SOLID WASTE MANAGEMENT AND COMPREHENSIVE PLANNING: ANALYSIS OF COSTS AND SERVICE REQUIREMENTS FOR RURAL AREAS

By

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Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1971

Submitted to the Faculty of the Graduate College
of Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
July, 1973

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PREFACE

This study is concerned with the analysis of costs and service requirements of solid waste management in a substate planning framework. Two solid waste collection technologies are analyzed to determine cost relationships associated with solid waste collection, transfer, and disposal. The sanitary landfill method was selected for analysis of disposal costs. Regression analysis is employed to explain expected relationships between system costs and factors that affect the total costs of solid waste system design. A comprehensive plan for solid waste management is developed with application to a rural region within the state of Oklahoma. It is hoped that the tools and findings of this study can be used by planners and administrators involved with the provision of solid waste service in the rural areas of Oklahoma.

The author wishes to express his sincere appreciation to his major adviser, Dr. Dean F. Schreiner, for the encouragement, suggestions, and assistance throughout this study. Appreciation is also expressed to Dr. Gerald Doeksen, Dr. Dan Badger, and Mr. Dean Barrett for their helpful suggestions and assistance in the preparation of the final manuscript.

Acknowledgement is also due to the Department of Agricultural Economics at Oklahoma State University for providing financial assistance during my graduate program. Special thanks is extended to Mrs. Pam Huff for her assistance and patience in typing earlier drafts and the final manuscript. Acknowledgement is also due the data processing section of the Agricultural Economics Department for their assistance in preparing the data needed for this thesis.

Sincere gratitude and appreciation are also expressed to my parents, Mr. and Mrs. Lester Davis for their encouragement throughout my graduate program.

Finally, particular thanks is offered to my wife, Sharon, whose constant encouragement, understanding, patience, and many sacrifices were a great asset toward the completion of this thesis.

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CHAPTER I

INTRODUCTION

Problems Related to Community Service Planning

Problems of efficiently allocating public resources for community services are frequently hindered by existing institutional decision rules or, perhaps, by lack of an appropriate institutional framework. As an example, community services showing economies of size in their supply may be restricted by inflexibility of local governments, such as cities and counties, to jointly supply the service on an areawide basis. And, even though it may be determined that an areawide supply is least cost, it may be difficult to create an appropriate public authority to administer the service.

In addition, efficiency in public management of resources is increasingly more critical as citizens become aware of the services a local governmental jurisdiction can provide. The combination of an increasing demand for community services and the rising costs of supplying them has put considerable financial pressure on local governments. Hence, the need for planning efficient public service systems must receive increased attention at local and areawide planning levels.

One service for which local governments increasingly accept responsibility is that of solid waste collection and disposal. While the public management of this service has received much attention in urban centers, there has been little study and application to smaller communities and rural areas. However, the large accumulation of wastes by households, as well as commercial and industrial sectors, is nationally recognized as an environmental problem and poses a threat to the well-being of the community, regardless of its size.

The entire community suffers when the disposal of solid waste is not handled properly by a producing unit. When this disservice is extended across a region it becomes a social cost to society and produces a negative aesthetic effect on the environment as well as a significant health problem to the people. This provides a major justification for public involvement in solid waste collection and disposal.

Conceptually, there are no inherent difficulties in equating the involvement of the public sector with the supplying of community services such as solid waste collection and disposal. Profits need not be earned, tending to reduce the overall costs of the system. External costs produced by disposal facilities and activities may be reduced by public operation. Further, if households choose to withhold from purchasing the service, public intervention may be necessary.

The achievement of economies of size becomes a primary consideration when local jurisdictions are faced with limited resources and a restricted community service base. Coordination between local governments can be achieved on an areawide basis, distributing fixed investments across a larger area and meeting the desired levels of the public service.

Historically, communities and small area economies operate under the assumption that the main responsibility of local government is one of physical planning or the determination of public facilities location, size of plant, and facility operation and administration. Most local planners and administrators realize the need for public investment in community services, such as streets, parks, and police and fire protection. The provision of these types of services not only increases the general welfare of a community's inhabitants, but also enhances the environment needed to facilitate industrial and economic development. The problem arises when inadequate economic planning is utilized to meet service level demands for future time periods. The failure to recognize and employ comprehensive planning at local or small area levels neglects the principal instrument public officials have over the physical and social structure of a planning region and its subsequent impact on industrial and economic development. All too frequently, insufficient public services planning can be quite disastrous to rural areas.

The success of comprehensive planning for solid waste services is largely dependent on the attitudes of the public receiving the service in the sense that the cost effectiveness of solid waste service provision is subject to the level of service and the service quality that can be attained through system design. By and large, there has been a lack of concern by communities to participate in regional solid waste systems. There has been very little voluntary interaction among municipalities; mainly because communities seem inclined to concern themselves only with their own problems and hesitate to resort to coordination with other municipalities. One argument is that areawide cooperation can cause inequitable distribution of costs (both public and private) and complicated contractual arrangements.

Nonetheless, acceptance of regional or areawide coordination is frequently necessary for accomplishing desirable ends. Education of citizen groups in the social acceptability of areawide coordination and the possible advantages of economies of size is an important process. Planning can become a tool by which education and training can be provided to those authorities in charge of the solid waste system at the local level. Comprehensive planning can hopefully provide the means whereby desirable ends can be attained.

Solid Waste Legislation Affecting Rural Areas in Oklahoma

Within the last decade, many public and private interests have recognized the environmental problems associated with inadequate solid waste systems. Much of this recognition has come about from a national awareness of air and water pollution and subsequent hazards associated with pollution. Public concern has had a direct impact on federal and state legislation, resulting in efforts to upgrade current solid waste management practices.

More specifically, the intent of federal legislation has been toward providing technical and financial assistance in the form of training, research, and planning grants to local municipalities for the development of solid waste disposal plans and facilities [7, 27].

The 1965 Solid Waste Disposal Act [25] and the Resource Recovery Act of 1970 [21] are two examples whereby programs have been initiated to set standards and provide instruction for proper and efficient solid waste disposal at state and substate levels.

Currently, there are two state enactments which have had a direct impact on local jurisdictions' solid waste practices in Oklahoma. Specifically, these are the Oklahoma Solid Waste Management Act of 1970 [19] and the Oklahoma Clean Air Act of 1967 [18]. The Solid Waste Management Act of 1970 was established to regulate the collection and disposal of solid wastes in a manner that will protect public health, prevent air and water pollution, conserve natural resources, and enhance the beauty and quality of the environment. Specific regulations provide the impetus for area wide planning of solid waste management systems. The act authorizes municipalities of close proximity to enter into agreements with one another for joint or cooperative solid waste ventures. Particular provisions provide for the development of area wide collection and disposal plans, methods for financing, and regulations to issue, continue, or revoke authority for solid waste collection and disposal facilities.

The Oklahoma Clean Air Act of 1967 established the Air Pollution Council whose primary purpose is to recommend rules and regulations pertaining to air pollution to the State Department of Health. Specific regulations under this act were adopted by the State Board of Health June 13, 1971, and placed under the Solid Waste Management Act. The regulations which have the most direct impact on rural areas pertain to the prevention of open burning and dumping. These requirements were prorated by year according to city size, and required all communities above 5,000 inhabitants to have a sanitary landfill or other acceptable means of disposal under permit by July 1, 1972 [19, p. 8].

Further regulations require smaller incorporated areas to comply with a sanitary landfill or other acceptable means of disposal according to the following schedule: populations between 3,000-5,000, July 1, 1973; and less than 3,000, July 1, 1974. These requirements directly necessitate the need for planning and implementation of solid waste management systems in rural areas.

In addition, the disposal of solid waste by sanitary landfill must adhere to several standards. Some which directly affect costs include the following: (1) access roads shall be maintained so as to be passable in ordinary inclement weather; (2) a suitable shelter shall be provided for personnel employed at the landfill; (3) provisions shall be made for measuring all refuse delivered to the landfill; (4) measures shall be taken to prevent or control fires; and (5) access to the disposal site and the blowing of litter shall be controlled.

Likewise, specifications must be met concerning the spreading and compacting of refuse, depth of cells for each day's fill, and final cover and grading. Inspection by the State Department of Health is to be made annually for a period of at least three years, or such additional time as may be necessary to insure compliance.

Objectives and Organization of This Study

The main thrust of this study is to identify those factors which affect costs in the solid waste collection-transfer-disposal sequence and to measure their impact in the total cost of solid waste management systems. The intent is to provide information that can be useful to decision makers involved with the planning of solid waste systems in small communities and rural regions. A cost analysis of the collection-transfer-disposal process is presented, utilizing different technologies, from which implications can be drawn concerning efficiencies related to areawide solid waste management systems.

More specifically, the objectives of this study are to:

(1) specify a substate planning framework that can be utilized for analysis of regional solid waste management systems,

(2) estimate costs related to the collection and transfer processes of solid waste systems,

(3) estimate costs associated with solid waste disposal employing the sanitary landfill and

(4) provide an application in comprehensive planning of solid waste collection and disposal services for a multi-community planning region.

Chapter II of this study describes a general framework for community services planning at a substate level, with application to solid waste management planning. This chapter defines the factors relevant to the identification of solid waste management as a planning target and presents some policy issues affecting the implementation of solid waste service to rural area economies.

Chapter III identifies those factors affecting costs of collection and transfer in solid waste management systems. This chapter defines the variables which decision makers must consider when planning for solid waste systems on a local and area wide basis. Economic theory is used to explain the cost relationships associated with collection and regression analysis is used to explain expected relationships between dependent and independent variables.

Chapter IV analyzes the disposal aspects of the solid waste management system, incorporating those factors which influence the costs associated with the sanitary landfill method of disposal.

Chapter V presents a comprehensive solid waste management plan with application to a rural county in northern Oklahoma. The analysis is presented on an areawide basis, emphasizing interlocal governmental coordination to assess the benefits of economies of size.

Chapter VI summarizes principle results and presents basic conclusions of the study.

CHAPTER II

SOLID WASTE MANAGEMENT IN A REGIONAL PLANNING FRAMEWORK

The planning framework with regard to a solid waste management system should be structured so as to assist the decision makers responsible for its cost and performance in identifying all information necessary for the provision of an adequate facility design. The planning process is employed to meet objectives which are both efficient in terms of resource utilization and socially desirable to the recipients of the community service. The fate of planning for solid waste systems lies in its ability to accomplish a socially acceptable level of service that employs resource outlays at a reasonable cost to its recipients.

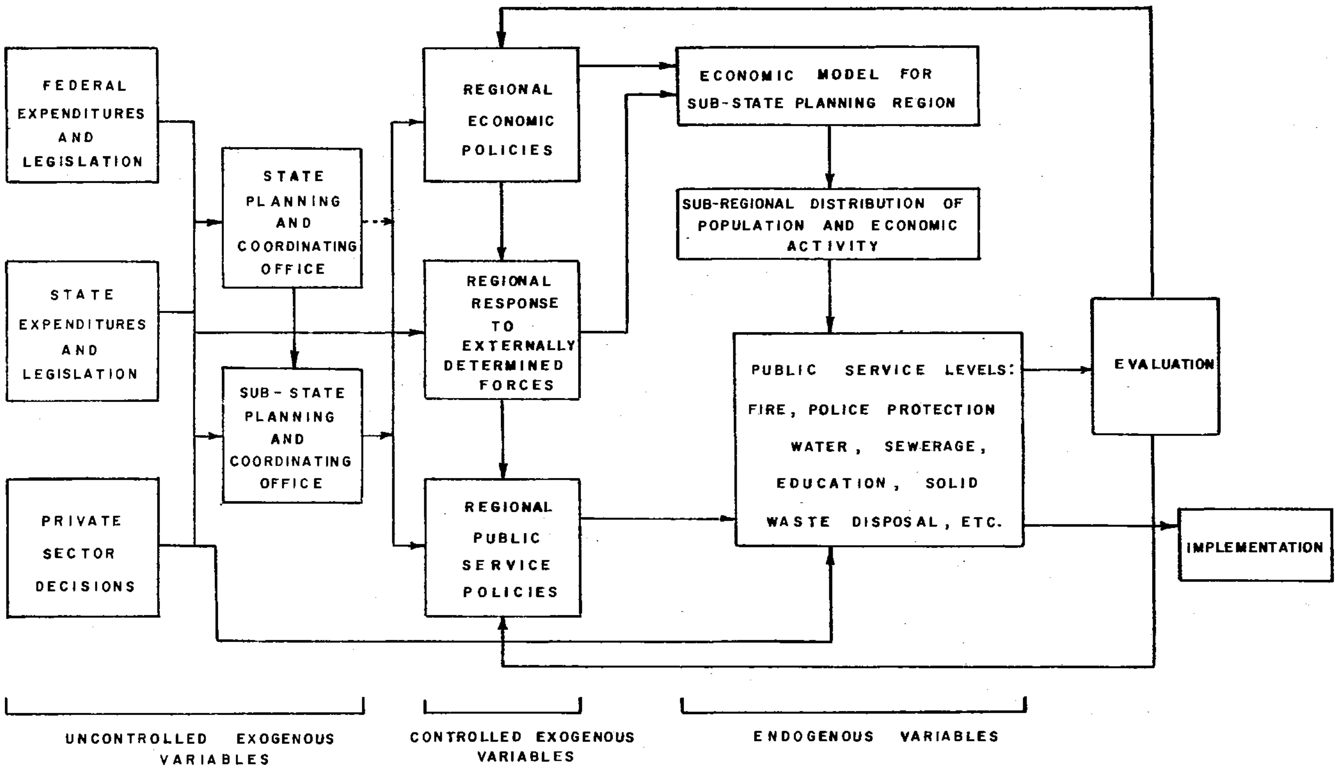
The methodological structure of evaluating areawide solid waste systems involves identifying a set of variables and behavioral and technological relationships that influence the desired level of service both in qualitative and quantitative terms. A regional solid waste management system can be established when all direct and indirect relationships affecting its performance are enumerated. When the resulting community service is specified, the system can be evaluated as to its overall effectiveness.

General Framework for Community Services Planning

When the planning framework for a specified community service is developed for an areawide delineation, it represents a subsystem of a much larger information design. The physical development of any areawide service is an outgrowth of a planning process which requires the complete portrayal of the social, technological, economic, and behavioral interrelationships which exist in or which influences the planning area receiving the service. Hence, the level and design of areawide community services is the result of a regional information system that identifies all components which stimulate regional economic change, and produces physical development.

The regional information system presented in this study follows a basic structure developed by Sonenblum and Stern [26]. The structure incorporates a set of exogenous and endogenous variables into a planning framework and links their associations into a model for specifying desired levels of community services on an areawide basis. The structure is presented in Figure 1. A brief explanation of its components should be given to facilitate a better understanding of its intent.

The exogenous variables represent existing policies, decisions, and policy tools of all governmental levels as well as private sectors. These variables can take two forms: the controllable variables, those with which the planner has some control such as government expenditures and land use; and the uncontrolled variables, those which cannot be altered by the local planner such as federal expenditures and the availability of natural resources.



Source: [26].

Figure 1. Public Service Planning Framework for a Sub-State Level

The endogenous variables are those which measure the characteristics of the regional economy which the planner wishes to change. Endogenous variables also include the irrelevant variables which may be affected by the plan but are extraneous to the planner. The structural relationships of the regional economy determine the effect that changes in the exogenous variables will have on the endogenous variables.

For illustration purposes, an example of the planning framework is discussed below. Federal legislation in the form of a grant program designed to stimulate local investment in a community service to alleviate an existing problem is funded by the Office of Management and Budget for allocation to the states. The program, when funded, provides an impetus for economic change at the local or areawide level but represents an exogenous variable in the sense that the local planner has no control over its distribution. However, the federal sector, through its actions, becomes an intrinsic component of the planning framework by establishing an objective related to a single functional area from which local or areawide entities can respond.

The state and local governments furnish a complementary input to the federal level in that the federal government relies on them as producers of most community services. While the federal level provides the impetus for change, the selection of methods for achieving resource allocation efficiency is delegated to the state and local levels. Hence, the federal government concerns itself with an equitable distribution of expenditures among broad functional areas, and the state and local jurisdiction levels focus on providing an equitable distribution of community services for its constituents.

The regional response to externally determined forces can frequently be influenced by information produced by a governmental central agency, usually in the form of a regional or multi-regional planning and coordinating office. The primary functions of these agencies are to collect, classify, and distribute information concerning available funding and projects at the federal level for dissemination to the local units. The local interests make applications to the federal agencies and coordinate projects and programs back through the channel via the regional and state clearinghouses.

The regional response to federal legislation constitutes an important input to the planning process mainly because regional activities are influenced by a transfer of funds brought about by either the desire for additional revenues or by the desire to accomplish certain objectives. The regional response takes the form of planning implementation and is governed by regional economic policies and public service policies aimed at satisfying service requirements. Changes in public service needs due to influences of the external forces are evaluated considering existing regional public service policies and economic policies, and adjustments are made in these variables so that the combination of public expenditures can be rearranged to better meet the needs of the impact areas. Subsequently, the controlled external forces affect the endogenous variables or desired public service levels.

The system for planning takes on a circular scheme in the sense that public service requirements are influenced by regional economic activities which, in turn, are subject to regional policy constraints and external forces. The informational components are evaluated and adjustments are made in regional public service and economic policies until desired levels of public services are attained both in terms of quantity and quality. A necessary prerequisite of the planning framework is its ability to evaluate any external policy change and incorporate such into the structure so that service efficiency can be improved.

Application of the Planning Framework to Solid Waste Management

Incorporation of solid waste management services as a public goal in the sub-state planning framework requires an appraisal of several additional models. Figure 2 depicts a solid waste management framework at a sub-state level.

In determining service requirements and costs of service supply for a solid waste system on an areawide basis, the initial problem is that of estimating solid waste generation [13]. The methodology describing generation involves determining the number and types of solid waste production units and the waste generation rates which relate the average quantity of waste generated over a specific period of time to each of the basic units of production. Generation is a function of the level and kinds of economic activity in the region, changes in economic activity or industry mix, and changes in population.

Data on solid wastes can be classified in different ways, using different criteria for classification [11]. Essentially, they can be classified by source and by composition. The major sources are the residential, commercial, public, industrial, and agricultural sectors. These can be classified in further detail by studying the present rate

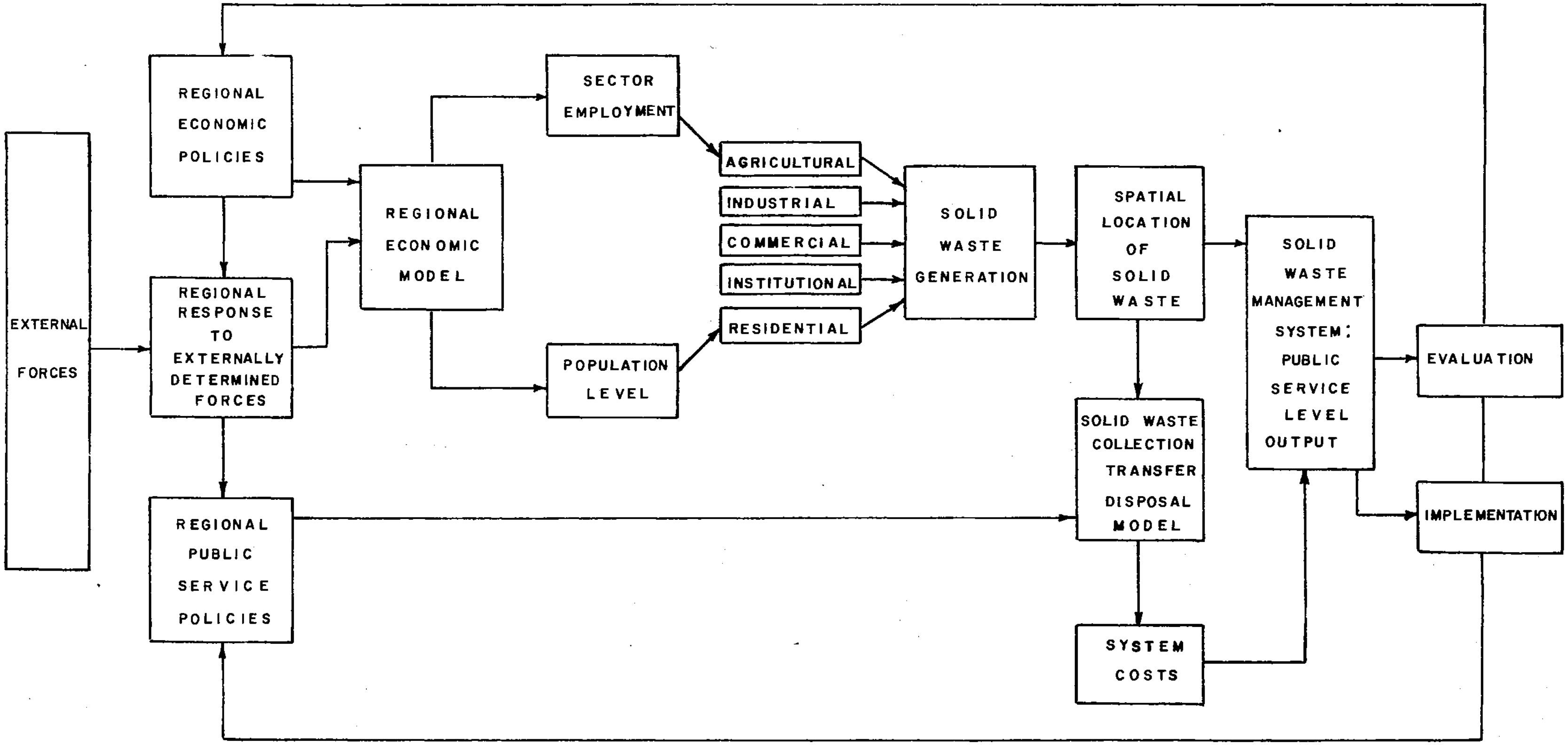


Figure 2. Solid Waste Management Planning Framework at a Sub-State Level

of generation and future changes in quantities of waste corresponding to changes in the sources. The composition of wastes can be classified according to physical or chemical properties or by the proportions of the different items. Regardless of what criteria is selected, the delineation of a complete cross-classification of wastes for any given region is quite difficult and usually very expensive to estimate.

One method for estimation involves measuring regional waste by source and level of economic activity [16]. Given employment data by industrial sector, a waste coefficient can be estimated by sector relating output to sector employment [6]. Multiplication of the coefficient times the output generated by a change in employment results in an estimate of solid waste generated per employee.

Waste generation can also be estimated by linking the level of economic activity to regional land use [8]. Land use becomes an explanatory variable and can be used in conjunction with land use planning to identify future locations of solid waste disposal sites. The generation of wastes is estimated according to land use and the resulting data gives the amount and nature of wastes entering disposal. This technique enables the planner to isolate waste according to its spatial location and thereby consider disposal requirements and location factors.

Once generation and location have been incorporated into the substate planning framework, collection, transfer, and disposal requirements can be developed from which system costs can be estimated. The interdependencies of all of these factors comprise the solid waste management system. The resulting system is an alternative that can be evaluated by the local policy bodies and their constituents for implementation or rejection. If local political decisions, policy constraints, or local responses to external forces, are such as to require further analysis, the planning framework is altered to embody the desired changes in either economic or public service policies at the regional level, and the model is transformed to include such changes. The planning scheme is so designed to allow alternatives to be employed until implementation is achieved.

CHAPTER III

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 or 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 employed in urban areas: one involves a rear-loader and by far is the most common system used in residential areas; and the other is a front-loader and is frequently employed in commercial, industrial, and multi-family complex areas. The principle difference in these two systems is that the front-loader requires a containerized collection unit whereas the rear-loader 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

Planners involved with solid waste management need information on costs for providing the collection service so that a system for implementation can be selected that will be both desirable to the constituents of the community and within certain financial restraints imposed by the community decision-makers.

A number of interrelated elements must be considered in determining the total costs of a collection system. A single measurement for solid waste collection service output is difficult to determine and perhaps inappropriate. For a specific type of collection service, whether residential or commercial, total costs are more sensitive to number of collections made than to any quantity or volume measurement of solid waste collected. In addition, total collection costs are influenced by certain spatial factors, quality characteristics of the collection system, and efficiency of system operations.

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. A brief description of these components is given to facilitate a better understanding of their composition within a solid waste collection system. Fixed costs represent those costs which do not vary with output. These costs represent a relatively small part of the total costs of providing for the collection service. They are comprised of the annual fixed administrative costs, building costs, general overhead expenses, equipment and facility costs, and interest on investment.

Variable costs include those costs which must be paid on the basis of the quantity of service output. In the case of solid waste collection, the quantity 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 influenced by the quantity of refuse generated for disposal by production source, the frequency with which this waste must be handled, the location and density arrangement of the producing units, the nature of the process used to facilitate collection, the type of equipment utilized, the quantity and efficiency of the labor input, and the hauling distance of a specified route.

The service area encompassed in the collection process influences costs in the sense that the 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 can be calculated.

Estimating Collection Costs by Means of Budget Data

Budget data were used to calculate cost per collection and per ton of solid waste collected for each of the 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. An example of the time and motion format is shown in the Appendix. 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.

Observed Budgets

Budgets for a municipality of approximately 25,000 persons using rear-loading technology and an institutional system using front-loading technology were observed and the results given in Tables I and II. 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 about $21,000 for the three-man crew rear-loading system versus about $23,000 for the two-man crew front-loading system. The rear-loading system requires about $1,600 of annual fixed vehicle costs per crew, as compared with about $3,800 in the front-loading system. This represents the annual cost of capital alone. The annual fixed costs represent only about 7 percent and 16 percent of the total collection crew costs of the rear-loading and front-loading systems respectively. Of the remaining outlays, labor comprises 74 percent of the annual collection crew costs for the municipality and

TABLE I

SOLID WASTE COLLECTION BUDGET FOR MUNICIPALITY
OF 25,000 REAR-LOADING TECHNOLOGY
(1971 DOLLARS)

<u>Fixed Administrative and Building Costs</u>			
Annual administrative costs			
Supervisory personnel			13,943
City overhead billing costs			18,279
Building costs			
General warehouse construction cost for 5,600 sq. ft. at 7.39/sq. ft.	41,384		
Annual building cost assuming 30 year life and 6% interest on average annual investment		2,621	
Annual maintenance (1% average value)		207	
Annual insurance (0.8% average value)		166	
Total annual fixed costs (TAFC)			35,216
<u>Cost per Collection Crew</u>			
Fixed vehicle and misc. cost			
Purchase price (20 cubic yard)	12,000		
Annual cost assuming 12,000 hour life, 6% interest, 12.5% salvage value, and 1,232 hours annual use		1,441	
Annual insurance (2% average value)		120	
Misc. fixed cost per crew		30	
Container cost per crew			
Average purchase price per container	152		
Average no. containers per crew (NCOPCR)	62		
Annual container cost per crew assuming 10 year life and 6% interest (COCPCR)		1,222	
Variable cost per crew			
Annual labor cost per 3 man crew		15,427	
Annual vehicle operation and maintenance cost		2,611	
Total annual cost per collection crew (COLCRC)		20,851	
Total annual collection crew cost: 9 crews			187,659
<u>Annual Municipal Fixed Costs and Collection Crew Costs</u>			222,875

TABLE II

SOLID WASTE COLLECTION BUDGET FOR INSTITUTIONAL FACILITY FRONT-LOADING TECHNOLOGY (1971 DOLLARS)

Fixed Administrative and Building Costs			
(Assumed 16% of total budget per results of municipal budget) (TAFC)			8,286
Cost per Collection Crew			
Fixed vehicle and mics. cost			
Purchase price (24 cubic yard)	25,000		
Annual cost assuming 12,000 hours life, 6% interest, 12.5% salvage value, and 1,523 hours annual use		3,533	
Annual insurance (2% average value)		250	
Misc. fixed cost per crew		30	
Container cost per crew			
Average purchase price per container	335		
Average no. containers per crew (NCOPCR)	82		
Annual container cost per crew assuming 10 year life and 6% interest (COCPCR)		2,827	
Variable cost per crew			
Annual labor cost per 2 man crew		11,298	
Annual vehicle operation and maintenance cost[a]		4,839	
Total annual cost per collection crew (COLCRC)		22,777	
Total annual collection crew cost: 2 crews			45,554
Annual Fixed Costs and Collection Crew Costs			53,840

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

and 50 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 time and motion analysis provided a fruitful approach from which several factors could be isolated that have an influence on collection rates and subsequently on the variable cost components of the total collection system costs. 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 for both systems for purposes of distinguishing spatial effects upon collection rates.

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 of the relationship is that the collection rate will increase the denser are the household and commercial collections for any given service area since less time is required by the crew and compaction vehicle to move between collection points. Further, it is expected that the collection rate will decrease the more nonroute miles there are associated with any service area. Nonroute miles are a proxy for size of community and subsequent distance to the solid waste disposal site. At this stage of the analysis, the disposal site is assumed to be located at the edge of the city.

Collection rate is also expected to decrease the greater the percentage of commercial collections for any given service area of the municipal system. Since 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, the collection rate is expected to decrease for increasing percentages of commercial collections.

Regression analysis was used to estimate the functional relationship between collection rate and the three explanatory factors. Observations on the municipal system included one-time data on each of the 23 biweekly routes plus a daily 100 percent 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 are the following:

Municipal system

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

$R^2 = .71 \qquad n = 24$

Institutional system

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

$R^2 = .85 \qquad n = 15$

where,

COLR = COLlection Rate, number per hour
NRM = Non-Route Miles
DEN = DENsity, number of collections per route mile
PCOM = Percent COMmercial (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 shows density of collections to be highly significant in explaining collection rate for both systems. Nonroute miles appeared to be significant in the municipal system but not in the institutional system.

Cost per collection. Total cost per collection can now be estimated by 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 is expressed in the following model:

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

where,

TCPCOL = Total Cost Per COLlection
FCPCOL = Fixed Cost Per COLlection
CRCCOL = CRew Cost per COLlection
COCCOL = COntainer Cost per COLlection
TAFC = Total Annual Fixed Cost
NACOL = Number Annaul COLlections
CRCPHR = CRew Cost Per HouR
COLR = COLlection Rate
COLCRC = annual COLlection CRew Cost
COCPCR = annual COntainer Cost Per CRew
NACRHR = Number of Annual CRew HouRs
NCOPCR = Number of COntainers Per CRew
NCOLCO = Number annual COLlections per COntainer

Tables III and IV give the results of the cost per collection model for the municipal and institutional systems. Cost per collection varied from about 25 cents for residential collections to 62 cents for commercial collections where the municipality provides the container. For the institutional system, cost per collection varied from $1.36 where a one man crew is employed to $1.72 for a two man crew, assuming

TABLE III

SOLID WASTE COLLECTION RATE, COST PER COLLECTION, VOLUME PER COLLECTION, COST PER TON COLLECTED, AND OTHER DATA: MUNICIPAL SYSTEM, REAR-LOADING, 1971

	Variable Name[a]	Residential Service Areas	Commercial Service Areas with Containers
Number of Collections (annual)	NACOL	777,089	71,447
Fixed Cost per Collection ($)	FCPCOL	0.0415	0.0415
Crew Cost per Collection			
Crew Cost per Hour ($)	CRCPHR	15.93	15.93
Collection Rate (# per hr.)	COLR	78[b]	37[c]
Cost per Collection ($)	CRCCOL	0.2042	0.4305
Container Cost per Collection ($)	COCCOL	--	0.1516[d]
Total Cost per Collection ($)	TCPCOL	0.2457	0.6236
Monthly Cost ($)		2.13[e]	6.75[d]
Volume per Collection (yd^3)	VPCOL	0.0546[f]	0.3537[g]
Quantity per Collection (lbs.)[h]	APCOL	19.66	127.33
Collection Cost per Ton ($)	COLCTN	24.99	9.80

[a]See text for model formulation.

[b]Average of 40 pickups per route mile, 16.5 non-route miles and zero percent commercial.

[c]Average of 10 pickups per route mile, 16.5 non-route miles and 100 percent commercial.

[d]Average of 2.5 pickups per container weekly.

[e]Two pickups weekly.

[f]Evaluated at zero percent commercial and 40 pickups per route mile.

[g]Evaluated at 100 percent commercial and 10 pickups per route mile.

[h]Assumed 360 lbs. per cubic yard of compacted (3:1) refuse following data in [10, p. 26].

TABLE IV

SOLID WASTE COLLECTION RATE, COST PER COLLECTION, VOLUME PER COLLECTION, COST PER TON COLLECTED AND OTHER DATA: INSTITUTIONAL SYSTEM, FRONT-LOADING, 1971

	Variable Name[a]	Two Man Crew	One Man Crew
Number of Collections (annual)	NACOL	31,772	31,772
Fixed Cost per Collection ($)	FCPCOL	0.2608	0.2608
Crew Cost per Collection			
Crew Cost per Hour ($)	CRCPHR	13.10	9.39[b]
Collection Rate (# per hr.)	COLR	10.23[c]	10.23[d]
Cost per Collection ($)	CRCCOL	1.2805	0.9179
Container Cost per Collection ($)	COCCOL	0.1792	0.1792
Total Cost per Collection ($)	TCPCOL	1.7205	1.3579
Monthly Cost ($)[e]		27.58	21.77
Volume per Collection (yd^3)[f]	VPCOL	0.7317	0.7317
Quantity per Collection (lbs.)[g]	QPCOL	263.41	263.41
Collection Cost per Ton ($)	COLCTN	13.06	10.31

[a]See text for model information.

[b]Assumed 50 percent labor cost of two man crew.

[c]Evaluated at sample means of 13.4 non-route miles and 3.477 collections per route mile.

[d]Assumed equal productivity for one man crew as with two man crew.

[e]Average of 3.7 pickups per container per week.

[f]Computed as the average compacted volume per collection over a two week period.

[g]Assumed 360 lbs. per cubic yard of compacted (3:1) refuse following data in [11, p. 26].

the same collection rate in both instances. Collection rates were evaluated at average conditions for density and nonroute 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 solid waste collection-transfer-disposal is then calculated on a cost per ton basis. As became evident in the discussion on factors affecting collection costs, number of collections influences total collection costs more than quantity of solid waste collected. Therefore, in this section, cost per ton of solid waste is 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 is hypothesized that routes with a higher percentage of commercial collections would show a higher volume per collection. Density is a proxy variable for indicating low income neighborhoods or service areas. From a cursory inspection of collection routes in the observed municipal system, 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 density would negatively influence volume of solid waste per collection.

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

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

where,

VPCOL = Volume Per COLlection (cubic yards at a 3:1 compaction ratio)
PCOM = Percent COMmercial (by number of collections)
DEN = DENsity, 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:

$$COLCTN = [TCPCOL \div QPCOL]\ 2{,}000$$
$$QPCOL = VPCOL \cdot WPCUBY \quad (3.5)$$

where,

COLCTN = COLlection Cost per ToN
TCPCOL = Total Cost Per COLlection
QPCOL = Quantity Per COLlection in pounds
VPCOL = Volume Per COLlection (cubic yards at a 3:1 compaction ratio)
WPCUBY = Weight Per CUBic Yard in pounds

Weight per cubic yard of solid waste is highly variable and depends upon many factors. Using data from [11, p. 26] 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. Those results are assumed for this analysis of cost of solid waste collection per ton.

Tables III and IV give the results of the model on cost per ton of solid waste collected for the municipal and institutional systems. Cost per ton varied from about \$25 for residential solid waste to \$9.80 for commercial solid waste in the municipal system. For the institutional system, cost per ton varied from \$13.06 for a two man crew to \$10.31 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

To demonstrate the effects that density and transfer distance have on collection costs, these factors were allowed to vary in the cost models. 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 counterpart 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[1] 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.

---

[1]See Chapter IV for an analysis of solid waste disposal costs.

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

$$COLC\ (DEN) = FCPCOL + COCCOL + CRCPHR \div [b_o + b_1\ NRM + b_2\ (DEN) + b_3\ PCOM] \tag{3.6}$$

All variables have been previously defined in equations 3.1, 3.2, and 3.3. The b_j's are parameters from the previously estimated collection rate equations. Density of collection is 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 is given by the following model:

$$\begin{aligned} C(TRM) &= C(DEN) + [CPTNM \cdot QSWCOL]\ TRM \\ CPTNM &= CTRM \div TKCAPQ \\ CTRM &= CPCRHR \div VEL \end{aligned} \tag{3.7}$$

where,

C(TRM) = Cost per collection as a function of TRansfer Miles
C(DEN) = Cost per collection as a function of DENsity with zero transfer miles
CPTNM = Cost Per ToN Mile
QSWCOL = Quantity of Solid Waste per COLlection, tons
TRM = TRansfer Miles
CTRM = Cost per TRansfer Mile
TKCAPQ = TrucK CAPacity in solid waste Quantity, tons
CPCRHR = Cost Per CRew HouR
VEL = VELocity, miles per hour

Spatial Effects on Residential Collection Costs

Parameter data for the residential portion of the municipal rear-loading system is applied to equation 3.6 to determine density effects on collection costs. Utilizing average values for nonroute miles of the municipal system gives the following results:

$$\text{COLC (DEN)} = 0.0415 + 15.93 \div [66.5028 - 1.2247\ (16.5) + 0.788\ \text{DEN}]$$
$$= 0.0415 + 15.93\ [1/(46.2952 + 0.788\ \text{DEN}] \qquad (3.8)$$

The results of equation 3.8 are presented graphically in Figure 3. Cost per residential collection varies from about 30 cents for a density of 20 collections per route mile to about 21 cents for a density of 60. On a monthly basis with two collections per week the cost variation is $2.60 versus $1.82.

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:

$$\text{C(TRM)} = 0.2457 + [0.1106 \cdot 0.00983]$$
$$= 0.2457 + 0.001087\ \text{TRM} \qquad (3.9)$$

Figure 4 shows the effect of transfer miles on residential cost per collection.

Since equation 3.9 is linear, each additional transfer mile adds about one-tenth of a cent 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 cents per collection. Assuming the above relationship, monthly costs for the collection and transfer process with two collections per week is $2.38 for a disposal site 10 miles from the edge of the city and $2.60 when the disposal site is 25 miles out.

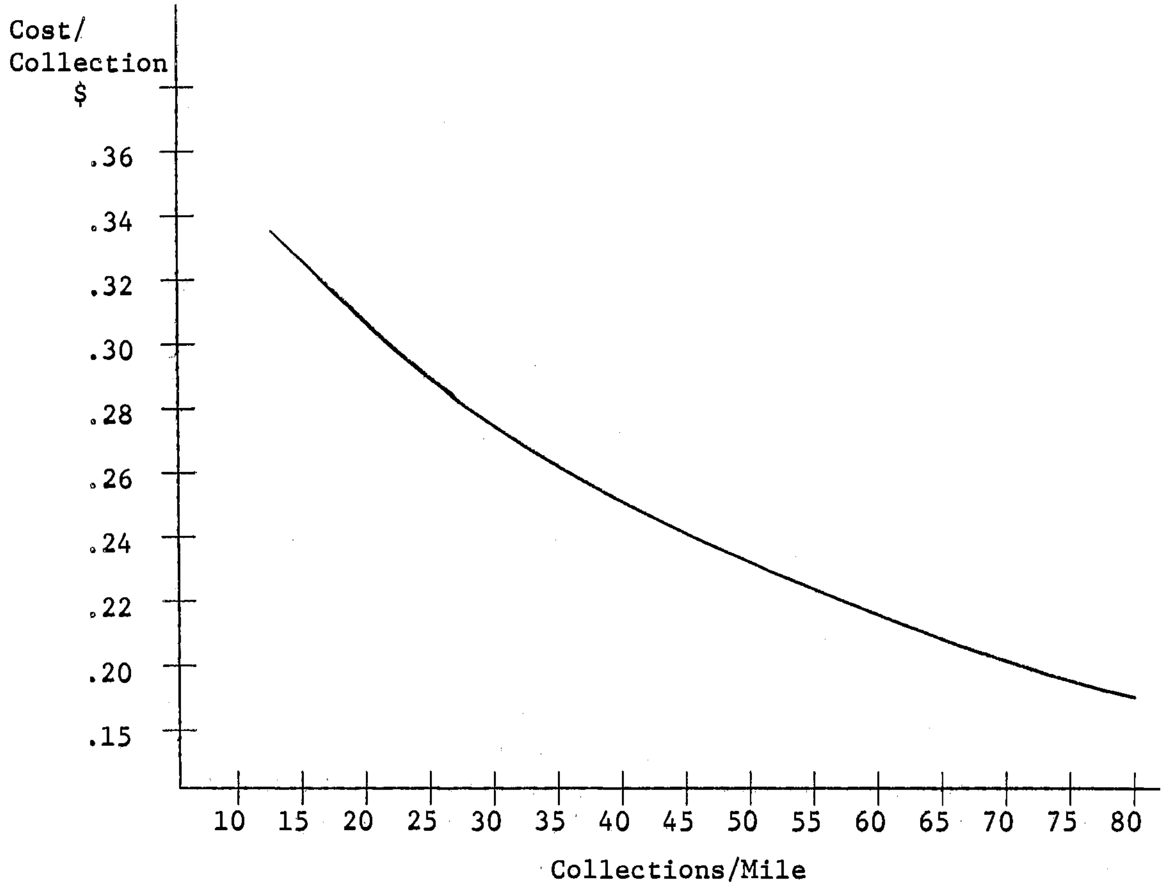


Figure 3. Average Cost Per Residential Collection Under Different Densities

Spatial Effects on Commercial Collection Costs

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

$$COLC\ (DEN) = 0.2648 + 13.10 \div [4.0954 - 0.0391\ (13.4) + 1.9156\ DEN]$$

$$= 13.3648\ [1/3.5115 + 1.9156\ DEN] \qquad (3.10)$$

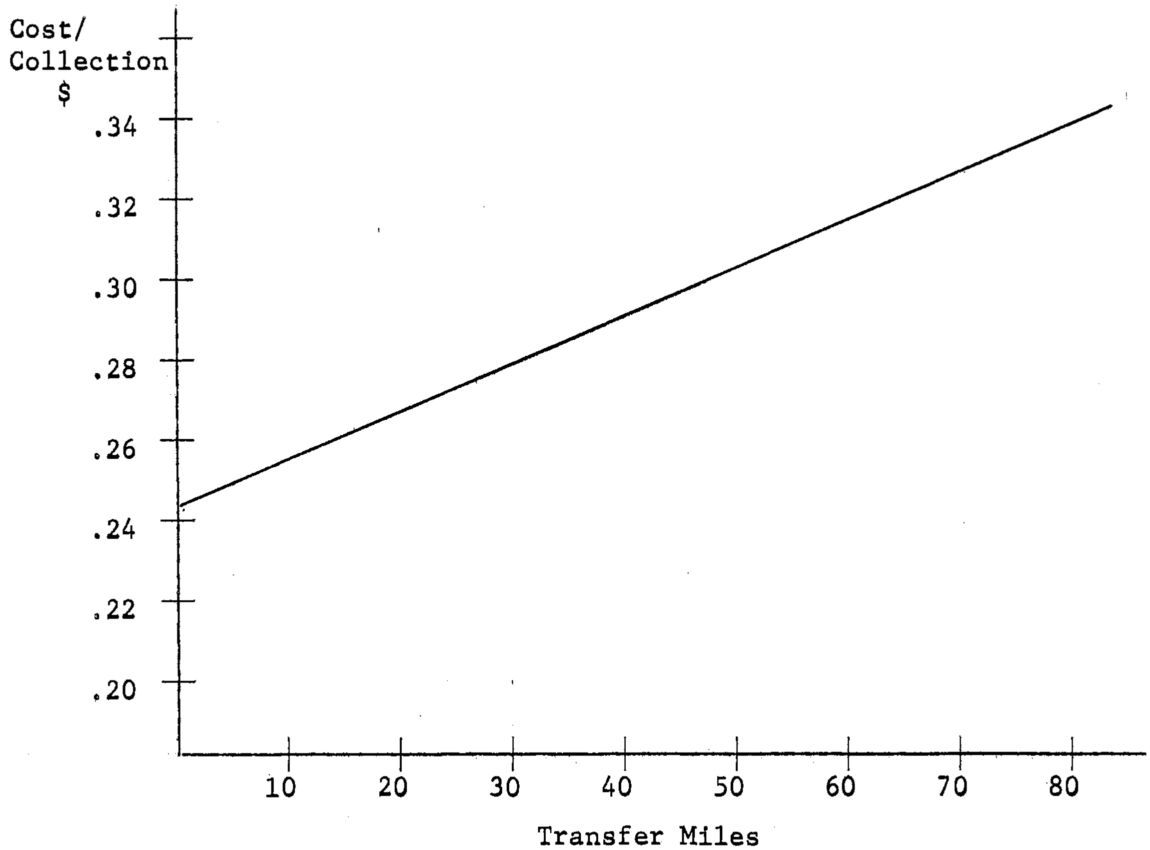


Figure 4. Average Cost Per Residential Collection Under Different Transfer Distances and Density of 40 Collections Per Route Mile

Allowing density to vary, cost per commercial collection varies from about $1.68 for a density of 2 collections per mile to about 69 cents for a density of 10 collections per mile (Figure 5). On a monthly basis, assuming transfer miles to be fixed, the cost of two collections per week ranges from $14.54 to $5.97.

The effect that transfer miles has on collection costs when a front-loading system is employed can be shown by graphing the results of equation 3.7 and assuming the total costs per collection from Table IV. As illustrated in Figure 6, the cost per collection

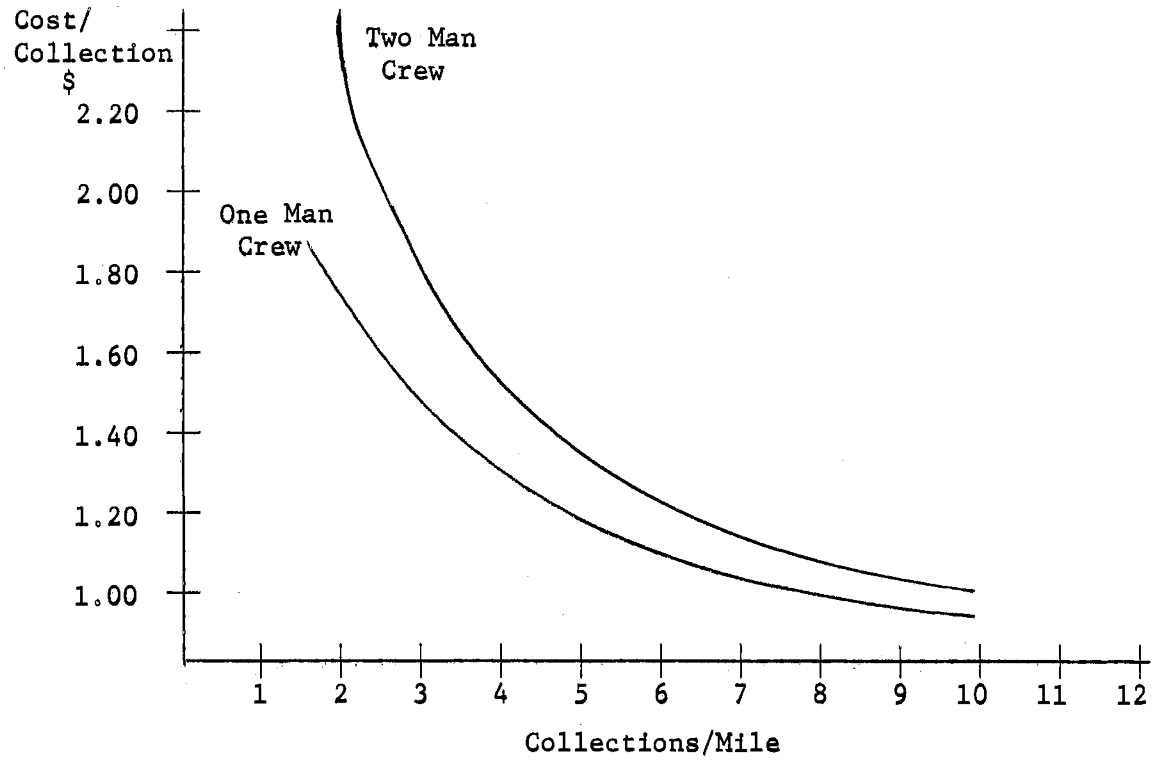


Figure 5. Average Cost Per Collection of Solid Waste Using Front-Loading Equipment With Different Densities

utilizing a one man crew ranges from $1.36 to $1.44. A two man crew ranges from $1.73 to $1.80 per collection.

It is interesting to note that in both technologies examined in this analysis, increasing transfer miles and holding density constant does not contribute as much to total collection costs as does 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 distance is normally substantial; both factors contributing to higher per unit costs.

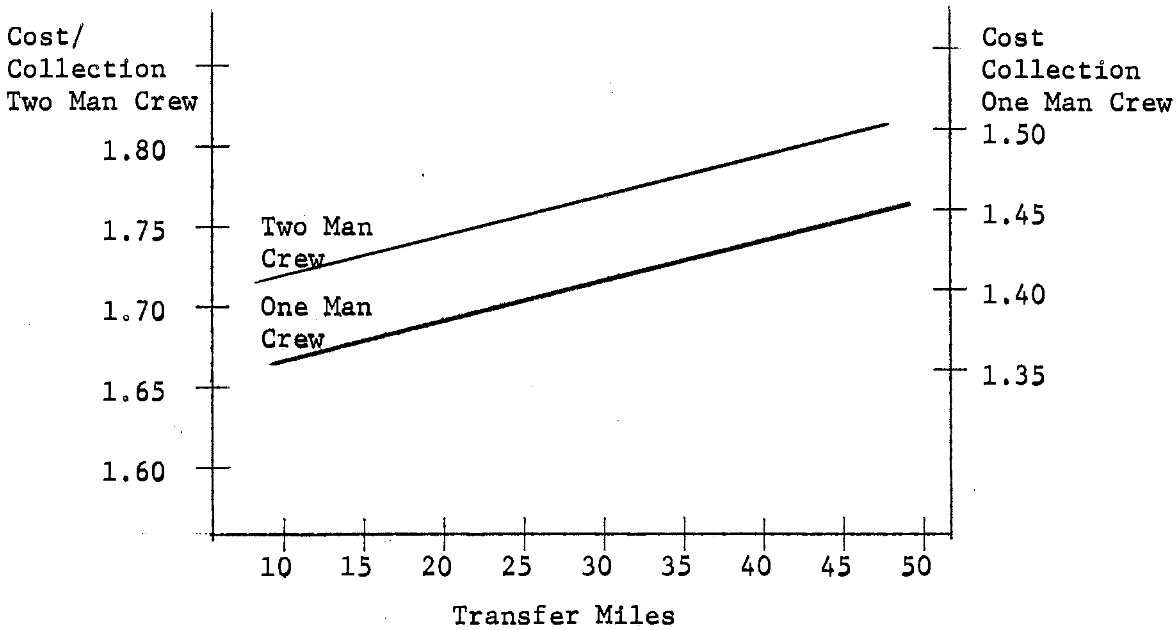


Figure 6. Average Cost Per Collection of Solid Waste Using Front-Loading Equipment With Different Transfer Miles

In summarizing the two systems analysed to the factors that effect collection costs, it appears that areawide 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 effect 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 should be 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 collection system design. The analysis clearly defines the perplexing nature of rural area solid waste collection in the sense that low production source density and relatively high transfer miles contribute substantially to high collection costs.

While the use of residential cans and commercial containers appear to produce lower costs than a totally containerized system, the ability and willingness of residential subdivisions and commercial areas to jointly utilize collection facilities can make an automatic process associated with the front-loading system cost competitive. Further, labor costs can be decreased significantly when a total hydraulic system is employed. It should be noted that the same level and quality of service can be provided by both systems. However, the qualitative aspects of solid waste systems must include local response to the physical requirements of the collection service. This aspect is beyond the control of the planner and must be evaluated after initial service requirements and cost analysis is complete.

The ability of the procedures outlined in this chapter to accurately appraise solid waste collection system costs depends to some degree on the variances not captured by the process employed in the analysis. The analysis is limited by its inability to define operational changes that may result 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.

Cost data derived from the budgets only represent observations over one year, and hence, it was necessarily assumed that the observed fixed and variable vehicle costs represent realistic averages over any given year. This is substantiated on the basis that the compaction vehicles were of different ages and hence the operation and maintenance costs captured the variances that may exist.

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 operation efficiency from routing would only affect the magnitude by which these factors are associated with collection costs.

The accuracy of the values estimated for collection rates and volume of solid waste collected depend upon the accuracy of the estimated empirical relationships between the independent and dependent variables. The regression coefficients for the selected models indicate that the variables associated with collection significantly explain part of the variation in collection rates, and volume per collection for both systems. However, as indicated by the R^2 values, not all of the variation in collection rates and volume are explained by the resulting equations. Several additional predictive equations were attempted, but a better fit could not be attained.

CHAPTER IV

ANALYSIS OF SOLID WASTE DISPOSAL SYSTEMS

Solid waste management functions of disposal must be constrained to evolve within the legal limitations established through state and/or national legislation designed to minimize public health problems. Hence, the disposal design and implementation process is primarily one of selecting a method that satisfies a predetermined set of legal standards and at the same time meets public approval both in terms of the method employed and the costs of operating the system.

A number of considerations are important when planning for solid waste disposal on a local or areawide basis. In a densely populated area, where alternative land uses and high land values limit the availability of disposal sites, location factors must be considered in terms of the costs associated with transfer and the land requirements of disposal [6]. In addition, the size of service area or production base must be known so that service requirements for disposal can be defined. The existence of economies of size related to disposal may produce some impetus for areawide cooperation and may produce a technically feasible disposal system in sparsely populated areas that otherwise would not exist or would be relatively more costly for smaller, individual service areas.

Regardless of the factors that determine selection of the solid waste disposal method, the disposal process must be planned as an integrated part of the total solid waste management system. The costs of supplying the disposal service must be covered by revenues that are received from the total collection-disposal process. Generally, the recipient of the total solid waste management service does not differentiate between the two processes.

More importantly, because location of the disposal site determines transfer distance, and, in some cases, capital requirements for the collection process (for instance, transfer stations requiring additional collection-transfer vehicles), planning for total system design is an integral consideration when planning the disposal service [3]. Trade-offs between site operating costs, transfer costs, and fixed or capital costs are considered only after total process selection has been determined. When the interdependents associated with collection and disposal are ignored, the cost of the total solid waste system can become excessively high.

Alternative Solid Waste Disposal Methods

Several disposal methods currently are employed in solid waste management systems: sanitary landfills, incinceration, recycling, composting, grinding, and pyrolysis [14]. These methods are designed to either reduce the volume of solid waste for ease of handling or to discard the total quantity of solid waste generated. With the exception of the sanitary landfill method the alternatives mentioned require separate means of disposal to handle specific types of wastes or to handle the refuse remaining after the process is complete. In addition, most methods of disposal are expensive and require high volume service areas to be economically feasible. A brief discussion of each of the major disposal methods used is presented below.

The incineration method involves the 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 [14, p. 8].

Grinding cannot technically be considered a disposal process in the sense that its objective only is to reduce the volume of waste. This alternative is largely a processing method whereas the household or business establishment is individually responsible for installation. The wastes are disposed into the sewerage system and, hence, non-digestible residue must be facilitated in some other fashion. The costs are reported to vary from $0.25 to $3.00 per ton of solid waste processed [14, p. 9].

Composting is used solely in large metropolitan areas and involves the biochemical reduction of organic materials to sanitary, humus-like material. While under certain conditions, this process may be no more expensive than incineration, costs are normally higher 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 the problem of air pollution normally attended with incineration. The costs of the pyrolysis method range from $7 to $12 per ton. The method offers some advantages over conventional incineration in that smaller units can be employed, with total construction being underground [14, p. 9].

However, it should be noted that separate disposal processes are required and this would have to be considered in total costs of solid waste disposal.

For small municipalities and rural areas the apparent least cost method for disposing solid waste is by means of landfill. Several research studies indicate that the average cost for sanitary landfill is about $1.13 per ton of solid waste disposed with a range of $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. However, the ability of the landfill method to be cost effective is largely governed by site location.

Because disposal and collection processes are considered to be interrelated operations, the disposal site selection is an important consideration for total cost analysis as shown in Chapter III. The ultimate landfill location is largely governed by local policy and economic constraints in the form of high land values and/or the willingness of land-owners to cooperate in site provision. 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 service requirements and the 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

Costs of solid waste disposal by sanitary landfill include fixed costs of equipment, access road construction and other 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 an appropriate compaction of refuse. Data reported on landfill operations of 138 cities showed that all but 34 cities with populations of 15,000 or less operated the fill with only one piece of equipment [14]. Furthermore, other data show that one piece of equipment can handle landfills serving populations up to 50,000 [8]. Because of daily covering of solid waste in landfills, compaction equipment must remain at the site and is considered a fixed cost of the landfill disposal method. 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 topographical 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. Topographical 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 sites once 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 [11].

Two approaches have been used to estimate solid waste disposal costs by means of landfill. One approach was to 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. A second approach utilizes cross section data from a number of landfill operations and regresses cost per ton of solid waste disposed against quantity of solid waste.

Budget Technique

Total estimated quantity of solid waste disposed for the observed system is shown in Table V. The landfill served a municipality composed of residential and commercial collection service areas, a large institutional system, and an estimated quantity deposited by private individuals and establishments. The estimated annual quantity of solid waste entering the landfill is 21,830 tons.

TABLE V

ESTIMATED QUANTITY OF SOLID WASTE DISPOSED ANNUALLY IN THE OBSERVED LANDFILL

	Number of Collections	Estimated Lbs./Collection	Tons/Year
Municipality			
Residential	777,089	19.66	7,639
Commercial	71,447	127.33	4,549
Institution	31,772	263.41	4,185
Private (25% or total)			5,457
Total			21,830

A budget for the observed landfill is shown in Table VI. Annual fixed site development costs is an estimate of what is required to meet minimum conditions of the Oklahoma law and with an expected life of the landfill of about 10 years. Marginal increases (or decreases) in site development cost due to larger (or 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 fixed 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. Assuming an expected maximum life of 10 to 12 years, which may be reasonable due to machine technical obsolesence, equipment depreciation may be considered a fixed cost for less than 12,000 hours use in that time period. 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, in most cases, should be considered a fixed cost. Annual insurance and interest cost are also considered a fixed cost.

Labor and vehicle operation and maintenance are considered to be variable costs to the landfill and can be adjusted in accordance with the amount of solid waste to be disposed. It is assumed that labor can be used for other local government functions and hence that labor used at the landfill is charged against the disposal system. Vehicle operation and maintenance costs were computed using the Caterpillar Performance Handbook [2]. Local fuel prices were used and normal production dozing in clays, sands or gravels with intermittant full throttle operation and idling time was assumed.

A simple model describing total costs of solid waste disposed and cost per ton can be given and estimated using the budget data:

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

where

TCDP = Total Cost of DisPosal
FCDP = Fixed Cost of DisPosal
VCDPTN = Variable Cost of DisPosal per ToN
TQSWDP = Total Quantity of Solid Waste for DisPosal
ACDPTN = Average Cost of DisPosal per ToN

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

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

For the observed landfill with an annual disposal of 21,830 tons, cost per ton is estimated at $1.25. 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 are based on local conditions. Productivity of labor in terms of amount of solid waste that can be disposed of per hour is based on one observation which may not be typical for other

TABLE VI

SOLID WASTE LANDFILL DISPOSAL BUDGET
(1971 DOLLARS)

Site Development			
Annual fixed site development cost			3,000
Fixed Equipment Costs			
Purchase price (DC6 Crawler Tractor)	45,000		
Annual cost assuming 12,000 hour life, 6% interest, 12.5% salvage value, and 1,100 hours annual use		4,958	
Annual insurance (2% average value)		450	
Total annual fixed equipment cost			5,408
Variable Costs			
Annual labor costs including insurance and fringe benefits		12,480	
Annual vehicle operation and maintenance costs on the basis of 1,100 hours annual use[a]		6,369	
Total annual variable costs			18,849
Annual Fixed and Variable Cost (TCDP)			27,257
Total Quantity of Solid Waste Disposed, Tons (TQSWDP)		[21,830]	
Cost per Ton Disposal (ACDPTN)			1.25

[a]Computed from the Caterpillar Performance Handbook [2].

communities. No attempt is made to analyze cost differences for different complements of equipment including used equipment. Vehicle operation and maintenance costs are based on averages both in terms of machine efficiency and soil conditions. For these reasons, results of the budget technique are compared with results of a cross-sectional analysis of several landfill sites where costs of operation and quantities of solid waste disposed have been 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. In addition, long term capital expenditures for purposes of site modification were excluded.

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

$$ACDPTN_c = 0.6479 + \underset{(4,973)^{***}}{28,380}\ (1/TQSWDP) \qquad (4.3)$$

$$R^2 = .54 \qquad n = 30$$

where all variables are as previously defined. The inverse relationship of quantity of solid waste disposed annually is highly significant

(1% level) although the total amount of variation in cost per ton accounted for is only 54 percent. Including important quality characteristics of the landfills could be hypothesized to account for more 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 1971 level from the 1968-69 observed data using the Department of Commerce composite construction cost index [31]. These corrections amounted to an adjustment of 2 percent reduction in cost per ton as reported in equation (4.3). Results of equation (4.3) with the above adjustments have been graphed in Figure 7.

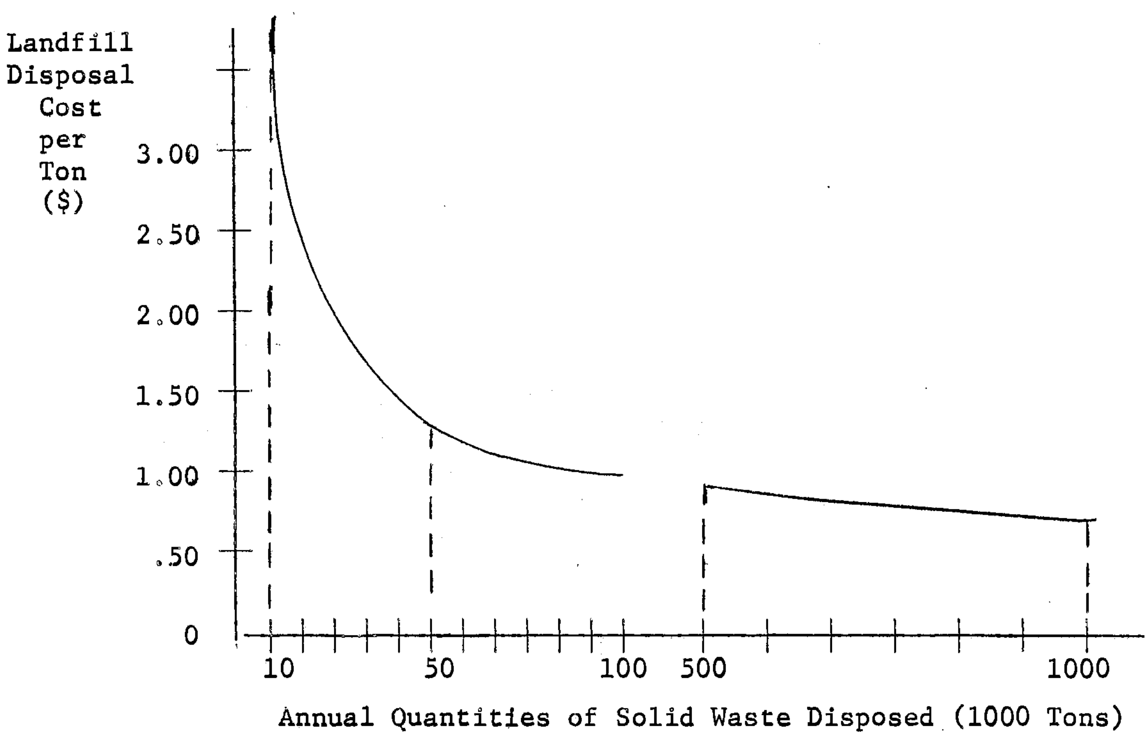


Figure 7. Average Landfill Disposal Costs per Ton

Capacities of over one million tons annually tend towards a cost of $0.63 a ton, but such capacities are unrealistic for rural areas.[1] Cost per ton almost doubles for capacities of 50 thousand tons over the minimum cost and equals $3.42 per ton for capacities of only 10 thousand tons.

Using the quantity of solid waste disposed in the observed landfill (Table V) the estimated cost per ton is equal to $1.91, which is in the rapidly decreasing range of the average cost curve. This estimate of disposal costs is over 50 percent more than the $1.25 estimate derived from the budget results.

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 nonmetropolitan areas of Oklahoma. Further analysis for this study will utilize the equation for estimating cost of solid waste disposal derived from the budget technique.

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.

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

Summary and Conclusions

The purpose of the analysis presented in this chapter was to develop a cost function for landfill operations from empirical data so that the parameters which most directly influence disposal costs could be identified. Insofar as landfill methods are mainly of a physical nature, engineering data were used to formulate a cost budget for an observed landfill operation. These results were compared with disposal costs estimated from a sample of existing landfill operations. For comparable quantities of solid waste disposed, budgeted costs were significantly lower per ton of solid waste than those estimated from the cross sectional data.

Total cost of landfill development and operation is largely allocated to site development, capital equipment, labor, and equipment operation and maintenance necessary to facilitate its intended use. 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 in this study was not determined, mainly because land requirements vary substantially depending on the depth of cells, the compaction process, and the soil characteristics of the site.

While the basic parameters affecting costs were relatively easy to identify due to their physical nature, no attempt was made to consider the operating efficiency of the site or facility. The objective of the analysis was to formulate a cost function that would characterize the factors associated with landfill operation. It is assumed that any cost variations resulting from inefficiencies of operation is a variance not amenable to economic analysis and that such variances should be rectified by management and implementation policies and left to the local planning body to reconcile. However, inability to capture the magnitude by which operational inefficiences affect total costs is the main limitation of the budgeting procedure used in this study.

The disposal analysis clearly identifies several important aspects that should be considered when planning for solid waste systems at an areawide level. The capital requirements necessary for disposal are relatively fixed, with one unit of equipment being capable of handling a substantial quantity of solid waste and subsequent service area. Investment sharing in landfill site development and capital equipment produces significant economies of size related to landfill operations and has the effect of reducing per unit disposal costs. Fiscal constraints characteristic of small communities can be compensated to some extent by areawide cooperation in solid waste management whereby capital requirements can be kept to a minimum. However, it is doubtful that full benefits from economies of size can be realized in rural regions where solid waste volume is dissipated over large areas. In addition, costs associated with significant 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. For reasonable size landfills the major share of solid waste management costs is to be found in the collection process.

CHAPTER V

A COMPREHENSIVE SOLID WASTE MANAGEMENT PLAN FOR A RURAL COUNTY IN NORTHERN OKLAHOMA

Federal and state legislation designed to upgrade current solid waste management practices in Oklahoma provides the basis for solid waste management planning aimed at solving the environmental problems resulting from open burning and uncontrolled dumpsites within and adjacent to urban areas. At present nearly all of the efforts to achieve technological advances have been expanded to combat solid waste problems in the larger urban areas. While these areas present the most significant problems in terms of volume of waste and affected population, many of the small rural communities are also faced with significant solid waste problems. These problems are of a different scale and magnitude but are nevertheless real and of major concern to local officials.

Little attention has been directed to solving the problems of refuse disposal in the rural communities, even though legislation places constraints on the allowable time these communities have to comply with the Oklahoma Solid Waste Management Act of 1970 [19]. To augment the problem of rural areas, implementation of conventional alternatives found in urban areas is severely hampered due to the difficulty of adaptation to rural areas and due to their high initial cost. By and large, the initial capital investment required for collection and disposal of solid waste in small communities is a financial impossibility for local governments and there are currently no means of federal assistance in the form of grant programs to offset these high costs. Loans are available through the Farmers Home Administration but in most instances the small communities individually do not possess a large enough service area to make loan payments and meet operating costs at a reasonable cost to the citizenry.

Regardless of the financing alternative employed, the revenue generated from the solid waste service should be sufficient to cover the long term costs of operation. These factors provide the impetus for considering implementation of a solid waste system on an areawide basis. The basic objective is to provide the same quality of service to an area economy that can be provided to an individual community. Feasibility of the areawide solid waste service lies in its ability to spread a relatively large fixed capital investment over a larger service area and thereby expanding the revenue sources needed to pay the long term collection service and landfill operation costs.

The areawide system should be designed to minimize total collection-transfer-disposal costs.[1] Insofar as the collection process represents the 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.

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[1]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 areawide system.

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

To estimate total costs for any service area, regardless of its delineation or size, the basic procedure is identical to that utilized in the municipality observed in the previous chapters. The total cost of the solid waste system is represented by the summation of residential and commercial collection costs, transfer costs associated with distances and solid waste volumes, and disposal costs at the sanitary landfill(s).

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

$$TCSWS = \sum_{j=1}^{s} TCOLC_j + TCDP$$

$$TCOLC_j = COLCTN_j \cdot TQSW_j \qquad (5.1)$$

$$TCDP = ACDPTN \cdot \sum_{j=1}^{s} TQSW_j$$

where,

TCSWS = Total Cost of Solid Waste Services for the planned area, ($)
$TCOLC_j$ = Total COLlection Cost for the j^{th} service area, ($)
$COLCTN_j$ = COLlection Cost per ToN of the j^{th} service area, ($)
$TQSW_j$ = Total Quantity of Solid Waste in the j^{th} service area, (tons)
TCDP = Total Cost of DisPosal, ($)
ACDPTN = Average Cost of DisPosal per ToN, ($)

Using the observed municipality as the planned area and incorporating the derived estimates for nonroute miles and density into the cost equations, the total solid waste system costs are shown in Table VII[2]. Insofar as the service 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.

Application to a Rural Planning Region

To develop a comprehensive solid waste management plan on an areawide basis, a decision was made to select a county as the planning area and to choose a county which comprises communities that have until July 1, 1974 to comply with the Oklahoma Solid Waste Management Act. The county selected for the study area is Grant County, located in northern Oklahoma. A map outlining this area is shown in Figure 8. The largest municipality is Medford, with a population of 1,304 [30]. It is hoped that by choosing a rural county with a time allowance for compliance, implementation may be achieved and, hence, maximum benefits of the research effort will be realized.

Other reasons for choosing Grant County include: (1) the county is situated on fairly flat terrain, hence, the physical factors related to landfill operation that influence costs and were mentioned but not captured in the disposal analysis of Chapter IV, will be minimized; (2) there are a number of small communities in the county and, with the exception of one twon, all have populations of less than 1,000 persons; (3) the communities do not have the fiscal capability or service area to individually finance a solid waste system and, hence, are faced with a

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[2]Total system cost was derived from equations defined in Chapter III, page 25, and Chapter IV, page 47.

TABLE VII

TOTAL COST OF COLLECTION AND DISPOSAL OF SOLID WASTE FOR THE OBSERVED SERVICE AREA

Source of Solid Waste for Disposal	Collection Cost per Ton of Solid Waste ($) COLCTN	Disposal Cost per Ton of Solid Waste ($) ACDPTN	Collection and Disposal Cost per Ton ($)	Quantity of Solid Waste, tons TQSW	Cost of Collection and Disposal ($) TCSWS
Municipal					
Residential	24.99	1.91	26.90	7,639	205,489
Commercial	9.80	1.91	11.71	4,549	53,269
Institution	13.06	1.91	14.97	4,185	62,649
Private (25% of Total)	--	1.91	1.91	5,457	10,423
Total	--	--	--	21,830	331,830

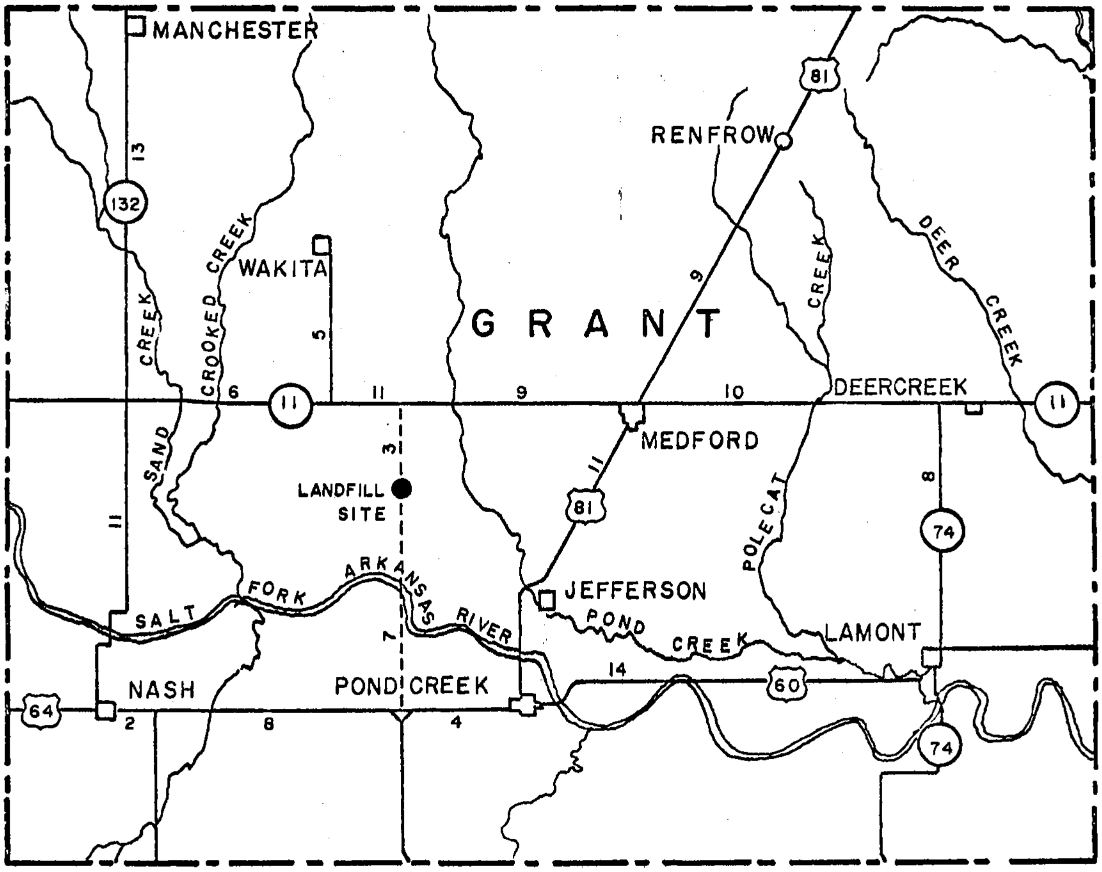

Figure 8. Application Area and Sanitary Landfill Site

serious problem and need for assistance in developing a system that complies with legislative requirements; and (4) the communities expressed a willingness to cooperate in a joint solid waste venture, thereby reducing the political constraints exogenous to the planning process.

Service Requirements

To estimate the capital requirements necessary for the provision of a solid waste system that services all of the communities of Grant County, it is necessary to determine the magnitude and nature of the service areas comprising the county. To achieve this, a housing survey was conducted in each of the towns within the county. The total number of residences, commercial establishments, public concerns, and industries were enumerated (Table VIII) and their approximate locations were placed on maps provided by the Oklahoma State Department of Highways. This procedure enabled the researcher to determine household density and route miles necessary for the collection process.

In addition, a landfill site has been determined and approved by the Oklahoma State Health Department, thereby enabling the researcher to estimate the transfer miles associated with any given routing scheme. The landfill location is shown in Figure 7 and transfer distances are given in Table VIII.

It is interesting to note the significant differences in density of the rural communities (computed as the number of collections per route mile, Table VIII). This variable captures the sprawling nature of many small towns and has the effect of increasing the amount of time required for collection and, hence, the costs associated with collection. This

TABLE VIII

GRANT COUNTY SOLID WASTE SERVICE
REQUIREMENTS SURVEY, 1972

Town	Population	Weekly Residential Collections	Weekly Commercial Collections[a]	Collections per Route Mile (DEN)[b]	Distance to Landfill (TRM)	Non-Route Miles[c]
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
Hash	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			

[a] Includes commercial establishments, schools, churches, industries, and public utilities.

[b] Evaluated by dividing the total collections by the total street miles.

[c] Evaluated as a weighted proportion of the observed municipal system presented in Chapter III.

presents an example of the case of divergence between the marginal cost of supplying a public service and the typical average pricing of the service to the public. Smaller communities, in general, for Grant County are less densely populated than larger communities and hence represent higher marginal costs for collection services to the residents and commercial establishments. The general pricing procedure, however, is to assess a user charge based on average cost for all residences and average cost for all commercial establishments. The result of such a pricing procedure in this case is to subsidize the smaller communities with lower densities.

Communities also show differences in marginal costs of supplying the entire solid waste service because of differences in transfer distances to the landfill site. Those communities closer to the landfill represent lower marginal cost in utilizing the service than those communities further out. The usual pricing procedure, however, is to sum all transfer costs and establish a user charge equal to the average transfer cost. Because of significant economies of size in landfill operations, savings from combining several service areas is expected to more than compensate those communities assesed transfer costs higher than their marginal costs.

The above is true only for those utilizing the public collection and transfer service. Those individuals supplying their own collection and transfer service to the public disposal site, such as most farmers and farm businesses, pay a marginal cost in proportion to their distance from the landfill.

Local public service policy was integrated into the planning process and resulted in some modifications to the observed system as reported in previous sections of this study. The rear-loading technology is used but the same service quality is not maintained as in the observed municipal system. It was the desire of the local communities to have once per week residential and commercial collection service as a means to lower costs to all users.

Collection and Transfer Costs

Reducing the frequency of collection from twice a week to once a week requires some adjustments in the equational models as presented in Chapter III. Volume per collection is assumed to double which increases the amount of 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. Collection rates are given in Table IX from the adjusted equational models in Chapter III.

Collection rates for comparable densities as used in Chapter III are much larger since the number of nonroute miles is significantly reduced. The number of nonroute miles was computed as directly proportional to the size of the community using the observed municipality as a base. In fact, nonroute miles is not a significant factor for such small communities.

Cost per collection and per ton of solid waste collected are given in Table IX by community. Collection cost per ton of solid waste is substantially less than that recorded in Chapter III since the volume of solid waste per collection is doubled with but a small increase in cost per collection. Also, the cost per ton figure in Table IX includes

TABLE IX

COST PER COLLECTION AND TOTAL COLLECTION AND TRANSFER COST PER TON OF SOLID WASTE GRANT COUNTY, 1972

Town	Collection Rate (#/hr.)	Total Cost Per Collection ($)	Collection Cost Per Ton ($)	Transfer Cost Per Ton ($)	Total Collection and Transfer Cost Per Ton ($)	Total Collection and Transfer Cost per Collection ($)
Deer Creek	93	0.2128	5.81	3.89	9.70	0.3551
Jefferson	69	0.2724	6.90	2.48	9.38	0.3705
Lamont	76	0.2511	7.75	4.42	12.17	0.3942
Manchester	70	0.2691	7.38	4.25	11.63	0.4238
Medford	90	0.2185	6.02	2.12	8.14	0.2956
Hash	74	0.2568	7.11	3.01	10.12	0.3655
Pond Creek	88	0.2225	6.38	1.95	8.33	0.2907
Renfrow	68	0.2758	6.40	3.72	10.12	0.4358
Wakita	88	0.2225	6.38	1.77	8.15	0.2842

both residential and commercial collections whereas in Table IV of Chapter III the two were computed separately.

Cost to transfer the solid waste from each community to the sanitary landfill has been computed on a ton basis and is shown in Table IX. Assuming a cost per crew hour of $15.93 and an operating velocity of 50 miles per hour on open country roads, cost per transfer mile is about $0.32. Utilizing a 20 cubic yard compaction vehicle and a volume to weight exchange of 360 pounds per cubic yard, the transfer cost per ton mile is $0.0885. This cost figure was applied to twice the distance separating each community from the sanitary landfill and is recorded in Table IX.

Total collection and transfer cost per ton (Table IX) varied from about $8.15 for those communities 10 miles from the landfill to over $12 for those communities 25 miles out. A final calculation for comparison purposes expresses the total collection and transfer cost per collection and ranges from $0.30 to over $0.43 compared to the residential cost of $0.25 in the observed system where the landfill was at the edge of town.

The total hours required for the collection process is determined by dividing the number of collections for each community by its collection rate and summing across all communities. About 24 hours per week is required for the collection process and an additional 6 hours of transfer time. The total of 30 hours of truck operating time is 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 a purchase price of $12,000.

Fixed administrative and building costs were assumed at the same rate per collection as calculated for the observed system. This is possible if 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 is estimated in Table X. In a rural setting, a problem exists in placing estimates on the amount of solid waste entering disposal by rural residents. While the total number of rural homes in Grant County can be estimated, the generation of solid waste for public disposal by these units varies from that of city residents because of the structure of the legislative requirements pertaining to solid waste disposal by rural establishments. Disposal can be facilitated in its entirety by the landowner constructing individual landfills on his own property. However, it can be assumed that this task will not be done by most rural residents, and at least a proportion of the total solid waste generated will enter the areawide public landfill site. Therefore, an estimate of this volume must be 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 urban areas. Assuming rural households generate comparable amounts of solid waste as urban households and that about 50 percent will enter

TABLE X

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 establish-ments	294	15,288	0.12733	1,945
Rural Farm Homes	1,467	--	--	750[a]
Private (25% of total)	--	--	--	1,482
Total				5,930

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

the sanitary public landfill, the total estimate of rural household solid waste for disposal is 750 tons annually.

An additional amount equal to 25 percent of the total is estimated as privately deposited solid waste and is consistent with the quantity estimated for the observed system. The total annual 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 VI of Chapter IV, variable cost per ton of solid waste disposed equalled about $0.86.

Annual fixed costs for equipment and site development equalled $8,408. For Grant County the estimated cost per ton of solid waste disposed at the landfill is equal to $2.28.

Since labor is considered a variable cost for the landfill operation, it must be 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 is estimated at $47,004 (Table XI). This estimate includes collection service only in the communities and once per week servicing for both residential and commercial establishments. One sanitary landfill is utilized to serve the entire county. Transfer costs for the public collection service is included but transfer costs of rural residents and others using the landfill are excluded.

Collection, transfer, and disposal cost per ton of solid waste for all communities equals $11.33. Monthly cost per user is equal to $1.74. This includes both residential and commercial users. This compares with the residential collection and disposal cost in the observed municipality of $2.46 monthly for a two-a-week collection service. The cost difference reemphasizes the point that collection costs are the major component of any total waste management system.

TABLE XI

TOTAL COST OF COLLECTION-TRANSFER-DISPOSAL OF SOLID WASTE FOR GRANT COUNTY, 1972

Source of Solid Waste for Disposal	Collection Cost Per Ton ($)	Transfer Cost Per Ton ($)	Disposal Cost Per Ton ($)	Total Cost Per Ton ($)	Quantity of Solid Waste (tons)	Total Cost ($)
Deer Creek	5.81	3.89	2.28	11.98	206	2,463
Jefferson	6.90	2.48	2.28	11.66	78	910
Lamont	7.75	4.42	2.28	14.45	470	6,791
Manchester	7.38	4.25	2.28	13.91	146	2,030
Medford	6.02	2.12	2.28	10.42	1,184	12,338
Hash	7.11	3.01	2.28	12.40	295	3,656
Pond Creek	6.38	1.95	2.28	10.61	795	8,434
Renfrow	6.40	3.72	2.28	12.40	52	639
Wakita	6.38	1.77	2.28	10.43	475	4,954
Rural Farm Homes	--	--	2.28	2.28	750	1,710
Private	--	--	2.28	2.28	1,482	3,379
Total					5,933	47,004

Concluding Remarks

It is evident from the analysis that solid waste service on an areawide basis can be provided thus reducing unit costs from a relatively large fixed investment. 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 not captured due to the inability to produce the necessary volume to achieve cost economies. However, since the collection-transfer process contributes largely to the total cost of the solid waste service, emphasis should be placed on minimizing those costs associated with the collection process.

For the planning area analyzed in this study, the capital investment required includes only one 20 cu. yd. closed compactor, with an approximate value of $12,000. This assumes labor requirements of three men. It should be noted that the unit is fully employed as it requires approximately 30 hours for collection and transfer process and 2.5 hours at the disposal site. This leaves 7.5 hours for general maintenance of the capital items. This assumes that the quality of service is once per week collection from the rear or side of the house. It is recommended that alley collections be made where possible to reduce collection time, thereby increasing the collection rate and reducing the cost per collection.

The pricing scheme generally employed is that of user charges with average pricing of the service to the public. This causes some inequity in pricing because the marginal cost of supplying the service varies by community due to differences in densities and transfer miles. However, it is argued that all communities benefit from lower per unit costs of a combined solid waste service and hence, the distribution of costs is generally not accounted for on a per unit basis.

The main problem with a no charge public disposal operation is that rural farm residents are allowed to utilize the disposal site at no cost. Hence, a portion of the disposal costs attributed to rural solid waste volume must be paid by the urban user of the service. The legal requirements under the Oklahoma Solid Waste Management Act places restrictions on rural residents but does not require that they be publicly provided for. Thus, there is an incentive to utilize the landfill at no cost. It is recommended that the county governing body subsidize that portion of the disposal expenses accountable to rural farm refuse volume through allocations of the general fund budget. This would be a further incentive to utilize the disposal site since the rural farm population would be financing at least their portion of the public disposal service through ad valorem taxes. This may help reduce the incidence of roadside dumps, thereby aiding in fulfilling the objectives of state legislation. Also, a pricing scheme could be employed at the landfill site and prorated according to volume for any private user of the disposal site.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The provision of community services in rural areas is frequently constrained by a limited and/or fragmented service base and by a limited fiscal capability. However, the demands placed on local units of government continue to increase as citizens look toward them as providers of desired community services. The financial pressure placed on municipalities accepting the responsibility of arranging for the provision of services demanded by their constituents produces a perplexing situation for many rural communities. Consequently, the need for planning to assist local governments providing community service efficiently is being recognized by local and areawide planning authorities.

If the need for a particular community service results from a long neglected problem that produces negative effects on the social and environmental health of an area, federal and state legislation may be required to stimulate an improvement in the existing level of service. The provision of adequate solid waste systems to prevent air and water pollution, and protect public health through the control of disease and vectors, is an example where legislation provokes local investment in solid waste collection and disposal practices.

High initial investment costs and limited knowledge of adequate solid waste facility design for rural areas provided the impetus for this study. Providing information needed for comprehensive planning aimed at achieving a desirable level of service at a reasonable cost to the recipients was the major objective of this study.

Analyzing solid waste management in a public service planning framework facilitates collection and organization of information pertinent to local decision making. A solid waste planning framework is a subsystem of a larger regional information system designed to capture all external forces affecting plan implementation at the local or regional level. The framework for rural planning is depicted in Figure 1, Chapter II, and is intended to serve as a guide to isolate external forces, policy tools, and economic activity affecting a target area so that public service outputs can be more accurately evaluated.

When the target area and affected public service are specified, additional models are required to identify the service requirements and system costs so that the planning process can be evaluated as to its overall effectiveness and performance. Local policy is changed and incorporated into the planning framework until desired service levels are attained and plan implementation is achieved. A general description of a rural planning framework specifying solid waste management as the desired public service is described in Figure 2, Chapter II.

An adequate solid waste planning process requires that all factors that define service quality and service costs be identified. A procedure was developed to observe two existing solid waste systems and to identify those variables important to 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 often 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. It was found that 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 expense, equipment and facility costs, and interest on investment. Fixed administrative and building costs amounted to 16 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 13 percent of total collection crew cost for the rear-loading technology and 29 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 about $21,000 in 1971 prices. The average collection crew made about 94,000 residential and commercial collections annually or, for a two-a-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 about $23,000 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 a fruitful approach whereby factors could be isolated which have a significant influence on the variable costs component 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 largely 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 total collections comprised of commercial containers affects the rate with which collections can be made because of larger volume of solid waste and the time involved to connecting the container onto the hydraulic system.

Regression equations were used to explain variations in collection rates (collections made per hour) by variations in density of collections per route mile, number of nonroute miles, and percentage of commercial container collections. Using the regression results and the budgeted cost data, various models were specified to estimate cost per collection, cost per ton of solid waste collected, effect of density on collection costs, effect of distance from service area to landfill site on collection costs, and cost differences between technologies and between residential and commercial collections. These data are presented in equational, tabular, and graphical form in Chapter III of this study.

Results of this study conclude that densely populated subdivisions, as normally found in older, low income areas, had the affect of significantly reducing cost per collection. Thus, in a municipality where policy dictates that service charges are equal over all residential collections, the denser subdivisions are subsidizing the cost of sprawling subdivisions, as is normally found in areas of new residential development. For a totally containerized process, more service units can be facilitated per collection, thereby reducing costs per service unit. Location of the disposal site is an important consideration when attempting to minimize total collection and transfer costs. In evaluating the collection systems observed in this study, it is apparent that no significant economies of size exist in the collection process of solid waste management systems as long as one collection crew can be fully employed. When considering areawide solid waste collection, the advantages of interarea cooperation lie mainly in the investment sharing of disposal equipment.

A review of the literature indicates that substantial economies of size exist in disposal operations in that increasing the quantity of solid waste disposed of is attended by lower per unit costs. An analysis was made to appraise the magnitude of economies of size related to disposal operations and to assess the potential benefits of undertaking a joint solid waste disposal venture for a rural, multi-community region.

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 is currently less than other conventional disposal practices and the degree to which solid waste is disposed of is more complete. The costs of sanitary landfill, in addition to effects of total volume of solid waste, depend on the topographical nature of the site, the process used in covering solid waste, and the 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 $0.86 per ton of solid waste disposed. Fixed costs equalled about $8,400 annually and 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 $1.25. Decreasing the annual quantity of solid waste to be disposed to 10,000 tons has the effect of increasing cost per ton by $0.45. Expanding the annual capacity beyond the 22,000 ton quantity is also possible since it is 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 per ton varies from $0.64 for over one million tons disposed of to $3.42 for quantities of less than ten thousand tons.

Results of these analyses show that a wide range in the volume of solid waste disposed can exist before additional capital equipment beyond that of a single bulldozer must be acquired. In addition, landfill costs represent a relatively small percentage of the total costs of a solid waste management system. It was found that an advantage in investment sharing of disposal practices does exist.

Finally, models representing total costs per ton of collection, transfer, and disposal of solid waste attributed to residential and commercial sectors 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 the solid waste management planning framework.

The exogenous forces, in the form of state legislation forcing adoption of a solid waste system that eliminates open burning and dumping for all communities in Oklahoma, represent the external influence for regional response. Regional response, as depicted by local and areawide public service policies, is determined by local policymaking bodies and incorporated into the analysis. Initial response from the local decision makers was for analysis of a rear-loading collection system, requiring a three man labor input, and utilizing residential and commercial noncontainer collection cans. The service output was to be in the form of once a week collection in the communities. One public sanitary landfill for the entire county is to be established at a predetermined location.

Nine individual service areas in the county were combined into one areawide system and collection, transfer, and disposal costs per ton of solid waste by source were evaluated. The solid waste system provided service to all municipalities within the region and facilitated a little over 4,000 persons. It was found that only one compaction vehicle was required to accomodate the entire area, thereby minimizing capital requirements over the nine service areas. Costs per unit were substantially less for the region as compared to individual service areas due to spreading a relatively fixed investment over a larger number of units.

The total annual collection, transfer, and disposal cost to the communities in the areawide plan was estimated at about $42,000. The monthly cost per user is equal to $1.74. In addition, disposal costs for farm homes and other private users of the landfill equalled about $5,100.

The process of planning for a solid waste system for a community or region is not completed at this stage. The planning body and community decision makers must interchange ideas at this point so that decisions will be focused on yielding a level and quality of service consistent with public goals. The process of planning 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. More research is needed to consider least cost system development. Programming optimum routing, disposal site location, and other alternative systems would appear to yield high benefits to local or areawide 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 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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APPENDIX

Collection Time and
Motion Study

Route#________________

City________________

Date________________

Questionnaire#________________

(a) type and size of collection vehicle: ________________

(b) compaction ratio: ________________

(c) time left equipment house: ________________hr.

(d) speedometer reading at equipment house: ________________miles

	Segment 1	Segment 2	Segment 3
(e) time at first pickup for	hrs.	hrs.	hrs.
(f) speedometer reading	miles	miles	miles
(g) number of collection units (all units whether pickup was made or not) . .	2yd.		
	3yd.		
	4yd.		
	5yd.		
(h) time at last pickup for	hr.	hr.	hr.
(i) speedometer reading	miles	miles	miles
(j) reason for change in routine			

(k) time arrived at equipment house after last segment: ________________hr.

(l) speedometer reading at equipment house: ________________miles

(m) volume of solid waste: first trip to landfill ________________%full.

second trip to landfill ________________%full.

third trip to landfill ________________%full.

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