resource prices due to local markets should not affect costs significantly for other non-metropolitan areas of Oklahoma. Thus, the equation for estimating cost of solid waste disposal derived from the budget technique was used for further analyses in this study.

Both methods of estimation verify the economies of size in operating landfills. The cross-section study shows economies of size over a significant range of landfill sizes although the major economies are achieved at least by the 50,000 tons annual capacity level.

Summary and Implications

Total cost of landfill development and operation is largely allocated to site development, capital equipment, labor and equipment operation and maintenance. Scale of operation depends on the quantity of waste for disposal, which, in turn, is dependent on the size of the service area utilizing the disposal site. The amount of actual land required to facilitate the disposal of solid waste was not determined in this study. Land requirements vary substantially depending on depth of cells, compaction process, and soil characteristics of the site.

The disposal analysis identifies several important aspects that should be considered when planning for area wide solid waste systems. The capital requirements necessary for disposal are relatively fixed, with one compaction vehicle capable of handling a substantial quantity of solid waste. Investment sharing in landfill site development and capital equipment produces significant economies of size, thus reducing per unit disposal costs. Fiscal constraints characteristic of small communities can be compensated to some extent by area-wide cooperation in solid waste management and thereby reducing requirements. However, it is doubtful that full benefits from economies of size can be realized in rural regions where solid waste collection must be made over large areas. Costs associated with transfer distances can eliminate much of the benefits of cooperative solid waste disposal efforts.

Although landfill operations show significant economies of size, disposal costs for the observed system with about 22,000 tons of solid waste disposed annually represents only about 5 percent of total collection and disposal costs for residential collections and about 11 percent for commercial collections. The major share of solid waste management costs remain in the collection process.

A Solid Waste Management Plan For A Rural County in Northern Oklahoma

Many small rural communities are faced with significant solid waste problems. Until recently, little attention has been directed to solving these problems even though legislation places constraints on the allowable time communities have to comply with the Oklahoma Solid Waste Management Act of 1970 [20]. The initial capital investment required for collection and disposal of solid waste in small communities is a financial burden for local governments and there are currently few assistance programs. Loans are available through the Farmers Home Administration but in most instances small communities do not possess a large enough service area to make loan payments and meet operating costs at a reasonable charge to the constituents.

Regardless of the financing alternatives employed, revenues for solid waste service should be sufficient to cover long term costs of operation. These factors provide the impetus for considering area-wide solid waste systems. The basic objective is to provide a similar quality of service to an area that can be provided to individual communities. Feasibility of the area-wide solid waste service lies in its ability to spread relatively large fixed investment costs over a larger service area and thereby reducing collection and landfill operation costs.

The area-wide system should be designated to minimize total collection-transfer-disposal costs.[6] Insofar as the collection and transfer process represents a major cost item, use of more than one landfill may be optimum even though unit disposal costs at any one landfill may continue to decline.

Costs of Collection-Transfer-Disposal for the Observed Service Area

To estimate total costs for any service area, the basic procedure is similar to that utilized for the municipality presented earlier. Total cost of the solid waste system is the summation of: (1) residential and commercial collection costs, (2) transfer costs associated with distances and solid waste volumes, and (3) disposal costs at the sanitary landfill(s).

Combining collection, transfer and disposal costs for one service area or a combination of service areas, the following system was developed:

$$\begin{aligned} TCSWS &= \sum_{j=1}^{s} TCOLC_j + TCDP \\ TCOLC_j &= COLCTN_j \bullet TQSW_j \\ TCDP &= ACDPTN \bullet \sum_{j=1}^{s} TQSW_j \end{aligned} \qquad (5.1)$$

where,

TCSWS = *T*otal *C*ost of *S*olid *W*aste *S*ervices for the planned area, ($)
$TCOLC_j$ = *T*otal *COL*lection *C*ost for the j^{th} service area, ($)
$COLCTN_j$ = *COL*lection *C*ost per *T*o*N* of the j^{th} service area, ($)
$TQSW_j$ = *T*otal *Q*uantity of *S*olid *W*aste in the j^{th} service area, (tons)
TCDP = *T*otal *C*ost of *D*is*P*osal, ($)
ACDPTN = *A*verage *C*ost of *D*is*P*osal per *T*o*N*, ($)

Using data from the observed municipality as the planned area, the total solid waste system costs are shown in Table 7. Insofar as the service

[6] To minimize costs associated with collection and transfer requires that optimum routing and disposal location be developed. This is beyond the scope intended for this study. The term minimization is used here only in the sense that capital and labor investment can be spread over a significant service area before additional investment is required. Hence, the costs on a per unit basis represents the minimum between the alternative of an individual system as compared to an area-wide system.

quality and the service process remains similar, the total system costs for any delineated planning area can be expressed in the same manner. It is upon this basis that application is made to a rural planning region in the following section.

Table 7—Total Annual Cost of Collection and Disposal of Solid Waste for the Observed Service Area of About 25,000 Population (1974 dollars)

Source of Solid Waste for Disposal	Collection and Transfer Cost COLCTN	Disposal Cost[3] ACDPTN	Collection Transfer & Disposal Cost	Quantity of Solid Waste[4] TQSW	Total Cost of Collection, Transfer & Disposal TCSWS
	$/Ton	$/Ton	$/Ton	Tons	$
Municipal					
Residential	27.72[1]	1.51	29.23	7,639	223,238
Commercial	11.67[1]	1.51	13.18	4,549	59,956
Institution	14.59[2]	1.51	16.10	4,185	67,378
Direct	---	1.51	1.51	5,457	8,240
Total	---	---	---	21,830	358,862

[1] Table 3
[2] Table 4
[3] Table 6
[4] Table 5

Application to a Rural Planning Region

The county selected for application is Grant County, located in northern Oklahoma (Figure 7). The largest municipality is Medford, with a population of 1,304 [31].

Reasons for choosing Grant County include: (1) there are a number of small communities in the county and, with the exception of one town, all have populations of less than 1,000 persons; (2) the communities do not have the fiscal capability to individually finance a solid waste system, and (3) the communities expressed a willingness to cooperate in a joint solid waste venture, thereby reducing any political constraints.

Service Requirements

Service requirements were determined for all of the communities of Grant County. To achieve this, a housing and business survey was conducted for each of the towns. The total number of residences, commercial establishments, public concerns and industries were enumerated (Table 8) and their approximate locations were placed on maps provided by the Oklahoma Department of Highways. This procedure enables determination of household density and route miles necessary for the collection and transfer process.

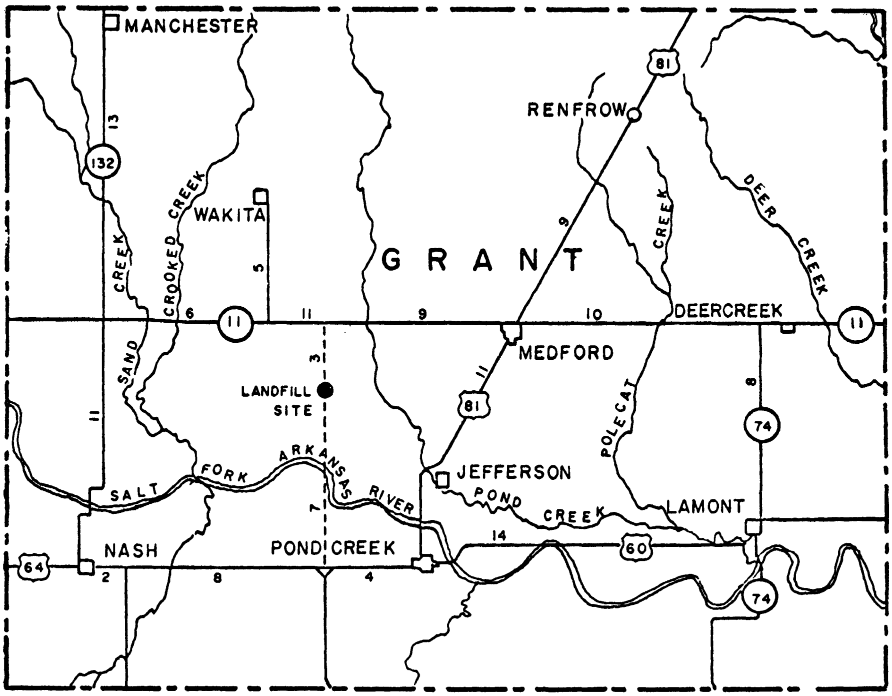

Figure 7. Application Area for Solid Waste Management Plan, Grant County, Oklahoma.

A landfill site had been determined and approved by the Oklahoma State Health Department, enabling estimation of transfer miles associated with any given routing scheme. The landfill location is shown in Figure 7, and transfer distances are given in Table 8.

There are significant differences in density of the rural communities as measured by the number of collections per route mile (Table 8). The sprawling nature of many small towns has the effect of increasing the amount of time required for collection, and hence, the costs associated with collection. The smaller communities of Grant County are generally less densely populated than the larger communities and hence represent higher costs for collection services.

Communities also showed differences in costs of supplying the entire solid waste service because of transfer distances to the landfill site. Those communities closer to the landfill represent lower cost in utilizing the

Local public service policy was integrated into the planning process and resulted in some modifications to the data of the observed system service than those communities farther away from the landfill.

Table 8—Grant County Solid Waste Service Requirements Survey, 1972

Town	Population	Weekly Residential Collections	Weekly Commercial Collections[1]	Collections Per Route[2] Mile (DEN)	Distance to Landfill (TRM)	Non-Route Miles
Deer Creek	203	91	17	49.1	22	.40
Jefferson	128	31	7	10.8	14	.14
Lamont	478	246	33	34.4	25	1.08
Manchester	165	65	12	22.7	24	.28
Medford	1304	530	97	45.4	12	2.34
Nash	295	133	24	19.3	17	.58
Pond Creek	903	376	62	41.7	11	1.66
Renfrow	39	18	5	10.0	21	.08
Wakita	545	225	37	41.2	10	1.00
Total	4060	1715	294			

[1] Includes commercial establishments, schools, churches, industries, and public utilities.
[2] Evaluated by dividing the total collections by the total street miles.

as reported in previous sections. The rear loading technology was used with once a week residential and commercial collection.

Collection and Transfer Costs

Reducing frequency of collection from twice a week to once a week required some adjustments in the models as presented earlier. Volume per collection is assumed to double, which increases time spent at the landfill and hence decreases the collection rate. Time spent at each collection point was not adjusted since the volume of solid waste collected at each point did not significantly affect collection rate in the time and motion study. Colelction rates are given in Table 9 from the adjusted equational models.

Collection rates for comparable densities as used earlier are larger since the number of nonroute miles was significantly reduced. Nonroute miles were computed as directly proportional to the size of the community using the observed municipality as a base. In fact, non-route miles were not a significant factor for such small communities.

Cost per collection and per ton of solid waste collected are presented in Table 9 by community. Collection cost per ton of solid waste is substantially less than that recorded earlier since the volume of solid waste per collection is doubled with but a small increase in cost per collection.

Cost to transfer the solid waste from each community to the sanitary landfill was computed on a ton basis (Table 9). Assuming a cost per crew hour of $17.78 and an operating velocity of 50 miles per hour on open country roads, cost per transfer mile is about $0.3556. Utilizing a 20

Table 9—Cost Per Collection and Total Collection and Transfer Cost Per Ton of Solid Waste, Grant County, (1974 dollars)

Town	Collection Rate	Total[1] Cost Per Collection	Quantity[2] Per Collection	Collection[3] Cost Per Ton	Transfer[4] Cost Per Ton	Total Collection & Transfer Cost Per Ton	Total Collection & Transfer Cost per Collection
	#/Hr.	($)	Tons	($)	($)	($)	($)
Deer Creek	93	0.2357	.0366	6.44	4.10	10.54	0.3858
Jefferson	69	0.3022	.0395	7.65	2.61	10.26	0.4053
Lamont	76	0.2784	.0324	8.59	4.66	13.25	0.4293
Manchester	70	0.2985	.0364	8.20	4.47	12.67	0.4612
Medford	90	0.2421	.0363	6.67	2.24	8.91	0.3234
Nash	74	0.2848	.0361	7.89	3.17	11.06	0.3993
Pond Creek	88	0.2465	.0349	7.03	2.05	9.08	0.3169
Renfrow	68	0.3060	.0430	7.12	3.91	11.03	0.4743
Wakita	88	0.2465	.0348	7.08	1.86	8.94	0.3111

[1] See Equation (3.3) and Table 3 for data.
[2] Quantity per collection is weighted by residential and commercial collections. See Tables 8 and 3.
[3] See Equation (3.5) and Table 3.
[4] Cost per ton mile (Equation 3.7) times round trip distance to landfill (Table 8) Truck velocity was assumed at 50 miles per hour and truck capacity at 20 cubic yards, and 360 lbs. per cubic yard.

cubic yard compaction vehicle and a volume to weight exchange of 360 pounds per cubic yard, the transfer cost per ton mile is $0.0932. This cost figure was applied to twice the distance separating each community from the sanitary landfill and is recorded in Table 9.

Total collection and transfer cost per ton varied from about $8.94 for those communities 10 miles from the landfill to $13.25 for those communities 25 miles out (Table 9). A final calculation for comparison purposes indicated the total collection and transfer cost per collection and ranged from $0.31 to over $0.47. This compares to the residential cost of $0.27 in the observed system where the landfill was at the edge of town.

The total hours required for the collection process was determined by dividing the number of collections for each community by its collection rate and summing across all communities. About 24 hours per week was required for the collection process and an additional 6 hours for transfer time. The total of 30 hours of truck operating time was slightly more than the average computed for the 9 trucks in the observed system.

These results indicate that one collection crew and vehicle should be sufficient to handle the solid waste collection and transfer services for the entire 9 towns in Grant County. Investment would be limited to one packer truck with an estimated purchase price of $15,500.

Fixed administrative and building costs were assumed at the same rate per collection as calculated for the observed system. It was assumed that the solid waste services are integrated with other local government functions for purposes of billing and sharing in overall management operations.

Landfill Disposal Costs

Total quantity of solid waste disposed of in the sanitary landfill for Grant County was estimated at 5,930 tons (Table 10). In a rural setting, a problem exists in placing estimates on the amount of solid waste entering disposal by rural residents. Disposal can be facilitated in its entirety by the landowner constructing individual landfills on his own property. However, it was assumed that this task will not be done by most rural residents, and at least a proportion of the total solid waste generated would enter the area-wide public landfill site. Therefore, an estimate of this volume was made, as it affects the landfill size and operation.

There are approximately 1,467 rural homes located in the county, representing nearly 85 percent of the same number of homes situated in the nine communities. Assuming rural households generate comparable amounts of solid waste as the community households and that about 50 percent would enter the sanitary public landfill, the total estimate of rural household solid waste for disposal was 750 tons annually.

Table 10—Estimated Annual Quantity of Solid Waste To Be Disposed, Grant County, 1972

Source of Solid Waste for Disposal	Number	Annual Collections (#)	Quantity per Collection (Tons)	Total Annual Quantity (Tons)
Municipalities				
Residences	1,715	89,180	0.01966	1,753
Commercial establishments	294	15,288	0.12733	1,945
Rural Farm Homes	1,467	--	--	750[1]
Direct	--	--	--	1,482
Total				5,930

[1] Annual quantity of solid waste disposed from farm homes is assumed at one-half the annual quantity from homes in the communities.

An additional amount equal to 25 percent of the total is estimated as direct solid waste deposited and is consistent with the quantity estimated for the observed system. The total amount of solid waste entering the sanitary landfill is estimated at slightly less than 6,000 tons for Grant County.

Utilizing the landfill disposal budget in Table 6, variable cost of solid waste disposed was estimated to be about $1.00 per ton. Annual fixed costs for equipment and site development was estimated to be $11,321. For Grant County the estimated cost of solid waste disposed at the landfill was $2.90 per ton.

Since labor is considered a variable cost for the landfill operation, it was assumed that labor can be employed on an hourly basis to perform the functions of disposal. If the same labor can be used for other local government functions, this assumption is not limiting.

Total Collection-Transfer-Disposal Costs

Total annual costs of solid waste collection, transfer and disposal for Grant County was estimated at $54,104 (Table 11). This estimate included collection service only in the communities and once per week tary landfill was utilized to serve the entire county. Transfer costs for the public collection service was included but transfer costs of rural residents and others using the landfill were excluded.

Collection, transfer and disposal cost of solid waste for all communities was $12.87 per ton. Monthly cost per user was estimated to be $1.98. This includes both residential and commercial users. This compares with the residential and commercial collection and disposal costs servicing for both residential and commercial establishments. One sani-

Table 11—Solid Waste Management, Grant County, 1972 (1974 Dollars)

Source of Solid Waste for Disposal	Collection Cost $/Ton	Transfer Cost $/Ton	Disposal Cost $/Ton	Total Cost $/Ton	Quantity of Solid Waste (Tons)	Total Cost ($)
Deer Creek	6.44	4.10	2.90	13.44	206	2,769
Jefferson	7.65	2.61	2.90	13.16	78	1,026
Lamont	8.59	4.66	2.90	16.15	470	7,590
Manchester	8.20	4.47	2.90	15.57	146	2,273
Medford	6.67	2.24	2.90	11.81	1,184	13,983
Nash	7.89	3.17	2.90	13.96	295	4,118
Pond Creek	7.03	2.05	2.90	11.98	795	9,524
Renfrow	7.12	3.91	2.90	13.93	52	724
Wakita	7.08	1.86	2.90	11.84	475	5,624
Rural Farm Homes	---	---	2.90	2.90	750	2,175
Direct	---	---	2.90	2.90	1,482	4,298
Total					5,933	54,104

in the observed municipality of $2.94 monthly for two collections per week for residents and 2.5 collections per week for commercial establishments. The cost difference reemphasizes that collection costs are the major components of any waste management system.

Implications for Grant County Solid Waste Management System

Solid waste management can be provided on an area-wide basis, thus reducing costs to the recipients of the service. For the case of rural regions where service areas are comprised of small and dispersed populations, a number of individual service areas may be combined before an additional investment in capital equipment must be made.

In rural areas, benefits from economies of size related to disposal operations are frequently not available due to low volumes of solid waste. However, emphasis should be placed on minimizing total costs associated with the entire collection, transfer and disposal process.

For the planning area analyzed in this study, the capital investment required for collection and transfer includes one 20 cubic yard closed compactor, with an approximate value of $15,500. One collection crew is fully employed since it requires approximately 30 hours for the collection and transfer process and 2.5 hours at the disposal site. This leaves 7.5 hours for general maintenance of the capital items. Pickup service is once per week from the rear or side of the house. It is recommended that alley collections be made where possible to reduce collection time. This would increase the collection rate and reduce cost per collection.

Solid waste disposal requires a further investment of $50,000 to $65,000 for a crawler tractor. Neither the equipment nor the operator would be fully employed for the size of landfill needed in Grant County. Estimates of disposal costs considered equipment fixed but labor as variable.

Summary and Conclusions

The solid waste planning process requires that factors affecting service quality and service costs be identified. A procedure was developed to observe two existing solid waste systems and to identify those variables important for system operation. One system represented a municipality of about 25,000 population and the other system represented a rather large public institution. Data, in the form of a time and motion analysis, were collected pertaining to two current collection technologies frequently employed by municipalities. One involved a rear loading process amendable to residential containers and commercial containers, and the other, a front loading process requiring all commercial type containers.

Observations were made relating to the number of collections per collection route; total time required for the collection, transfer, and disposal process; percent of the total collections comprised of commercial pickups; and total nonroute miles traveled in the collection process.

Total annual costs of the observed collection systems were determined and placed in budget form so that calculations could be made evaluating costs on a per collection and per ton basis. The fixed costs component of solid waste collection comprises a small proportion of the total costs, and consist of administrative costs, building costs, general overhead expenses, equipment and facility costs, and interest on investment.

Fixed administrative and building costs amounted to 15 percent of total annual costs for the municipal system and the same percentage was assumed for the institutional system. Fixed vehicle and container costs amounted to 15 percent of total collection crew cost for the rear loading technology and 27 percent for the front loading technology. The principal variation lies in the higher initial investment in the packer vehicle and the costs associated with additional containers since the front loading technology requires a total containerized system.

Total annual cost for one collection crew in the observed municipal system with rear loading technology amounted to $23,657 in 1974 prices. The average collection crew made about 94,000 residential and commercial collections annually or, for a two-week collection frequency, this amounts to about 900 service units. Total annual cost per collection crew in the observed institutional system with front loading technology was $25,549 and, on an average, made slightly under 16,000 commercial container collections annually or serviced 153 units on a two-a-week frequency.

The time and motion study provided an approach to isolating factors having a significant influence on variable costs of the total collection system. The most important of these include the nonroute miles, i.e., the interim miles not associated with the actual collection route; and the collection density, or the number of collection units served per route mile.

While the solid waste service has a single measure of output, characterized by volume collected and transported to the disposal site, the total system costs are more affected by the collection rate associated with a given service area. Cost per collection thus depends on the characteristics of the service area, as defined by the density of collection units, and the distance separating the service area from the disposal site. Furthermore, the percent of commercial collections affects the rate with which collections can be made because of larger volumes of solid waste and the time involved in connecting the container to the hydraulic system.

Variations in collection rates (collections made per hour) were explained by variations in density of collections per route mile, number of nonroute miles and percentage of commercial container collections. Using estimated regression results on collection rates and budgeted cost data, various models were specified to (1) estimate cost per collection, (2) cost per ton of solid waste collected, (3) effect of density on collection costs, (4) effect of distance from service area to landfill site on collection costs, (5) cost differences between technologies, and (6) cost differences between residential and commercial collections.

Cost per collection was computed at $0.2724 for complete residential areas under conditions of 40 pickups per route mile and 16.5 nonroute miles. Commercial costs varied from about $0.74 cents per collection under conditions for typical business establishments where rear loading technology was used to $1.92 per collection under conditions of larger containers, more solid waste volume, and front loading technology used in a large public institution. Variations in collection costs were computed for differences in collection rates and transfer distances to a landfill. For commercial collections using front loading technology, each transfer mile to a disposal site adds 8.6 cents per collection.

The most widely used method of solid waste disposal currently employed in rural areas is the sanitary landfill. The capital investment required for landfill operations currently is less than other conventional disposal practices. The costs of operating a sanitary landfill, in addition to effects of total volume of solid waste, depend on the topographical nature of the site, depth of covering solid waste and site location for the landfill.

To estimate sanitary landfill costs, two procedures were employed. One procedure combined budgeting data from an observed landfill, which met all requirements of the State Health Department, and engineering data on equipment operation and maintenance costs under conditions of normal operating loads and suitable soil characteristics. Land costs were not considered in the analysis due to the cost variances that exist in site location and the broad range of expected uses that can be employed once the landfill is terminated.

Variable costs were estimated at $1.00 per ton of solid waste disposed. Fixed costs were estimated at $11,321 annually. For the observed budgeted system this was distributed over about 22,000 tons of solid waste. This amounts to an average cost (fixed and variable) per ton of $1.51. Decreasing the annual quantity of solid waste to be disposed to 10,000 tons had the effect of increasing cost per ton by $0.62. Expanding the annual capacity beyond the 22,000 tons quantity was also possible since it was estimated that the most limiting capital item was used only 3.5 hours per day.

A second procedure for estimating landfill costs used survey data of thirty existing disposal operations in California and adjusted for cost differences between California and Oklahoma. The results indicate that the expected disposal cost varies from about $0.75 per ton for over one million tons disposed of to about $4.00 for quantities of less than ten thousand tons.

Models representing total costs of collection, transfer, and disposal of solid waste were formulated so that application could be made to a specific service area or combination of service areas. An application was made to a rural county in northern Oklahoma to assess the usefulness of solid waste management planning.

Nine individual service areas in the county were combined into one area-wide system and collection, transfer and disposal costs of solid waste were evaluated. The solid waste system provided service to all municipalities within the region with a population slightly over 4,000 persons. It was found that only one collection vehicle was required to accomodate the entire area, thereby minimizing capital requirements for the nine service areas.

The total annual collection, transfer and disposal cost to the communities in the area-wide plan was estimated at $47,631. The monthly cost per user was estimated at $1.98. In addition, disposal costs for farm homes and other direct users of the landfill was estimated at $6,473.

The process of planning for a solid waste system is completed only when policy evaluation leads to plan implementation. Alternatives should be evaluated and analyzed to consider least cost routing patterns and optimum landfill locations. Programming optimum routing, disposal site location, and other alternative systems would appear to yield high benefits to local or area-wide planning authorities. In addition, alternative financial arrangements should be studied to provide local decision makers with a better foundation for plan implementation.

While rural farm areas need not be publicly provided for at present, research is indeed needed to determine financing alternatives and routing patterns that will facilitate rural collections if Oklahoma's goal of completely eliminating problems of unsanitary solid waste disposal is to be fully achieved.

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