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METHODOLOGY FOR AIR FORCE OPTIMIZATION OF SOLID WASTE MANAGEMEN--ETC(U)
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METHODOLOGY FOR AIR FORCE OPTIMIZATION OF SOLID WASTE MANAGEMENT

DIRECTORATE OF ENVIRONICS

SEPTEMBER 1976

FINAL REPORT:

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AIR FORCE CIVIL ENGINEERING CENTER
(AIR FORCE SYSTEMS COMMAND)
TYNDALL AIR FORCE BASE
FLORIDA 32403

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This report summarizes a methodology for optimizing solid waste management at Air Force installations. The methodology was originally developed by contract and applied to four Air Force bases. The purpose of this report is to provide a cogent and readily accessible source of guidance for Air Force base managers who need to reevaluate their solid waste management program because of increased cost and environmental pressures.

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PREFACE

This report was adapted for Air Force implementation from a report originally prepared by Ralph Stone and Company under Contract F 29601-74-C-0084 for the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. Responsibility was later transferred to the Air Force Civil Engineering Center, Tyndall Air Force Base, Florida, upon transfer of environics activities to that facility from Kirtland Air Force Base. The original research was performed under Job Order 21036W09.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

In response to the need to "do more with less," the management method described herein has been developed to augment AFM 91-11 and assist the base civil engineer and associated staff in maintaining/upgrading the solid waste management services. Such upgrading is often required as evidenced by the fact that during case studies of this methodology's application, it was observed that Air Force bases were generally paying more for waste handling on a per ton and per collection basis than comparable municipal and commercial systems in the same localities. Improved methods (as described in this report) may help to substantially lower costs while maintaining (or improving) the level of service.

The following sections provide step-by-step guidance for evaluating a base in an organized manner that will produce basic information for optimizing the installation's solid waste handling system. The method is applicable in its entirety to bases of over 1,000 population (residents and/or workers). Only selected portions of the method will be applicable to bases smaller than 1,000 since they are unlikely to generate sufficient solid waste to justify large-scale equipment or a large planning and management staff. Small bases may best contract for collection with a private contractor in an adjacent municipality or use smaller equipment and staff.

The method (based on extensive research and experience) was tested for validity by applying it to four Air Force bases. Based on these applications, appropriate changes were made to account for the specific characteristics of the Air Force environment.

Table 1 summarizes base activities to be evaluated in the optimization. The entries under "data requirements" are the basic measurements and observations required to implement the optimization method on a specific base. The amount of data required for any specific case will depend on the climate and the base's size, mission, and types of facilities. The analytical methods developed are described step-by-step. Applying the methodology requires a working knowledge of solid waste management practices, time and motion studies, and industrial engineering.

TABLE 1. AIR FORCE BASE EVALUATION SUMMARY FOR OPTIMIZATION OF SOLID WASTE HANDLING ACTIVITIES: STATISTICAL SOLID WASTE WEIGHT, VOLUME, TIME, AND COST DATA

Activity	Data Requirements	Practices to be Optimized
Generation	Weight by facility Volume by facility (Listed by significant components)	Minimize quantities of wastes Maximize quality of salvageable wastes Optimize types of material wasted Optimize location of sources
On-site Gathering	Weight by area of facility Volume by area of facility (Listed by significant components) Costs	Eliminate vector generation Optimize service level Optimize equipment used Minimize labor cost
Storage	Weight by container Volume by container Containers' location, type, size, and features Costs Container reliability	Optimize locations For each location, optimize container types, sizes, collection frequency, and features Investigate use of concrete slabs, signs, pavement lines, etc. Use uniform container colors, and signs
Collection	Equipment characteristics Collection methods Motion-time measurements Human factors Routes Weight collected Volume collected Stops collected Costs (especially maintenance) Equipment reliability Absenteeism	Optimize: types of collection, collection frequencies, routes, equipment characteristics, crew size, collection method, number of vehicles Maximize safety of vehicle maneuvers Maximize driver visibility vehicle visibility to others, use of flashing lights and reverse horns or bells Inspect: overhead clearances, side clearances, electric and gas lines and equipment, pedestrian and vehicle traffic, playgrounds along collection routes, especially at collection points
Disposal	Weight into site Volume into site (Listed by significant components)	Control entry into landfill Control entry of hazardous and toxic wastes Optimize service of arriving vehicles[a]

[a] Decide: layout, hours of operation, method of working the fill, access road maintenance.

TABLE 1 (Cont.). AIR FORCE BASE EVALUATION SUMMARY
FOR OPTIMIZATION OF SOLID WASTE HANDLING ACTIVITIES:
STATISTICAL SOLID WASTE WEIGHT, VOLUME, TIME, AND COST DATA

Activity	Data Requirements	Practices to be Optimized
Disposal (Cont.)	Distribution of arrivals during a day Site geology Site hydrology Leachate production and migration at site Vector generation Air pollution as dust and odors Litter generation Volume of fill Volume of available cover soil Seasonal wind direction and speed Neighboring activities Motion-time measurements Costs	Minimize leachate production Minimize vector generation Optimize compaction and covering equipment and activities Minimize litter Minimize dust Inspect: odor problems, vector interactions, and neighborhood children interactions between the landfill and neighborhood
Processing	Weight into processors Volume into processors (Listed by significant components) Distribution of arrivals during a day Motion-time measurements Equipment reliability Equipment availability Human factors Costs	Optimize use of processing, types of processing, and locations of processors Optimize site layouts, processing activities, equipment, labor, hours of operation
Recycling	Facilities generating salvageable waste Quantities of salvageable waste generated Advantages of processing waste Salvage value of wastes Location of recyclers Cost trade-offs between alternative ways of delivering scrap Available transportation Equipment	Minimize cost, balancing handling cost with quantity of waste to recycle

TABLE 1 (Concluded). AIR FORCE BASE EVALUATION SUMMARY FOR OPTIMIZATION OF SOLID WASTE HANDLING ACTIVITIES: STATISTICAL SOLID WASTE WEIGHT, VOLUME, TIME, AND COST DATA

Activity	Data Requirements	Practices to be Optimized
Management	Maintenance cost of equipment Reliability of equipment Incentives Absenteeism Productivity: $/stop, $/ton, min/stop Record keeping: cost records, weight of waste records	Maximize vehicle reliability Minimize absenteeism Maximize productivity Maximize incentives Keep complete cost records Optimize use of records on productivity: weights of waste, time performance Record overflowing containers and user complaints

SECTION II

STEP ONE: DEFINE SOLID WASTE MANAGEMENT PRACTICES

The first optimization phase is to define existing solid waste characteristics by source. Data required (see Table 1) consist of weight, volume, composition, and time for solid waste collection by source.

IDENTIFY STORAGE CONTAINERS

Storage container locations should be plotted on a base map showing streets and buildings. This container mapping is necessary only for bins, not for residential housing using cans or bags. But the location, size, and number of cans should be noted. Container location, size, and pick up schedule are used to evaluate and optimize collection routes. A container list should be developed as in Table 2. Collectors can fill in building location and their supervisors can complete the form. Locations are identified by building name and number. Container condition refers to the cleanliness, condition of paint, and serviceability of frame, lids, and doors. These data are used to assess the need for maintenance and replacement. Extra containers on reserve should be included. Also, if the scope of waste management covers liquid and sludge wastes, include those as well as underground storage of waste fuel.

LOCATE DISPOSAL SITES

Locate all existing or proposed disposal sites that can be used for Air Force base wastes and mark them on the same base map. Determine the types of wastes permitted for disposal and the distance from base facilities or the nearest base gate if located off base. Determine the life of the facility, projected costs or fees, and hours of operation. For disposal sites on base, use the landfill evaluation form illustrated in Table A-1 (Appendix A) to determine the acceptability of the landfill site.

LOCATE WASTE PROCESSING SITES

Locate (on the same maps and tabulations as previously) all existing or proposed waste processing sites both on base and in the immediate area. Include garbage disposals, compactors, balers, incinerators, shredders, pulpers, and

TABLE 2. WASTE STORAGE CONTAINER DATA FORM

Location		Container Type[a]	Type of Waste[b]	Capacity (cu yd)	Features Lid/Doors	Condition of Container:				
Bldg. & No.	Side					Clean	Paint	Frame	Lid	Doors

a. Types: 32-gallon can = can; front loading bin = F.L. bin; hoist bin = H. bin; etc.

b. Types: Trash, garbage, metal, rubber, oil, etc.

Conditions: ++ like new; + = acceptable for foreseeable future; - = acceptable for present; -- = unacceptable; O = remove A.S.A.P.

any others. Record data on the type of process, type of waste processed and its composition, capacity (tons per hour), hours of operation, any user waiting time, and costs or fees.

LOCATE SCALES

Identify the location and capacity of any truck scales on-base or nearby, and of any equipment on-base which has a weighing capability (forklift, crane scale, axle scale, etc.) Determine the fee (if any) or cost.

COLLECTION METHODS

Determine the collection methods used for the different types of containers, the existing routes, equipment types, crew types, work shifts, and other records. The base and residential collection methods, equipment and crew sizes may differ as well as those facilities that produce special wastes or recycle. For example, the commissary, BX, or warehouses usually recycle corrugated paper. The waste collection agent and handling method must be identified.

RECYCLING PRACTICES

Determine the types of materials, composition, and quantities recycled on base. The Defense Property Disposal Office (DPDO) should have accurate records of the weights of recycled material, but they may not record the sources of recycled wastes or handle all recycled materials. Distinction between materials returned to the DPDO as "items" and "scrap" is necessary to determine exactly what is recycled. Items are still useful objects which are sometimes sold or given away, while scrap consists of metal shavings, old wire, paper, etc., which are recycled in the true sense, thus should be included in the list of material to be recycled. Scrap is disposed of by bids or term contracts. All data on recycled material weights should be recorded. Methods used to store, collect, process, and transport scrap should also be noted.

The commissary, BX, and any large supply or maintenance organization should be investigated for on-site gathering methods, local processing, composition, applicable regulations, costs, and records. The study steps are flexible and should be modified to fit base needs. Not all facilities generate quantities sufficient to warrant complex investigation, but high volume and large facilities and organizations should be carefully analyzed.

SECTION III

STEP TWO: MONITOR SOLID WASTE HANDLING OPERATIONS

The data obtained in Step 1 will be used to determine the monitoring required to optimize the solid waste management system. The data gathering should be conducted during a minimum of one complete 7-day operating cycle; 2 consecutive weeks (or longer) are recommended. The greater the period, the greater the statistical accuracy. Even 2 weeks will not show seasonal or longer-term random fluctuations, but these can be accounted for by allowing an extra margin over observed collection times and quantities in designing the system. The basic monitoring steps are outlined below.

SOLID WASTE QUANTITIES

All trucks hauling waste for disposal can be weighed on an existing truck scale, or a portable axle scale can be rented. The collection vehicle driver(s) will be responsible for obtaining the weights in the format shown in Table 3, Weighing Station Data Form. The driver should list each building collected and indicate the last building collected for each load. During collection, the driver or a second crewman, if available, is to look inside each bin and note the type of waste, then measure the distance to the waste surface from the container top before emptying: the data forms of Table 4 and Table 5 are to be used. For large containers (40 cubic yard bins or more) a visual estimate of percent filled without measuring will be sufficient. This will enable conversion of volume of waste generation sources by subtracting the distance from the total container height (cans and bins). The inside dimensions of each type of storage container should be measured, and the volume approximated from these.

Existing data on the weights of wastes currently being recycled should have been obtained in Step One. If a base recycling program is being considered, wastes from major buildings must be weighed to determine the available quantities of recyclable materials. The buildings generating the greatest quantities should be collected and weighed individually. This can be done by assigning a collection vehicle and driver to collect exclusively from the selected buildings and weigh the truck after each collection without

TABLE 3. WEIGHING STATION DATA FORM

Route No. ______________________

Date ______________________ Operator ______________________

Vehicle No. and Road [a]	Collector's Unit	Generating Facility	Type of Waste	Gross Weight	Tare Weight

a. Draw a line below the last building collected in each load.

TABLE 4. BIN COLLECTION DATA FORM

Date________________ Operator________________

Time________________ Vehicle No.________________

Route No.________________ Page ____ of ____

Location Bldg.No.	Side[a]	Container No.	Distance to Top of Waste	Volume Filled Percent	Container Size	Waste Type[b]	Comments: overflow, odor, blocked bin, etc.

a. Side: north = N, southeast = SE, etc.
b. Waste Type: trash, steel, wood, steel strap, etc.

TABLE 5. SOLID WASTE GENERATION - RESIDENTIAL VOLUME

Date ____________ Completed by ____________

Weather ____________ Traffic ____________

	Containers, Cans			Other Cont.		Distance Containers to Street	Accessible to Wheeled Cart
	No. at Stop	No. with Waste	Height of Waste in Containers	Liners/ Cans	Bags/ Sacks		

going to the disposal site. Special lift scales can be used for local weighing. After collecting the last selected building, the collector can return to his regular collection route. The data form of Table 3 should be used.

WASTE CHARACTERIZATION

Two methods are available to characterize waste, one by sorting and the second by visual observation. The choice depends on the desired accuracy and available budget. The sorting method accurately determines composition by weight, but is time consuming and expensive. The visual method determines composition by volume, is quick and inexpensive but less accurate. The visual method may be an "eyeball" estimate or a 40-inch square wire grid with 100 4-inch squares. A grid can be made from standard hogwire fencing. The data form is shown in Table 6. The data from both approaches give the waste composition in percent by volume.

Visual observation involves looking at the surface of solid waste in bins (by storage) or spread out at a disposal site (residential can collection). Plastic bags containing waste must be broken open and their contents included in the visual composition. The observer should estimate the percentage of the waste surface area occupied by each of the waste components listed in Table 6. Special wastes are then entered in the last two blank columns.

The grid method is most applicable to a landfill site. After the wastes are unloaded and spread on the working face, the grid is tossed over it randomly. The investigator simply counts the number of grid squares or parts of grids covering each type of solid waste. Grid analysis may also be used on bins. The landfill procedure should be repeated three times for each truckload of solid waste and the three sets of data averaged. The visual method is not as accurate ($\pm$50 percent) as the sorting method because small, dense items often differentially settle to the bottom of the waste and are not always observed.

Sorting involves randomly selecting a 200- to 300-pound sample of solid waste (at the storage or disposal site) and hand sorting it into the components listed in Table 6. If done at the landfill, two 200- to 300-pound samples per day are necessary. Sorting and weighing one 300-pound sample requires about 4 to 6 man-hours. A 200-pound capacity platform scale is needed for weighing the components after

TABLE 6. SOLID WASTE COMPOSITION FORM

Date/Day____________________ Completed by______________________________

Time

Route & Source	Number of Grids																		
							Glass												
	Corrugated	Other paper	Ferrous	Aluminum	Other non-ferrous	Wood	Clear	Green	Brown	Textiles	Plastics	Rubber	Leather	Food wastes	Lawn & light trimmings	Wood & heavy trimmings	Sludge	a	a

a. Specify special wastes: (1)____________; (2)____________.

they have been sorted into separate containers. To determine composition from individual types of buildings, the composition of buildings selected for individual weighings as described in the previous discussion should be observed.

An inventory of hazardous and toxic wastes can be accomplished using the data form shown in Table 7. Visits to locations generating and handling hazardous and toxic wastes are necessary and available generation records should be obtained. Composition can usually be obtained from the generating source and verified by laboratory analysis.

An inventory of reclaimed wastes can be obtained from records of recycling operations, if available. Otherwise, recycled wastes should be weighed as described above. The composition of potential recyclable wastes on the base as a whole should be derived from the disposal site composition measurements and the composition studies at the selected representative building sources.

DISPOSAL SITE EVALUATION

The identified available disposal sites should be evaluated for useful life and fee or cost trends. For Air Force base landfills, the Landfill Evaluation Form of Table A-1 (Appendix A) and the data form in Table 8 are to be completed. Other necessary data for Air Force sites are: distance from routes to the disposal site, estimated travel time, available cover soil quantities, local surface drainage entering the landfill, and minimum depth of the groundwater table. It is necessary to locate and sample water in wells upstream and downstream from the landfill site to monitor possible leachate pollution.

COLLECTION OPERATIONS STUDIES

Timing of collection activities will be necessary to evaluate the work efficiencies of crews and the existing collection methods. Recording is done directly, using video or movies, and timing is done with precision stopwatches, calibrated in hundredths of a minute, mounted on time-study clipboards. The first timing can be done using the data form in Table 9. Compare the collection times in Table 9 with typical times for the type of collection given in Tables B-1 and B-2, and Figure B-1 (Appendix B). If timed collection is over 30 percent greater than the typical

TABLE 7. SW GENERATION - HAZARDOUS AND TOXIC WASTES

Date/Day__________ Completed by__________

(1) Explosive (2) Flammable (3) Volatile (4) Corrosive (5) Toxic (6) Pathological (7) Radioactive

Type	Source	Location Bldg No./Activity	Quantity[a] Cu yd	Quantity[a] lb	Frequency Collected	Handling (Safety, personnel protection, pollution, etc.)

a. Indicate period to produce quantity collected (lb/day, cu yd/week, etc.)

TABLE 8. LANDFILL ENVIRONMENTAL OBSERVATIONS

Date/Day____________ Temp.________ Wind________ Observer____________

Clock Time (start & end)	Dust (indicate cause-- wind, etc.)	Litter	Odor	Flies	Birds, Type No. On Refuse	Birds, Type No. At Site	Other Vectors Type	Other Vectors No. On Refuse	Other Vectors No. At Site	Comments

Dust - estimate height of dust and cause.
Litter - estimate number of pieces in a 100 sq ft area.
Odor - identify: none, negligible, weak, moderate, strong; and sour, sweet, rotten egg, compost.
Flies - estimate: none, few, moderate number, many (give estimated number).

TABLE 9. SOLID WASTE COLLECTION

TIME STUDY

Date/Day______________ Weather__________________________ Observer______________________

Route No.______________ Type of Housing_________________________ Traffic_______________________

No. Units*	Cans+ (No.)	Bags (No.)	Boxes (No.)	Bundles (No.)	Time per Task			Reason for Lost time
					Collection	Travel	Lost Time	

* Units refers to a bin (DD) or house. No. of units is one or more if collector goes to next house instead of returning to truck after each house.

+ Enter bins or DD for Dempster Dumpster.

times, then the data forms of Tables 10 and 11 should be used for household or front loader routes, and the collection work timed again. By analyses of the detailed task breakdowns in Tables 10 and 11 employing standardized MTM task element time data from industrial engineering handbooks for comparison, tasks taking excessive time may be identified. Corrective measures such as changing collection techniques, equipment, or improving labor performance can then be initiated.

Improvements in crew efficiency and their overall collection productivity may be evaluated by comparing measured times for existing collection methods with standard times for alternative collection methods to select the best operating procedure. Evaluating the effectiveness of labor and equipment utilization on a base landfill can be done by time studies using the data form of Table 12. "Nonproductive' refers to time when workers are talking, sitting, waiting for collection vehicles to unload, or any time when defined work tasks are not being actively performed. Equipment nonproductive time includes idling and waiting for collection vehicles to unload. "Moving refuse" refers to that period when the unloaded refuse is pushed onto the working face; "return" refers to equipment travel in reverse to push more waste.

TABLE 10 - HOUSEHOLD SOLID WASTE COLLECTION - MTM BREAKDOWN

Date/Day__________ Weather__________ Observer__________

Route No.__________ Type of Housing__________ Traffic__________

Travel, truck movement														
Dismount/walk														
Unload cart														
Walk to driveway														
Walk up driveway to cans														
Empty cans and collect bags														
Walk to next house														
Walk down driveway														
Walk to truck														
Dump container														
Help other dump container														
Compact														
Idle														

Idle - indicate talk, other.

TABLE 11. SW COLLECTION - FRONT LOADER MTM

Date/Day ______________ Weather ______________ Observer ______________

Route No. ______________ Locations ______________

Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
[a]Idle																		
Compact																		
Open Lid (truck)																		
[a]Idle																		
Position																		
Engage																		
Dump																		
[a]Idle																		
Return																		
Disengage																		
[a]Idle																		
Close Lid																		
Back Up																		
Travel																		
Total																		

[a] Explain long idle times and observed problems (safety, litter, leakage, breakdowns. ______________

____

TABLE 12. LANDFILL OPERATIONS MTM

Date/Day ____________

Weather ____________ Dozer Operator ____________ Observer ____________

Temp. ____________ Time Start ____________ Time End ____________

Travel	Solid Waste				Cover Soil				Non-productive
	Off Working Face		On Working Face						
	Moving Refuse	Return	Spread	Compact	Excavate	Carry or Push	Spread	Return	

SECTION IV

STEP THREE: DATA ANALYSIS

The following analyses should be performed separately for residential housing and for other base facilities.

WASTE QUANTITIES

The weights and volumes of wastes should be tabulated by route to determine weekly totals collected. The container and solid waste (in cubic yards per week) and frequency of collection should be tabulated by building number and route. Weights and volumes of wastes measured for selected individual buildings should be tabulated and the density calculated. These densities can then be used to estimate, from volume data, waste quantities (by weight) from buildings with similar operations by using the waste volume data.

WASTE COMPOSITION

The waste composition should be summarized by building number and type of operation. If composition data were not gathered for all building sources, then the composition at the buildings selected for weighing can be used as estimates for buildings with similar operations, to estimate base-wide percent composition and component quantities for housing and other base facilities. The base-wide estimate of total quantities and volumes of each solid waste component can be used for assessing the economic feasibility of recycling each component. If components are determined by visual observation (grid or other), then standard densities for each component will have to be used to calculate percent weight composition. A set of typical densities by (type of building operation) source are given in Table 13 which can be used to estimate percent weight composition. Hazardous, toxic, special, classified, and recycled wastes should be summarized on separate tabulations by building number, as described above for weights and volumes.

DISPOSABLE SITE EVALUATION

Costs of travel disposal as well as actual disposal costs. Cost factors for base sites are land, labor, equipment (fuel, oil, maintenance, and capital amortization), supplies, and facilities (sanitary, utilities, access road maintenance,

TABLE 13. SOLID WASTE COMPOSITION

Facilities	Densities of Wastes from Selected Sources (lb/cu yd)								
							Glass		
	Corrugated	Other paper	Ferrous	Aluminum	Other nonferrous	Wood	Clear	Green	Brown
Office (HQ, utilities)	79	100	341	360	155	289	610	428	900
Warehouse	52	221	233	360	153	289	600	428	600
Industrial (lab, CE shops)	167	138	233	400	153	405	453	428	500
Transportation (garages, motorpool)	130	140	343	360	742	405	657	428	500
BX	74	73	82	58	153	405	584	428	500
Commissary	100	114	82	58	153	405	584	428	500
Restaurants (Clubs: Officers', NCO, Airmen's)	265	219	85	56	153		294	519	766
Mess Hall	177	232	103	63	153	289	294	428	428
Hospitals (clinic, dispensary)	54	123	103	53	128	289	600	428	600
School	124	265	264	39	153	398	340	400	370
Residential (family quarters, barracks)	76	88	218	50	133	100	509	340	180
Recreational (picnic area, golf course, ballpark)	84	145	436	58	153*	158	420	452	500

Figure an average rather than source - specific.

TABLE 13 (cont). SOLID WASTE COMPOSITION

Facilities	Densities of Wastes from Selected Sources (lb/cu yd)							
	Textiles	Plastics	Rubber	Leather	Food Wastes	Lawn & light trimmings	Wood & heavy trimmings	Other
Office (HQ, utilities)	151	79	300*	40*	175	270*	400*	-
Warehouse	168*	13	300*	40*	436*	270*	400*	-
Industrial (lab, CE shops)	269	47	300	40*	436*	270	400	-
Transportation (garages, motorpool)	168	47*	333	40*	388	270*	400* (tile) 1650	-
BX	151*	37	300	40	184	270*	400*	-
Commissary	151*	28	300*	40*	419	270*	400*	-
Restaurants (Clubs: Officers', NCO, Airmen's)	158*	55	300*	40*	430	270*	400*	-
Mess Hall	158*	28	300*	40*	420	270*	400*	-
Hospitals (clinic, dispensary)	158*	45	300*	40*	436*	270*	400*	-
School	60*	47*	300*	40*	436*	270*	400*	-
Residential (family quarters, barracks)	63	105	227	40	436	107	400*	-
Recreational (picnic area, golf course, ballpark)	300	43	300*	40*	436	273	-	-

*Figure on average rather than source - specific.

etc.). The useful life of existing disposal sites should be established, and will indicate when alternate sites should be considered in long-term planning. If an Air Force base landfill is used, the Landfill Evaluation form should be reviewed to determine where site and operating improvements are needed. Any needed improvements should be cost estimated and included in the overall disposal cost.

COST ANALYSIS

The existing storage, collection, processing, and disposal costs should be calculated in dollars per year, dollars per ton, and dollars per service unit (person, bin, house, etc.) per month. Basic collection cost elements are listed in Table 14 and factors affecting costs are given in Table 15. For contractor collection the cost to the Air Force is the contract cost. A separate cost estimate should be calculated, however, to compare private contractor productivity and to determine if the Air Force is paying for a cost-effective operation.

Collection time study data must be summarized statistically to determine the mean, standard deviation, and probability of performing each activity. The probability of performance is the proportion of collection stops at which an activity occurs. Mean collection time consists of three components: time at each stop, travel time between stops and roundtrip travel time to disposal sites. These elements are evaluated to determine the efficiency of the existing system, and to revise routes to improve collection. Productivity standards are given in Table 16 for two- and three-man crews.

Standard costs may be used to complete the above storage and collection cost analysis; these costs are presented in Table 17 for container storage and Table 18 for collection. Superior productivity performance data for 11 representative residential collection systems are given in Table B-1 (Appendix B) for comparison purposes. The standard cost tables are useful for comparing costs of alternative methods and systems, but may vary with time and location in different geographic regions.

TABLE 14. COSTS OF SOLID WASTE COLLECTION: FOUR AIR FORCE BASES (1974)

Hanscom AFB	Rear-loading bin and can collection	55,400
	Rear hoist	67,576
		122,976
Vandenberg AFB	LoDal collection	71,723
	Rear hoist	47,260
	Can collection (contracted for housing)	98,766
		217,749
Charleston AFB	Can collection (contracted for housing)	135,840
	Bulky wastes collection	10,028
	Grounds	19,418
	Street sweeping	309,018
		474,304
Kelly AFB	LoDal collection	70,459
	Hoist bin	62,500
	Bulky wastes	23,723
	Can	23,156
	Tractor-trailer	54,600
	Street sweeping	139,622
		374,060

*Includes labor, equipment costs

TABLE 15. BASIC COLLECTION COST ELEMENTS.

Vehicle Capital Cost (fixed cost)
• Chassis
o Make
o Horsepower
o Fuel type (diesel vs gas)
o Number of axles
o Options (transmission, steering, auxiliary engine, etc.)
• Packer body
o Manufacture
o Type (front, rear, or side loader)
o Capacity
o Compaction capability
• Volume and type of purchase
Operating Cost (variable cost)
• Consumables (gas, oil, tires)
• Maintenance and repair (labor and parts)
Overhead Cost (fixed cost)
• Insurance
• Garage (imputed rent and utilities)
Labor Cost (variable cost)
• Wage rate (including fringe benefits)
• Crew size
• Number of pickups per shift
• Quantity of waste collected per pickup

Source: Adapted from Decision Maker's Guide in Solid Waste Management, Office of Solid Waste Management Programs, U.S.E.P.A., 1974.

TABLE 16. DENSITY AND TRAVEL DATA FOR RESIDENTIAL CURBSIDE COLLECTION

Distribution Between Stops	Housing Density (units/acre)	Average Collection Speed (mph)	(ft/min)	Average lbs/hr/man 2-man crew	Average lbs/hr/man 3-man crew
54 (ft)	Less than 10	2.18	192	1,575	1,830
54-35 (ft)	11-20	1.63	143	2,710	2,100
35-25 (ft)	21-40	1.63	143	2,645	2,030
25 (ft)	Over 40	1.58	139	2,550	1,880

TABLE 17. ANNUAL STORAGE COSTS (1974), ($)

Storage Equipment	Purchase Price *	Installation Cost *	Expected Life (yrs)	Annual Amortization*	Operating Cost/hr	Annual Maint. Cost *	Annual Cost
Front-Loading Bin							
2 yd	230	15	8	39	--	23	62
3 yd	275	15	8	47	--	28	75
4 yd	335	15	8	56	--	34	90
6 yd	435	15	8	72	--	44	116
8 yd	520	15	8	86	--	52	138
Hoist Bin							
2 yd	305	20	8	52	--	21	73
3 yd	365	20	8	62	--	26	88
4 yd	440	20	8	74	--	31	105
6 yd	555	20	8	93	--	39	132
8 yd	650	20	8	108	--	46	154
10 yd	735	20	8	122	--	51	173
Roll-Off Box							
20 yd	2,170	25	8	353	--	174	527
30 yd	2,400	25	8	391	--	192	583
40 yd	2,600	25	8	423	--	208	631
50 yd	2,900	25	8	471	--	232	703

TABLE 17 (Cont.). ANNUAL STORAGE COSTS (1974), ($)

Storage Equipment	Purchase Price *	Installation Cost *	Expected Life (yrs)	Annual Amortization*	Operating Cost/hr	Annual Maint. Cost	Annual Cost
Stationary Compactor and 8 yd F.L. Bin							
.5 yd charger+	3,400	250	8	588	0.03	320	815
.75 yd charger+	3,700	250	8	636	0.06	350	990
Stationary Compactor and Roll-off Box							
1.25 yd charger+							
w/30 yd box	7,600	300	8	1,270	0.11	600	1,810
w/40 yd box	7,900	300	8	1,320	0.11	610	1,865
1.5 yd charger+							
w/30 yd box	8,300	350	8	1,390	0.17	670	2,000
w/40 yd box	8,600	350	8	1,440	0.17	680	2,055
2 yd charger+							
w/30 yd box	8,900	350	8	1,540	0.18	740	2,215
w/40 yd box	9,200	350	8	1,540	0.18	740	2,215
2.5 yd charger+							
w/30 yd box	9,600	350	8	1,600	0.19	800	2,345
w/40 yd box	9,900	350	8	1,650	0.19	810	2,400
4 yd charger+							
w/30 yd box	16,400	370	8	2,700	0.23	1,280	4,000
w/40 yd box	16,700	370	8	2,750	0.23	1,300	4,070
w/50 yd box	17,100	370	8	2,810	0.23	1,320	4,150

TABLE 17 (Cont.) ANNUAL STORAGE COSTS (1974), ($)

Storage Equipment	Purchase Price *	Installation Cost *	Expected Life (yrs)	Annual Amortization*	Operating Cost/hr	Annual Maint. Cost	Annual Cost
G. I. Can							
20 gal	3.5	1	4	1.3	--	--	1.30
24 gal	4	1	4	1.4	--	--	1.40
32 gal	5	1	4	1.7	--	--	1.70
Pallet							
Flat	10 **	3	1	14	--	1	15
Wrap-around	15 **	3	1	19	--	1	20
Slotted box	15 **	3	1	19	--	1	20
Solid wall box	25 **	3	2	15	--	2	17
Engine Case	0 **	15	3	6	--	--	6

* Based on local distributors' prices. Installation cost may be conservative. Amortization is at 6 percent. Operating cost estimated at $0.015 per kilowatt-hour. Annual maintenance estimates are 10 percent of the purchase price for stationary compactors, 7 percent for roll-offs, and 8 percent for stationary compactors.

\+ N.S.W.A. rating. The cycle will vary between 30 and 55 seconds.

** Purchased used from base supply; there may not be a charge depending on their condition.

TABLE 18. HOURLY COLLECTION COSTS (1974), ($)

Collection Equipment	Purchase Price	Expected Life (yrs)	Annual Amortization	Amort. One Shift	$/hr Two Shifts	Labor Cost/hr *	Oper. and Maint.$/hr	Total Cost One Shift	$/hr Two Shifts
Front-Loading Truck						WG-7			
4,500 lb lift arms									
25 yd body	37,500	6	6,100	3.02	1.51	4.40	2.78	10.21	8.69
30 yd body	41,500	6	6,750	3.35	1.67	4.40	2.86	10.61	8.93
35 yd body	43,500	6	7,080	3.51	1.76	4.40	2.90	10.81	9.06
40 yd body	48,500	6	7,890	3.91	1.96	4.40	2.94	11.25	9.30
6,000 lb lift arms									
25 yd body	39,000	6	6,340	3.14	1.57	4.40	2.80	10.34	8.77
30 yd body	43,000	6	7,000	3.47	1.74	4.40	2.88	10.75	9.02
35 yd body	45,000	6	7,320	3.63	1.82	4.40	2.92	10.95	9.14
40 yd body	50,000	6	8,130	4.03	2.02	4.40	2.96	11.39	9.38
Hoist Truck						WG-7			
6,000 lb lift	13,700	6	2,230	1.11	0.55	4.40	0.85	6.36	5.80
10,000 lb lift	15,000	6	2,440	2.44	1.22	4.40	0.85	6.46	5.86
Tilt-Frame Truck						WG-7			
20 ton	34,000	6	5,530	2.74	1.37	4.40	2.70	9.84	8.47
25 ton	35,000	6	5,690	2.82	1.41	4.40	2.70	9.92	8.51
Side-Loading Truck						WG-7			
16 yd	22,100	6	3,600	1.78	0.89	4.40	2.69	8.88	7.98
20 yd	29,500	6	4,800	2.38	1.19	4.40	2.71	9.49	8.30
24 yd	31,100	6	5,100	2.53	1.27	4.40	2.75	9.68	8.41
28 yd	34,300	6	5,600	2.78	1.39	4.40	2.83	10.01	8.62
34 yd	39,000	6	6,300	3.12	1.56	4.40	2.88	10.41	8.82

TABLE 18 (Cont.). HOURLY COLLECTION COSTS (1974), ($)

Collection Equipment	Purchase Price	Expected Life (yrs)	Annual Amortization	Amort. One Shift	$/hr Two Shifts	Labor Cost/hr *	Oper. and Maint.$/hr	Total Cost One Shift	$/hr Two Shifts
Tractor						WS-8			
5 ton	25,000	6	5,084	2.52	1.26	4.65	0.85	8.02	6.76
10 ton	26,000	6	5,287	2.62	1.31	4.65	0.85	8.12	6.81
40 ft Flatbed with Lift Device									
Trailer	9,000	20	785	0.39	0.19	--	0.10	0.49	0.29
Lift	1,500	10	163	0.08	0.04	--	0.40	0.48	0.44
Both	8,500	--	--	0.47	0.23	--	0.50	0.97	0.73

* Based on delivered price from local distributors; amortized at 6 percent with 20 percent resale value; with designated civil service rated driver; with operating and maintenance costs based on $0.29/gallon diesel fuel and $0.21/quart oil and shop rates comparable to $11.00/hr; and 252 days/year and 8 hours/shift.

⊥ Based on an extra 0.125 gallons/hr for three axles or 5 extra cubic yards, $0.04/hr for maintenance of third axle, and 0.063 gal/hr for heavier lift arms.

SECTION V

STEP FOUR: OPTIMIZATION OF SOLID WASTE OPERATIONS

The recommended order for structuring an optimal solid waste management system is as follows:

1. Determine storage requirements at each building or facility.
2. Select the most appropriate container for each facility.
3. Using a base map, divide the base into geographically distinct areas based on street access, building clustering, and travel distances.
4. Determine the travel time through each area on the shortest route.
5. Determine collection time in each area for proposed collection methods.
6. Subdivide each area on the basis of collection frequency.
7. Summarize annual collection costs for each area and subarea.
8. Develop routing maps for trucks collecting each subarea.
9. Conduct cost tradeoffs for different collection frequencies, types of collection (curbside, back-yard, etc.), and storage container sizes.
10. Select the lowest cost system.

The optimal system will be the lowest cost system that provides the level of service desired. Since collection and storage costs are discrete rather than continuous for alternative methods for a given base, the approach outlined above will lead to an optimal system. The method is detailed below. Figure 1 presents a partial list of waste handling alternatives open to solid waste managers using state-of-the-art equipment and practices.

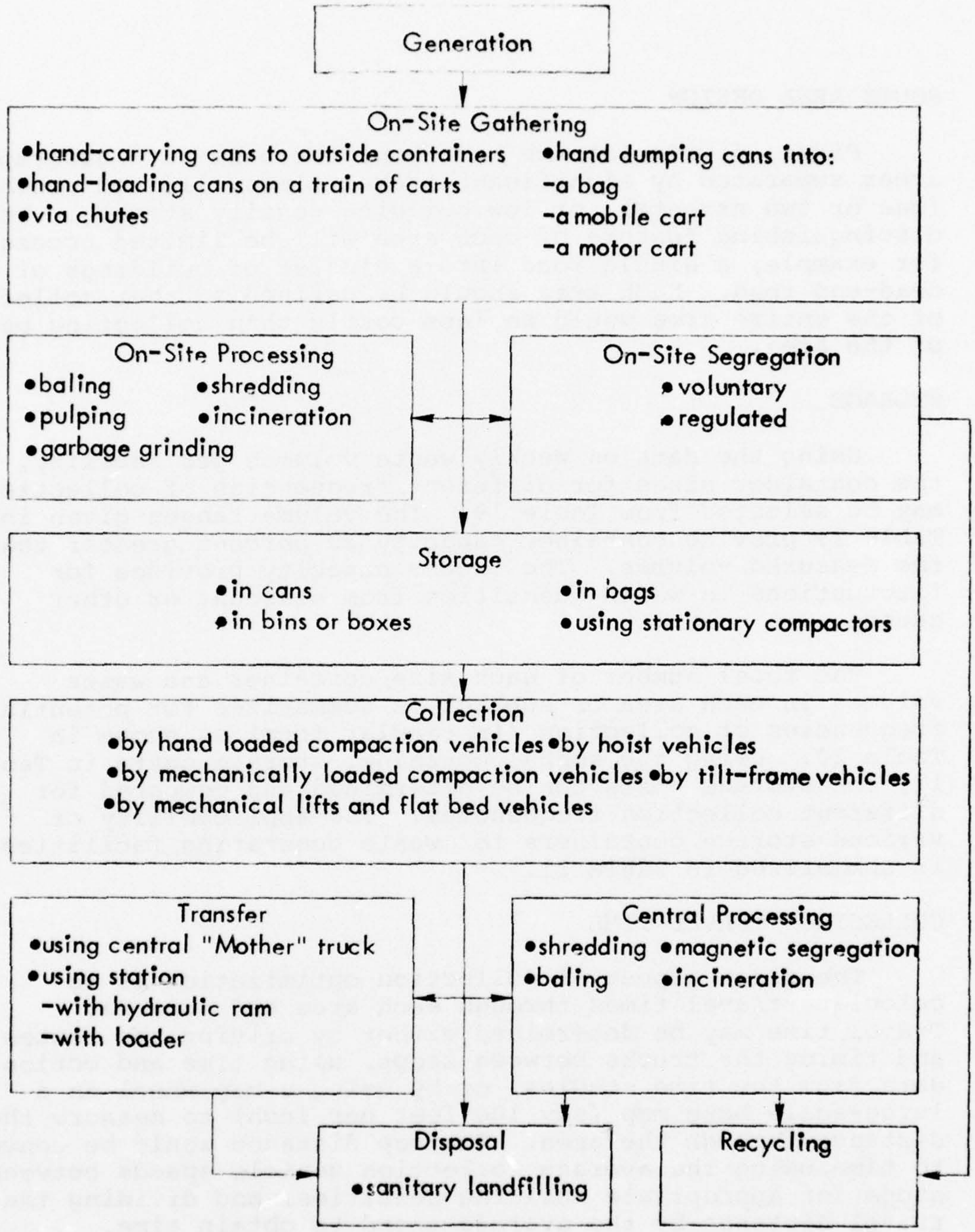


Figure 1. General Flow Diagram Indicating Basic Alternatives in Waste Handling Operations.

ROUTE AREA DESIGN

First, divide (on the base map) the base into geographical areas separated by significant travel times, limited access (one or two streets), or low building density streets. The distinguishing feature of each area will be limited access; for example, a single road into a cluster of buildings or a dead-end road. Each area should be defined so that collection of the entire area would be less costly than collecting part of the area.

STORAGE

Using the data on weekly waste volumes per facility, the container sizes for different frequencies of collection may be selected from Table 19. The volume ranges given in Table 19 provide container capacity 20 percent greater than the measured volumes. The excess capacity provides for fluctuations in waste quantities from seasonal or other causes.

The total number of each size container and waste volumes in each area or subarea is summarized for potential frequencies of collection (in tabular form) as shown in Table 20. Using the annual container storage costs in Table 17, the storage costs can be determined and compared for different collection frequencies. The applicability of various storage containers to waste generating facilities is summarized in Table 21.

COLLECTION TRAVEL TIME

The first aspect of collection optimization is to calculate travel times through each area and subarea. Travel time may be determined either by driving the routes and timing the trucks between stops, using time and motion data from the time studies, or by using a map wheel on a large-scale base map (say 100 feet per inch) to measure the distance through the area. The map distance would be converted to time, using the average collection vehicle speeds between stops for appropriate building densities, and dividing the travel distance by the average speed to obtain time.

Timing all of the collection routes would be the most accurate method, but it requires time to travel each collection route, and is the most costly approach. Time study travel time data can be used if the building densities are reasonably

TABLE 19. CONVERSION TABLE FOR CONTAINER COST AND CAPACITY

Container Types	Annual Cost($)	Volume Ranges in cu. yd. by Frequency of Collection 1/wk	2/wk	3/wk	4/wk	5/wk
4 yd	90	0. - 3.2	0. - 6.4	0. - 9.6	0. - 12.8	0. - 16.0
6 yd	116	0. - 4.6	6.5 - 9.6	9.7 - 14.4	12.9 - 19.2	16.1 - 24.
8 yd	138	4.7 - 6.4	9.7 - 12.8	14.5 - 19.2	19.3 - 25.6	24.1 - 32.
(2) 6 yd	232	6.5 - 9.6	12.9 - 19.2	19.3 - 28.8	25.7 - 38.4	32.1 - 48.
6 & 8 yd	254	9.7 - 11.2	19.3 - 22.4	28.9 - 33.6	38.5 - 44.8	48.1 - 56.
(2) 8 yd	276	11.3 - 12.8	22.5 - 25.6	33.7 - 38.4	44.9 - 51.2	56.1 - 64.
(3) 6 yd	348	12.9 - 14.4	25.7 - 28.8	38.5 - 43.2	51.3 - 57.6	64.1 - 72.
(2) 6 & 8 yd	370	14.5 - 16.0	28.9 - 32.0	43.3 - 48.0	57.7 - 64.0	72.1 - 80.
6 & (2) 8 yd	392	16.1 - 17.6	32.1 - 35.2	48.1 - 52.8	64.1 - 70.4	80.1 - 88.
(3) 8 yd	414	17.7 - 19.2	35.3 - 38.4	52.9 - 57.6	70.5 - 76.8	88.1 - 96.
(3) 6 & 8 yd	486	19.3 - 20.8	38.5 - 41.6	57.7 - 62.4	76.9 - 83.2	96.1 - 104.
(2) 6 (2) 8 yd	508	20.9 - 22.4	41.7 - 44.8	62.5 - 67.2	83.3 - 89.6	104.1 - 112.
6 & (3) 8 yd	530	22.5 - 24.0	44.9 - 48.0	67.3 - 72.0	89.7 - 96.0	112.1 - 120.
(4) 8 yd	552	24.1 - 25.6	48.1 - 51.2	72.1 - 76.8	96.1 - 102.4	120.1 - 128.
(3) 6 & (2) 8 yd	624	25.7 - 27.2	51.3 - 54.4	76.9 - 81.6	102.5 - 108.8	128.1 - 136.
(2) 6 & (3) 8 yd	646	27.3 - 28.8	54.5 - 57.6	81.7 - 86.4	108.9 - 115.2	136.1 - 144.
6 & (4) 8 yd	668	28.9 - 30.4	57.7 - 60.8	86.5 - 91.4	115.3 - 121.6	144.1 - 152.
(5) 8 yd	690	30.5 - 32.0	60.9 - 64.0	91.5 - 96.0	121.7 - 128.0	152.1 - 160.
32-gal	1.70	0 - 25.6 gal	0 - 51.2 gal	0 - 76.8 gal	0 - 102.4 gal	0 - 128 gal

TABLE 20. ANNUAL COSTS OF STORAGE FOR DIFFERENT COLLECTION FREQUENCIES

Locations		Collection Frequency													
Bldg. No.		0.5/wk		1/wk		2/wk		3/wk		4/wk		5/wk		Specify	
(type bin)	Yd^3	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.

*Front-loading = F.L./G.I. can = can/roll-off = R.O./stationary compactor and roll-off = S.R.O.

TABLE 21. APPLICABILITY OF STORAGE CONTAINERS

Type of Equipment	Multi-Unit Hsg.	Single Unit Hsg.	Commissary & BX	Food Service	Offices	Hospitals	Shops	Warehouses	Demolition	Grounds	Laboratories	Recreation	Waste Sludges	Hazardous & Toxic
	SOURCE OR TYPE OF WASTE													
Permanent														
Cans	▲	▲	●	▲	●	●	▲	▲	○	▲	●	▲	●	○
Barrels	▲	●	●	▲	●	●	▲	▲	○	▲	●	▲	●	○
Stationary storage bins	●	○	○	○	○	○	○	○	○	○	○	○	○	○
Bins	▲	○	●	▲	▲	▲	▲	▲	●	▲	▲	▲	○	○
Removable														
Roll-off	●	○	▲	▲	▲	▲	▲	▲	▲	▲	●	▲	○	●
Lugger boxes	●	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	●*	●
Trailer vans	●	○	▲	▲	▲	▲	▲	▲	▲	▲	●	▲	●*	●
Compactor containers	●	○	▲	▲	▲	▲	▲	▲	▲	▲	●	▲	○	○
Disposable														
Plastic bags	▲	▲	●	▲	▲	▲	●	●	○	●	▲	▲	○	○
Paper bags	▲	▲	○	○	▲	○	○	○	○	○	●	▲	○	○
Plastic bin liners	●	○	●	▲	○	●	●	○	○	○	●	●	○	○
Cardboard boxes	▲	▲	▲	●	▲	●	▲	●	○	●	●	●	○	○
Concrete drums	○	○	○	○	○	○	○	○	○	○	○	○	○	▲
Steel drums	○	○	○	○	○	○	○	○	○	○	○	○	○	▲

Key: ▲ = Useable
● = Possibly useable
○ = Not useable

*Tanks

consistent throughout the base, otherwise significant errors may result in nonconforming areas. Time study data may not be available for the entire base because it is usually not compiled for every route but only on representative routes. The map measuring method is the quickest and least expensive approach, but it is not as accurate as timing the travel route.

COLLECTION TIME

Standard collection times for the candidate collection methods can be used to determine the total time to collect all container stops in each area. Because average time values are used, the total collection time is the product of the number of bins and collection time. At buildings with more than one container, the time for the appropriate number of containers must be used (for bins the times are 2.1 minutes for the first bin and 1.7 minutes for each subsequent bin). If the existing collection method is used, the measured time study data can be used. If a new collection method is used, time data from that type of method may be used. Sources of standard times are Figure B-1 (Appendix B), and data from the base studies in Appendix C.

ROUTING

The least-time route must be determined to minimize collection time. This can either be accomplished through computerized assistance from the Air Force Civil Engineering Center (AFCEC) or through basic logic, heuristic routing. (AFCEC assistance for base residential routing should be available in mid-1977.) The objective of heuristic routing is to design a route acceptably close to the unknown optimal. Since collection system costs generally change in increments, the optimal system may be accurately reached. The steps in heuristic routing are summarized in Figure 2. Further guidance is also available in AFWL-TR-73-120, Improving Air Force Base Refuse Collection Vehicle Routing, dated July 1973.

Under actual conditions, a facility producing a large waste volume may be located adjacent to one producing a small volume. In this case, some areas may have to be divided into subareas requiring different collection frequencies. Selection of collection frequencies must be determined by a trade-off between storage container cost and collection cost. Storage cost increases (more containers) as collection

1. Routes should not be fragmented or overlapping. Each route should be compact, consisting of street segments clustered in the same geographical area.

2. Total collection plus haul times should be reasonably constant for each route in the community (equalized workloads).

3. The collection route should be started as close to the garage or motor pool as possible, taking into account heavily traveled and one-way streets. (See rules 4 and 5).

4. Heavily traveled streets should not be collected during rush hours.

5. In the case of one-way streets, it is best to start the route near the upper end of the street, working down it through the looping process.

6. Services on dead end streets can be considered as services on the street segment that they intersect, since they can only be collected by passing down that street segment. To keep left turns at a minimum, collect the dead end streets when they are to the right of the truck. They must be collected by walking down, backing down, or making a U-turn.

7. When practical, steep hills should be collected on both sides of the street while vehicle is moving downhill for safety, ease, speed of collection, and wear on vehicle, and to conserve gas and oil.

8. Higher elevations should be at the start of the route.

9. For collection from one side of the street at a time, it is generally best to route with many clockwise turns around blocks.

(Heuristic rules 8 and 9 emphasize the development of a series of clockwise loops in order to minimize left turns, which generally are more difficult and time-consuming than right turns and, especially for right-hand-drive vehicles, right turns are safer.

10. For collection from both sides of the street at the same time, it is generally best to route with long, straight paths across the grid before looping clockwise.

11. For certain block configurations within the route, specific routing patterns should be applied.

Source: Shuster, K. A., and D. A. Schur, Hueristic Routing for Solid Waste Vehicles, U.S.E.P.A. Publication No. SW13, 1974.

Figure 2. Heuristic Routing Technique.

frequency decreases. The tradeoff can be done by determining collection times (including collection and travel), for different collection frequencies. Standard costs per hour of collection are given in Table 18.

SYSTEM ANALYSIS

In applying the method to the four bases originally surveyed to test this methodology, it was found that the collection frequency decreasing the number of bins to one per stop was the least costly. Thus, the goal in optimizing is to minimize the number of bin containers and the frequency of collection. The exception would occur if all but one or a few buildings in an area required more frequent collection than the others. In this case, the few requiring less frequent collection would be collected as frequently as the majority. Collection time and cost are summarized in the Table 22 data format. Annual costs are calculated to evaluate alternative collection frequencies by area. Selection of collection truck capacity is based on maximizing the volume (minimum number of trucks) that will allow an integral number of truckloads to be collected each day from all routes. Minimizing the number of truckloads will minimize the number of trips to the disposal site.

In general, two loads per day provide a feasible low-cost goal without a transfer station. The truckloads are determined from the vehicle size and waste volumes. A compaction volume reduction factor (usually compacted to 1/4 of the uncompacted volume), is used for packer vehicles to estimate loads. An excess capacity of 20 percent compacted volume should be allowed in sizing the trucks to minimize the possibility of having to take a partial load to the disposal site or holding the load overnight.

The prevailing hourly labor rates and hourly collection vehicle costs will determine the least costly truck and crew size combination. In general, the fewer men on collection crews, the lower the collection cost. Because collection cost accounts for 70 to 80 percent of total solid waste management costs, it is a key operation to concentrate on cost cutting. The minimum practical crew sizes are: residential curbside collection--one man; bin collection from alleys or streets--one man; and residential backyard, set-out and set-back collection--two men.

The three types of collection vehicle loading points are generally recommended for application as follows: front

TABLE 22. COLLECTION ROUTING ANALYSIS

Area	Collection Trips per Week						
	0.5/week	1/week	2/week	3/week	4/week	5/week	Special
Travel*							
1) Miles/trip							
1) Aver.speed							
1) Hours/trip							
2) Miles/trip							
2) Aver. speed							
2) Hours/trip							
Total hours/trip							
Total hours/week							
Total hours/yr							
Travel cost/yr							
Collection							
F.L. stops/trip							
F.L. bins/trip							
F.L.'ing hours/trip							
G.I. can stops/trip							
G.I. cans/stop							
G.I.'s hours/trip							
Total hours/trip							
Total hours/week							
Total hours/yr							
Collect cost/yr							
Total cost/yr							

* 1) indicates unconstrained or normal travel, while 2) indicates constricted travel during residential collection curbside or backyard

loading--bin containers, limited household cans, one-man crew for bin collection, two-man crew for household can collection; side loading--one man crew, curbside collection of household cans; rear loading--collection of household cans, limited bin use, curbside or backyard collection.

COST ANALYSIS

The final step is to summarize the annual costs of storage and collection by area (route) in the manner illustrated in Table 23. The Table 23 data form should be used separately for each type of collection system being evaluated. In most cases the differences in cost between alternative methods will be large enough so that a more detailed comparison will not be necessary for final selection. Alternative routing structures may, on occasion, have to be compared at the area level. The lowest cost collection frequencies are selected for each area. The areas are then combined to form integral collection truckloads.

The total time per load is the sum of collection time, travel time between stops in each area, travel time between areas, and travel time for disposal. Travel time from the vehicle yard to the route and return are averaged over each trip. The minimum trip time occurs when each truck collects from adjacent areas on the same day, thus the nearest areas making up a truckload should be combined wherever feasible.

ROUTING SUMMARY

The areas should be grouped into daily routes for their appropriate collection frequencies. This may be done on the data form in Table 24. In setting the routes, the travel time for disposal, to and from the yard, and a lost time allowance must be included in the daily time schedule. The times to collect each area may be used to combine areas to complete a day's route schedule. It is advisable to allow some slack time (30 minutes is probably adequate) each day for those days when above average waste quantities are encountered. The collection route schedule of Table 24 may be used in combination with area route maps to show the collectors the order of collection for each street and building. (The AFCEC routing program will also produce a schedule for base residential areas.)

TRANSFER STATIONS

Transfer stations become economical if the disposal site is a great distance from the collection routes. The

TABLE 23. TOTAL ANNUAL COSTS OF STORAGE/COLLECTION BY AREA ($)

Areas	Collection Frequency						
	0.5/Week	1/Week	2/Week	3/Week	4/Week	5/Week	Special
Area							
Cost							
Volume/trip							
Time/trip							
Area							
Cost							
Volume/trip							
Time/trip							
Area							
Cost							
Volume/trip							
Time/trip							
Area							
Cost							
Volume/trip							
Time/trip							
Area							
Cost							
Volume/trip							
Time/trip							

TABLE 24. COLLECTION ROUTE SCHEDULE

Time / Day	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
7:00						
8:00						
9:00						
10:00						
11:00						
12:00						
13:00						
14:00						
15:00						
16:00						
17:00						

general method of determining break-even distances for transfer stations is shown in Appendix B, Figure B-2; cost comparisons of transfer versus direct haul in Appendix B, Figure B-3; and costs of transfer baling versus conventional disposal in Appendix B, Table B-3.

DISPOSAL

For Air Force base landfills, equipment needs may be determined from Tables B-4 and B-5 in Appendix B. Due to the relatively small quantities of solid waste on Air Force bases, the recommended approach would be to select one piece of equipment that can perform a variety of landfill functions.

BULKY WASTES COLLECTION

Collection of bulky waste is usually more costly on a dollar per ton basis than other types of collection because hand labor is usually used and because the relatively few points requiring collection are usually widely dispersed. Minimizing collection frequency will in most areas also minimize costs. For Air Force bases, collection of bulky wastes every 2 weeks to once a month would be satisfactory. A flat-bed truck with an hydraulic lift tailgate would be best suited for bulky waste collection.

PROCESSING

Given the sizes of Air Force bases, the feasible processes are baling, shredding, and pulping of classified wastes, and incineration of classified wastes. Incineration is more costly and therefore shredding and pulping should be preferred.

Food waste (garbage) grinders are feasible as a method of reducing collected waste quantities, odors, flies, and rats in solid waste. Available sewage treatment facilities should be evaluated to determine if they can handle the waste load from food grinders, and what additional costs may be involved. If the Air Force base disposes to a municipal sewage system, the sewage fee may be increased. A cost analysis for purchase, installation, maintenance, and sewage treatment should be completed to determine the feasibility.

CONTRACT/IN-HOUSE MANAGEMENT

Contract collection may be the most feasible method for small bases under 1,000 population. Collection vehicle costs would be high, particularly when a backup truck is included for small bases. A cost analysis should be completed for larger bases to select the lowest cost (optimal) system. The Air Force cost estimate can be used to evaluate contractors' bids. Monitoring and inspection of contract collectors are necessary to assure that the specified level of service is achieved and that the collectors are efficient. Regardless of the method chosen (contractor or in-house) consideration should be given to incentive work systems, such as allowing crews to go home early if they finish up their assigned collections early.

SECTION VI

RECOMMENDATIONS ON METHODS AND EQUIPMENT

ON-SITE GATHERING

Mobile carts with detachable 60-gallon cans are well-suited for small-to-medium size commercial buildings with access to large outside bins. Mobile work carts with detachable storage bags are better suited to small-to-medium size commercial buildings with stairs between janitorial areas and outdoor bins. Large commercial buildings may be optimally "gathered" by motorized carts or 1 to 4 cubic yard push carts, depending on clearances and waste quantities. Push carts with appropriate bin size (generally as large as possible) should be most efficient. For existing multistory buildings generating more than 350 gallons of waste per day from upper stories, gravity, and pneumatic chutes can be considered.

Mechanized gathering is usually not feasible in Air Force commercial installations because of limited waste volume and obstacles to the costly equipment. Hospitals, warehouses, shipping/receiving, and other commercial facilities that generate large quantities of waste within single buildings are exceptions; they are candidates for mechanized waste gathering with conveyors, sweepers, motorized carts, etc. Disposable coded (marked) plastic bags can be used where pathological or food wastes are generated. Hard to handle wastes should be identified clearly so that there is minimum hazard to collectors and disposers. The cost trade-offs between hand labor and mechanical equipment depend on the quantity of waste handled, travel distances, obstacles, and other local factors.

STORAGE

Front loading bins range in size from four to ten cubic yards capacity. Bins are normally the least-cost storage/collection system except in cases (infrequent on AF bases) where large amounts of waste are generated, or widely separated facilities each generating significant quantities of waste. Bins are not suitable in most single unit housing; for single houses, 32-gallon G.I. cans or bags are generally the least-cost containers. In areas with limited storage space, stationary compactors may be the least-cost containers.

If automated waste gathering is used in a large building (such as a hospital), stationary compactors may be necessary to mechanically compress waste into the storage bins. Modified front loading bins can be used; depending on whether tilt-frame trucks are available on-base, 40 cubic yard roll-off boxes can also be cost effective.

Although plastic bags may not be as cost-effective as 32-gallon G.I. cans (because of the relatively high cost of the bags--$0.08 (1974) each) for solid waste storage in single-family dwelling residential areas, the use of one way disposable bags should be encouraged to:

1. Reduce litter and odor.

2. Improve aesthetics and sanitation.

3. Ease the set out of waste, since normally a bag is one-half the weight of a metal G.I. can containing comparable refuse.

4. Increase collection productivity.

5. Provide overflow containers for residents (reduces the number of G.I. cans required by each resident).

6. Serve a variety of special functions (hold leaves, sawdust, organic wastes).

To promote their use, plastic bags should be purchased (preferably from the Government General Service Administration) for distribution to all commissaries and sale (at cost) to base personnel. Residents should have the option to purchase and use plastic bags; quantity government buying should reduce the purchase price.

Multiplex family housing should use front loading bins wherever possible. Bins should be placed to minimize walking distance for users (less than 125 feet). Parking in front of bins and other obstructions and interferences should be avoided, and signs warning not to block the bins posted. It is of aesthetic benefit to locate bins so that they are camouflaged by plantings, fences, or other attractive screening devices. Stationary compactors and roll-off bins may be costly for most applications on Air Force bases. First, costs of the combination are in the $2,000 to $3,000 range, with collection extra. The annual cost of an 8 cubic yard front-loading bin is about $138. Although annual collection costs are higher for the front-loading bin than the roll-off container, they do not approach the difference in storage costs, except where long travel times or high waste volumes are the rule. Front loading bins are the least-cost solution for most commercial and industrial applications.

Hoist bin containers should be removed from normal solid waste storage, due to their high handling costs. The significant cost effective use that hoist bins may have on base is for storing toxic or dense, noncompactible waste, dusts, liquids, and scrap. Under most collection conditions, mechanical hoist systems are relatively costly in relation to volume processed.

Use of 55-gallon drums should be discouraged for solid waste storage (too hard and dangerous to handle manually, they provide problems with vectors and odors, excessive handling costs). They can be replaced by 32-gallon cans, bags, or large bins, thus minimizing both the handling problems and reducing costs. Mechanically loaded bins should be 4 cu yd or larger to provide reasonable storage capacity. Bins should be top-loading (side-loading reduces effective volume up to 40 percent). The bins should be large heavy duty types with good door latches, since small or weak parts tend to fail quickly. Care and judgment should be exercised to locate and orient bins for easy use and rapid, safe collection as well as to minimize adverse environmental impacts. Spraying deodorants and disinfectants into bins holding food waste may reduce some odors and vermin problems. Many collection vehicles have a pressurized spray tank for this purpose. (A 25-gallon tank is about right). Bins should be steam cleaned as required--a scheduled program is wasteful since all bins do not require cleaning at identical intervals, and it is not possible to accurately estimate the proper time between cleanings. Too frequent steam cleaning damages the paint unnecessarily and increases cost. Too few cleanings cause odor, vector, and aesthetics problems.

Finally, standardized equipment should be used. This reduces costs, improves the availability of replacement parts, and promotes better efficiency and service.

COLLECTION

Collection deserves careful consideration and planning because collection costs are about 80 percent of the cost of all solid waste handling functions. Curbside collection in residential areas is much less expensive than backyard pickup. Both the cost saving and service reduction are particularly marked if once-a-week curbside is substituted for twice-a-week backyard collection. The cost savings (50 percent or more) result from lower labor requirements and higher crew productivity. Curbside collection permits a one-man crew; backyard collection requires at least a two-man crew. A one-man crew curbside can collect more than a two-man crew on backyard pickup. Also, accidents, injuries, and litter are significantly reduced. Because travel distance and time are reduced, fuel is saved. The dollar savings from use of a one-man crew result partly from elimination of waiting time (of one crew member for another). For two or three man areas, waiting time averages about 20 percent of the time on the route. Walking time is also substantially reduced with curbside collection. Time used to open empty containers is minimized, as are interferences and injuries from fences, pets, and other yard obstacles. Fatigue and job dissatisfaction are reduced. Federal EPA studies indicate that work crews experienced higher job satisfaction, manifested by longer careers when systems used curbside collection. The remaining cost savings result from a more effective use of collection vehicles, because containers are collected more rapidly. Curbside crews collect significantly more stops per shift.

Generalizing about collection:

1. Backyard collection is nearly twice as costly as curbside pickup.

2. Twice-a-week collection increases cost about 25 percent over once-a-week collection.

3. Twice-a-week collection reduces vehicle requirements 20 to 30 percent.

4. About 60 percent of residential collections in the US are curbside.

5. About 45 percent of the urban systems practice once-a-week collection.

The twice-a-week backyard collection method was practiced at the four bases investigated in the original study and their costs were correspondingly high. For example, collection costs at one base were $117 per ton, as compared to curbside collection, in many civilian systems which ranges as low as $10 per ton. Should curbside collection be substituted for backyard collections, some resistance should be anticipated, but consideration should be given to the large additional labor and capital costs involved in providing the extra service and also the negative impacts such as: waste of vehicular fuel energy, and increased noise and interference with privacy related to multiple collections each week. For safety reasons, one-man crews are sometimes not adequate for front-loader routes, since front-loaders must back away from each bin collected. Thus, a second man is sometimes needed to watch the rear and guide the driver. Private contractors almost exclusively use one-man crews with front loaders; they find significant savings and no known increase in their accident rate, even in congested urban communities. Residential manual routes are sometimes more efficiently collected with two men if any of the following are apparent: (1) backyard collection is required, (2) the route has streets so narrow that two-sided curbside collection is practical, or (3) haul time to the disposal site is relatively short. On the four Air Force bases studied, a one-man crew would be cost effective for the mechanically loaded bins located in the garden apartments, where most base personnel reside.

Size of compaction vehicles (whether front, side, or rear loading) substantially affects travel time, amortization, and operating and maintenance costs. Determining factors for selection are number of axles, gross vehicle weight, lift arm capacity, travel distance, operating costs, and maneuverability limits. Front loading vehicles with 35 cubic yard maximum capacity and three axles--are presently cost effective primarily because of their axle weight, operating characteristics, and maneuverability limitations. Lift arm capacity (according to manufacturers' specifications) ranges incrementally from 4500 to 10,000 pounds; the bases studied generally required only 4500 pound capacity for their front-loaders except for the pickup of dense demolition or industrial wastes. Obviously, pickup arms should be selected for the maximum load requirement.

Residential collection vehicles (such as rear or side loaders) are often smaller, around 16 to 20 yards capacity. These sizes permit about two full loads daily to the landfill. A 35 cu yd truck space might reduce the unloading to once a day. Residential waste loads are usually dumped at the end of the shift rather than permitting partial loads to sit in the vehicle overnight. However, this is inefficient, and some community systems allow partial loads to remain overnight to minimize travel to the dumping area.

Appropriate safety devices should be installed and used on collection vehicles:

1. Oversized rear-view mirrors.

2. Backup bells (crews seem to prefer bells to buzzers).

3. An orange, rotating light on top of the vehicle to improve its visibility.

Heavy duty cooling, oil, and other mechanical equipment should be specified on collection vehicles since heat and solid waste abrasion are major destroyers of collection vehicle mechanisms. The heavy demands on the hydraulic system, the frequent stops to pick up waste, the lack of forced air cooling, and the accumulation of dust from the waste and the landfill increase heat loading on the vehicle cooling system. A separate oil cooler is desirable to help maintain oil and additive viscosity lubrication properties.

At the Air Force bases previously studied, it was observed that some bases do not have enough housing units to keep one collection vehicle busy. In such cases, the shared use of a front-loading vehicle with a special 2-yard bin can be employed as the residential collection vehicle. Such dual use can reduce costs by eliminating the need for a special vehicle and crew that are only partially utilized. A front-loading vehicle with bin is intrinsically slower per stop than a dual drive, side-loading vehicle, but the time differences do not justify the costs for a special vehicle and crew. The front-loading collection vehicle and bin with one man is suitable for collecting up to 100 units in one day. If more units are to be collected, a second crewman should be provided. The basic reason a two-man crew would be better is that the height of the vehicle cab normally available requires the driver to continually enter or leave the cab--a time-consuming and fatiguing task.

Route planning and balancing can substantially reduce cost. It is necessary to carefully establish whether containers should be collected on a fixed schedule or on-call. The choice depends on the location, amount of waste generated, and the type of container. Residential waste should be collected on a schedule. Front-loading bins should also be collected on schedule, except at sites generating very small amounts of waste or intermittently accumulating waste, and those at remote locations. Hoist and roll-off bins are best collected on-call due to their high collection cost, variable generation rates, and the insensitivity of their collection cost to the amount of waste collected.

Scheduled routes should be divided according to the consolidated areas served and the frequency of collection, in order to minimize the total resulting storage and collection costs. When multiple crews are used, the time and work effort required on each route should be equalized.

Bulk residential collection should be on call. The trade off between scheduled and on-call collection of bulky residential wastes will depend on the building density, income levels, and other factors. On-call collection of bulky wastes appears to be optimum for most Air Force bases.

Once-a-week street sweeping is generally adequate for areas that tend to accumulate solid waste quickly, such as litter or falling leaves. Heavily trafficked main streets and other extensively used areas should be swept once a week. In other areas, sweeping is required once every two weeks or less. The trade-offs between frequency of collection and rate of filling up the sweeper should be analyzed to establish the number of sweepers required for an optimum sequence. The less frequent the collection pericd, the faster a sweeper will fill up. Drain clogging incidents may indicate that more frequent sweeping is required.

DISPOSAL

Sanitary landfills receiving less than about 50 tons of waste per day are probably inefficient because the heavy equipment required to handle and compact the waste is not fully utilized. For a small landfill to be efficient, the natural contours of the ground should permit filling with minimum excavation, and sufficient cover soil should be readily available adjacent to the working face. Specifically, trench landfills and landfills requiring excavation or hauling cover soil are far more efficient when large quantities of waste are disposed (more than 100 tons/day). Bases with small waste generation rates of less than 50 tons per day (this includes most bases) should use local off-base landfills or incinerators if they are available. The exceptions are hazardous wastes and dirt or demolition wastes. Hazardous substances require special handling and disposal. Paint cans and other containers may be cleaned and salvaged, carefully landfilled, or alternatively sold for scrap in a contaminated condition (if sold, careful labeling explaining the contents and hazards is necessary). Dirt and demolition wastes are expensive to transport but easily disposed of as clean inert fill on base. All disposal sites, used by the Air Force, whether owned or paid for on a fee basis, should comply with EPA standards. Proper equipment and methods may increase certain costs but provide other cost savings and benefits: fewer injuries and diseases to landfill personnel; reduced problems with vectors, littering and odor; elimination of methane explosion hazards, contamination of groundwater and surface bodies of water; longer landfill life; and others. In particular, hazardous and toxic wastes require special handling. Some of these might better be handled by chemical neutralization, biochemical stabilization, or encasement in multiple plastic bags before landfill disposal or incineration. With some toxic wastes, special protective steel or cement containers may be required for safe long-term storage. Other special handling and physical-chemical processes include evaporation, ion exchange, carbon adsorption, pyrolysis, masceration, reverse osmosis, and related methodologies.

PROCESSING

The Air Force bases previously studied did not generate enough waste to justify central processing as used in some large municipalities. Central refuse balers, shredders, and incinerators for communities generally have daily capacities in the range of 100 tons a day or more. Most Air Force bases do not approach that volume of daily waste generation. The small generation rates on most bases plus the substantial scale economies involved virtually rule out (except for very large bases) centralized processing, except perhaps as a joint venture with nearby municipalities.

Several types of local processing methods are applicable to Air Force waste systems. These include shredders, pulpers, balers, and incinerators. These may be adapted to specific applications on-base.

Security wastes require destruction, and there are specifically designed shredders, pulpers, and incinerators for this task. Pulpers are a superior process for security paper destruction. Because cold pulpers do not destroy film and plastic, shredders and incinerators are more generally used. Recycling should be considered for shredded security waste.

Incinerators are frequently used for disposal of pathological wastes and contaminated food. Incinerators are also frequently used for destroying other types of waste, such as packaging or oily materials. Only the smaller package-type incinerators are applicable to most bases. They tend to be expensive per ton processed, and create air pollution control problems. They do, however, offer several advantages (reduced quantities for landfilling, etc.).

Hydraulic balers are not generally recommended for Air Force base applications except for concentrated, high volume sources. Generally, hand strapping appears less costly. Hand strapping is particularly applicable to corrugated recycling programs. The hand strapper (or hand baler) tightly binds the corrugated with metal straps. Compaction is not as high as with a hydraulic baler, but it is adequate considering the cost savings involved. Hand strappers could be used at many locations base wide. The strapped bale is lifted by a forklift or wheeled off on a dolly. No new labor positions would be required for this type of baling. Special bins and collection vehicles, as required with central baling systems, would be eliminated. Instead, a flatbed trailer would collect bales and haul them directly to the salvage dealer.

RECYCLING

Some separation and recycling of various waste items are mandatory for all federal agencies, under recently promulgated EPA guidelines in these areas. Each base must critically examine its waste stream and the market potential for its waste items, and work with local representatives of the Defense Logistics Agency (DLA) to determine if and how some separation and recycling processes can be cost effective. These processes are not "end-all" functions, separate unto themselves, but functions integrally related to basic solid waste management.

Because much of the civilian sector management data available on this subject is nonapplicable to bases because of unique Department of Defense (DoD) directives and regulations, and because many, if not all, Air Force base recycling programs (other than traditional DLA managed activities) have failed due to these DoD unique factors, no further management guidance is possible within this section. DoD and HQ USAF guidance will be provided, in the near future, relative to the requirements of the EPA guidelines and will have to be utilized to effect optimum program management in this growing functional area.

REGIONALIZATION

Bases should actively cooperate with regional planning and solid waste agencies. Regional plans have been used to implement waste management methods at reasonable costs. In addition to potentially mitigating his own waste problems by cooperating in regional solid waste systems, the best waste manager can, by this involvement, also favorably demonstrate the concept of Air Force-community partnership in achieving mutually benefitting goals.

APPENDIX A

TABLE A-1. LAND DISPOSAL EVALUATION SHEET

	Points Possible	Site
A. EMPLOYEE FACTORS		
1. Facilities		
a. Adequate shelter, hygiene facilities	(3)[a]	___
b. Adequate shelter-minimal hygiene facilities	(2)	___
c. Inadequate shelter, hygiene facilities	(0)	___
2. Communications		
a. Radio or telephone on-site	(2)	___
b. Telephone or radio within 3 miles	(1)	___
c. No communications	(0)	___
3. Accident Prevention and Safety		
a. Periodic training given, equipment provided with safety features, first aid readily available on site	(2)	___
b. Periodic training given, equipment provided with safety features, first aid available within 3 miles of site	(1)	___
c. No training, no first aid available	(0)	___
d. Unsafe equipment and/or practices	(-5)	___
4. Fire Protection		
a. Adequate water supply, local fire company available on call, open burning prohibited	(3)	___
b. Poor fire protection, open burning prohibited	(2)	___
c. No fire protection, open burning allowed	(0)	___
5. Parking Facilities and Access Road Conditions		
a. All weather, adequate parking	(3)	___
b. All weather, inadequate parking	(2)	___
c. Negotiable only in good weather	(0)	___

[a]Indicates points to be assigned if condition is met.

TABLE A-1. LAND DISPOSAL EVALUATION SHEET (Continued)

	Points Possible	Site
B. OPERATIONAL FACTORS		
1. Weighing Facilities		
a. Fixed or portable scales available on-site	(2)	___
b. Scale available near site	(1)	___
c. No weighing facilities nearby	(0)	___
2. Access Limited		
a. Access by unauthorized vehicles and pedestrians prohibited and prevented	(3)	___
b. Access prohibited except during day	(2)	___
c. Uncontrolled access to site	(0)	___
3. Solid Waste Unloading Control		
a. Controlled, area restricted	(2)	___
b. Controlled, area unrestricted	(1)	___
c. No control	(0)	___
4. Working Area		
a. Size of working area small, but adequate for peak traffic	(2)	___
b. Working area larger than necessary to handle traffic	(1)	___
c. Much larger working area than necessary and/or uncontrolled dumping	(0)	___
5. Waste Spreading and Compacting		
a. Refuse spread evenly and adequately compacted	(5)	___
b. Refuse spread, but not compacted	(2)	___
c. No spreading or compacting	(0)	___
6. Depth of Waste		
a. If waste compacted in cells of 8 ft depth or less	(5)	___
b. If waste compacted in cells less than 12 ft depth but more than 8 ft	(2)	___
c. If uncompacted or cells greater than 12 ft deep		

TABLE A-1. LAND DISPOSAL EVALUATION SHEET (Continued)

	Points Possible	Site
7. Daily Earth Cover		
a. If cover material is of good quality and is compacted in unbroken layers no less than 6 inches deep	(20)	____
b. If cover material is of poor quality, but is compacted well	(15)	____
c. If cover is not earth material (e.g., incinerator ash) but is greater than 6 inches thick	(10)	____
d. No cover provided	(0)	____
8. Intermediate Cover		
a. One foot or greater thick, good quality	(4)	____
b. One foot or greater thick, poorer quality	(3)	____
c. One foot or greater thick, not soil	(1)	____
d. No intermediate cover or, if so, poor application	(0)	____
9. Final Cover and Grading		
a. Minimum depth - 2 ft good soil and grading	(8)	____
b. Minimum depth - 2 ft poor soil and grading	(5)	____
c. No final cover, or poorly constructed and poorly graded	(0)	____
10. Equipment Maintenance		
a. Maintenance facilities available on-site or standby equipment ready	(2)	____
b. Routine maintenance equipment available, service arrangements made for major repairs	(1)	____
c. Nonexistent or inadequate maintenance facilities available	(0)	____
11. Hazardous, Liquid, and Bulky Waste Handling Provisions		
a. Procedures adopted for handling hazardous, liquid and bulky products	(4)	____
b. Hazardous and liquid wastes excluded from site	(1)	____
c. Such materials accepted without special handling provisions	(0)	____

TABLE A-1. LAND DISPOSAL EVALUATION SHEET (Continued)

	Points Possible	Site
12. Record Systems		
a. Complete daily records maintained e.g., type of waste, location of deposition, total weight, number of vehicles served	(3)	___
b. Inadequate records kept	(1)	___
c. No records maintained	(0)	___
C. ENVIRONMENTAL FACTORS		
1. Blowing Litter		
a. Fences or other barriers control blowing litter	(4)	___
b. Some litter control exercised, but results poor	(2)	___
c. No controls established	(0)	___
2. Burning		
a. No burning allowed any time	(3)	___
b. Burning allowed	(0)	___
3. Salvage		
a. No salvage at disposal site proper	(3)	___
b. Controlled salvage practiced	(1)	___
c. Scavenging allowed	(0)	___
4. Vector Control		
a. Not practiced because unnecessary	(2)	___
b. Proper vector control supplied	(1)	___
c. Vectors (rats, flies, etc.) present, but no control	(0)	___
5. Dust Control		
a. Not required, or suitable control measures are supplied	(2)	___
b. Control provided, but inadequate	(1)	___
c. Necessary, but not provided	(0)	___

TABLE A-1. LAND DISPOSAL EVALUATION SHEET (Concluded)

	Points Possible	Site
6. Placement of Solid Wastes in Groundwater		
a. Refuse placement above high groundwater mark	(5)	___
b. Intermittent contact possible	(3)	___
c. Refuse deposited in water	(0)	___
7. Surface Drainage		
a. Surface waters diverted from fill area; no ponding present	(6)	___
b. Occasional water runs onto surface	(4)	___
c. No surface water control, cover scouring and erosion	(0)	___
8. Animal Feeding		
a. No animal feeding allowed, fencing provided to prohibit animals	(2)	___
b. Animal feeding allowed	(0)	___
GRAND TOTAL		[a]

a. Score of 85 is rated acceptable by EPA
Score of 70-85 is rated marginally acceptable
Score of 55-70 is rated minimally acceptable
Score less than 55 is rated unacceptable

APPENDIX B

TABLES AND FIGURES ON PRODUCTIVITY, COST COMPARISON AND EQUIPMENT SELECTION NEEDS

TABLE B-1. BEST KNOWN PRODUCTIVITY PERFORMANCE IN 11 RESIDENTIAL SOLID WASTE COLLECTION SYSTEMS [a]

Level of Service	Type of Operation			Productivity Performance Measures				
By: Point of Collection/ Frequency of Collection	Crew Size	Method	Incentive	Tons Collected/Crew Collection Hour	Households Served/Crew Collection Hour	$/Ton Collected	$/Stop	People Served/ Truck/ Week
	1	1-side	Task	2.2	100.9	8.44	0.19	7763
Curb or Alley	1	1-side	8-hr	1.9	54.7	8.75	0.29	4344
Once-a-week	2	1-side	Task	2.1	109.6	11.82	0.22	7517
	2	1-side	8-hr	3.0	118.2	8.29	0.21	9615
	3	2-sides	8-hr	1.7	63.7	18.93	0.51	4150
	3	2-sides	Task	3.8	99.2	10.34	0.38	7060
	1	1-side	Task	1.3	88.5	12.71	0.38	3636
Curb or Alley	2	1-side	Task	-	-	18.52	0.29	4607
Twice-a-week	3	2-sides	Task	3.0	199.5	13.65	0.45	6316
Backyard	2	Tote Barrel	Task	1.2	71.7	18.00	0.31	5130
Once-a-week	2	Tote Barrel	8-hr	1.1	43.8	19.72	0.47	3690

a. Measures based on following standardized costs: Wages: Drivers $4.34/hr; Collectors $4.15/hr; Fringe Benefits: 18.3% of wages. Personnel Overhead: 13.1% of wages. Depreciation Period: 5 years. Maintenance: 5.5% of capital cost/annum. Consumables: $0.17/gallon fuel: $0.23/quart oil.

Source: Opportunities for Improving Productivity in Solid Waste Collection, National Commission on Productivity, P. 11, 1973.

TABLE B-2. TIME TO COLLECT FRONT-LOADING BINS

First Bin at Site	2.1 Min.
Subsequent Bins	1.7 Min.

[a] Includes idle time due to spills, excludes travel time, and is for crews on the task incentive (i.e. when their daily tasks are complete and inspected).

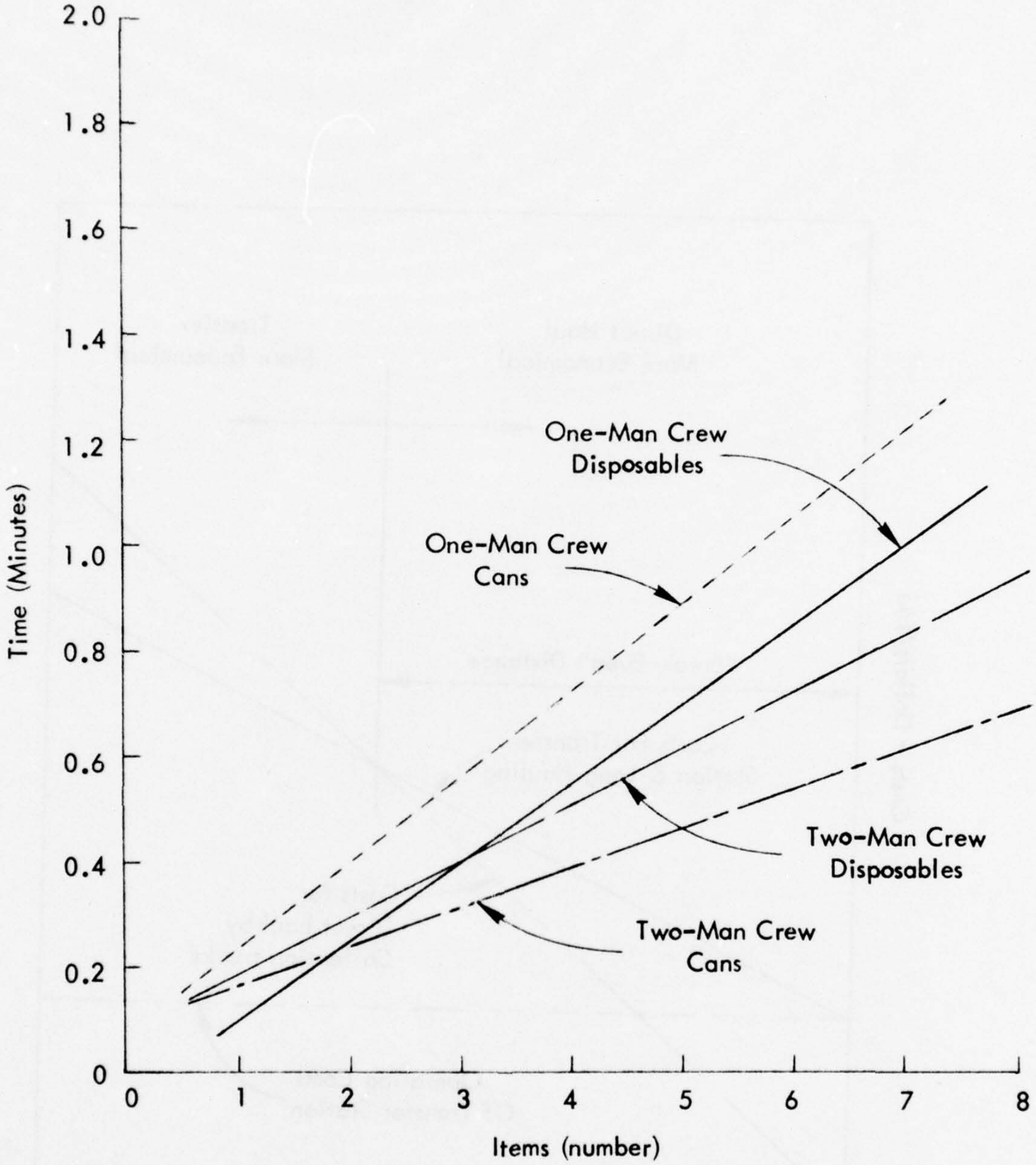
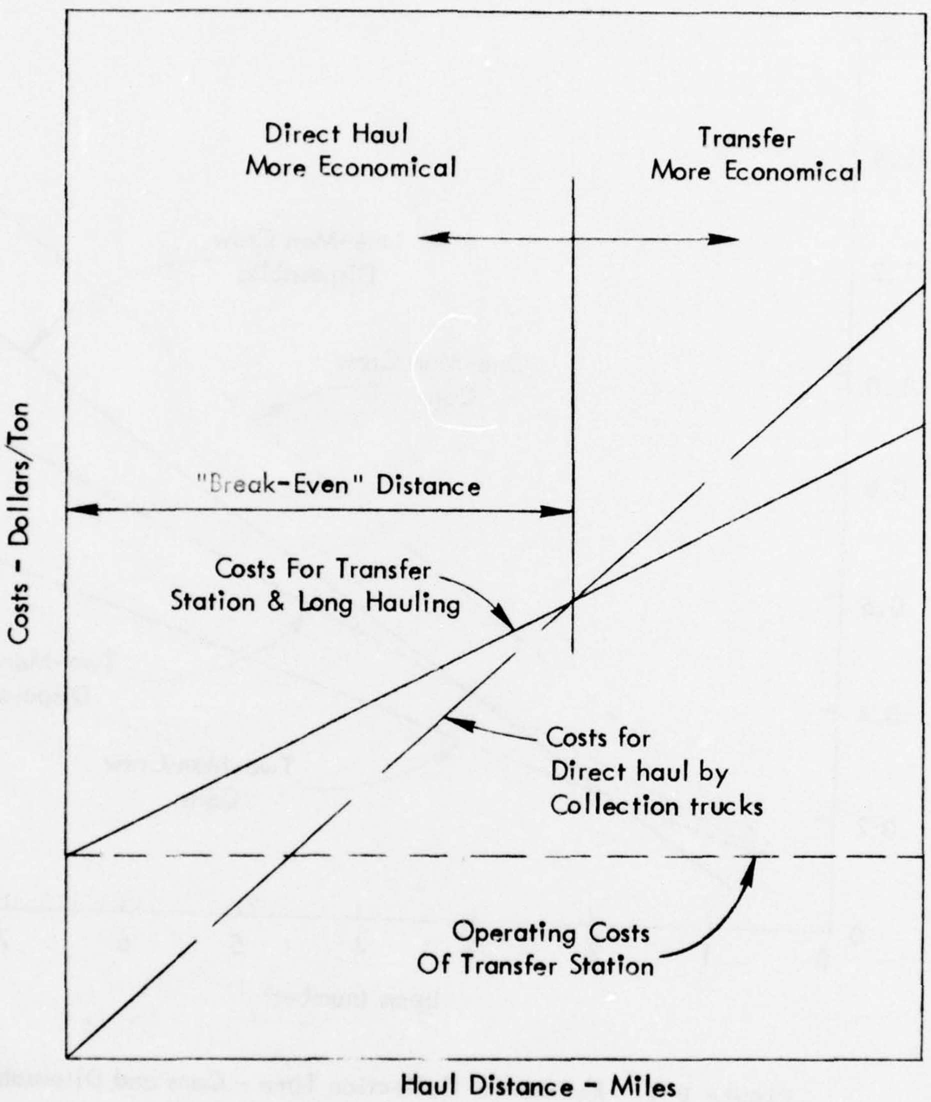
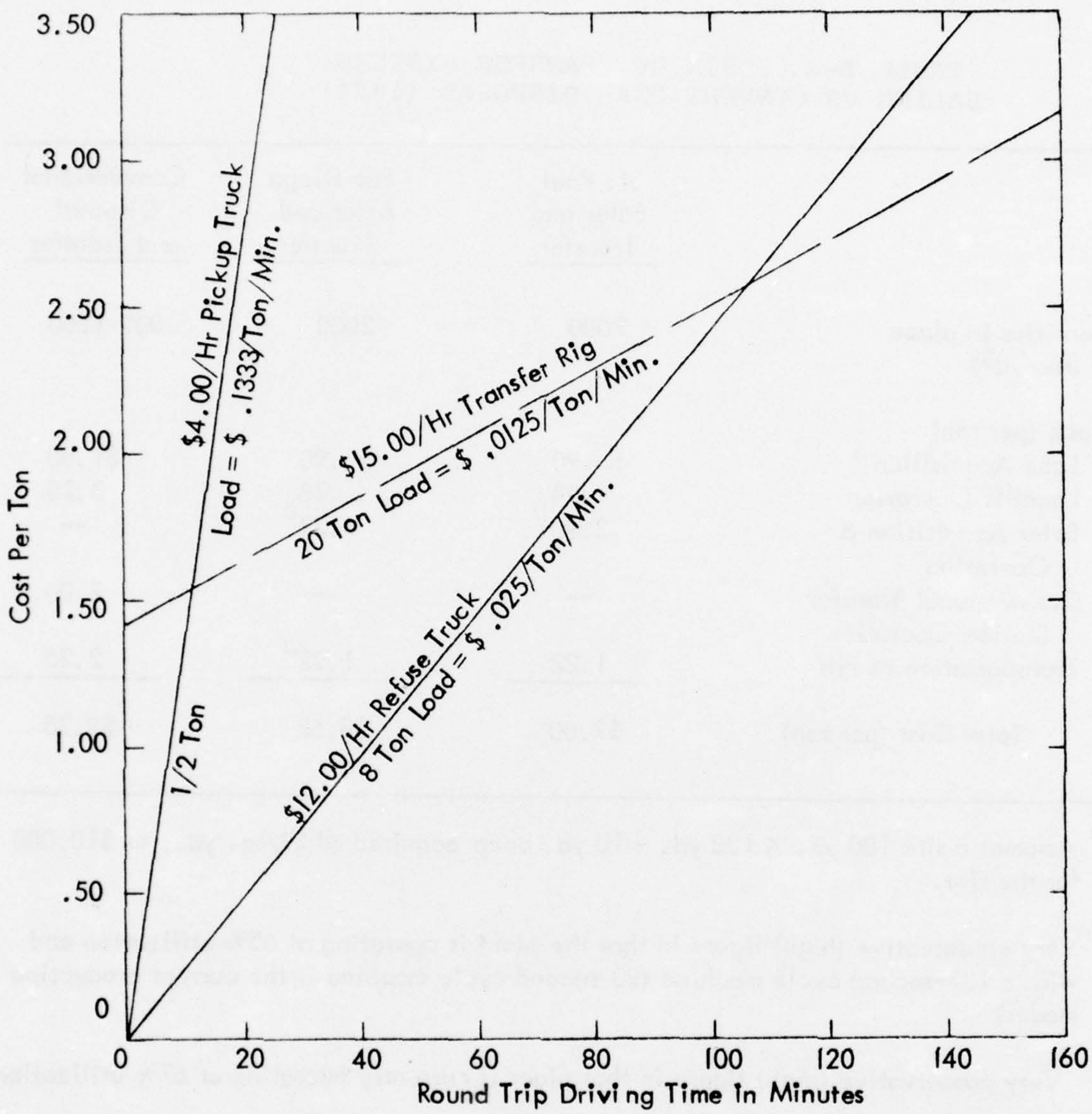


Figure B-1. **Residential Collection Time - Cans and Disposables.**



Source: Hagerty, D. J., et al, Solid Waste Management, Van Nostrand, New York, 1973.

Figure B-2. General Method of Determining the "Break-Even" Distance for Transfer Stations.



Source: Refuse Collection Practicing, Third Edition.
APWA, Committee on Solid Wastes, 1966.

Figure B-3. Cost Comparison: Transfer versus Direct Haul

TABLE B-3. COSTS OF TRANSFER SYSTEMS: BALING VS CONVENTIONAL DISPOSAL (1974)

	St. Paul Baler and Transfer	San Diego Baler and Transfer	Conventional Disposal and Transfer
Densities in place (lbs/yd^3)	2000	2000	800-1200
Costs (per ton)			
Land Acquisition [a]	$ .90	$ .90	$1.80
Landfill Operation	.98	.28	3.20
Baler Acquisition & Operation	3.90 [b]	6.22 [c]	--
Conventional Transfer Station Operation	--	--	2.00
Transportation to Fill	1.22	1.22 [d]	2.25
Total Cost (per ton)	$7.00	$8.62	$9.25

[a] Assumes a site 100 yd. X 100 yd. x 10 yd. deep acquired @ $9/sq. yd., or $10,000 for the site.

[b] Very conservative (high) figure in that the plant is operating at 65% utilization and with a 137-second cycle machine (90-second cycle machine is the current production model)

[c] Very conservative (high) figure in that plant is currently operating at 67% utilization.

[d] No data available--same figures as St. Paul used based on similar densities.

Source: Decision Maker's Guide in Solid Waste Management, Office of Solid Waste Management Programs, U.S.E.P.A., 1974.

TABLE B-4. LANDFILL EQUIPMENT NEEDS

Solid Waste Handled (tons/8 hr)	Flywheel Horsepower	Weight (lb)	Flywheel Horsepower	Weight (lb)	Flywheel Horsepower	Weight (lb)
0-20	70	20,000	80	15,000	100	20,000
20-50	70 to 100	20,000 to 25,000	80 to 110	15,000 to 20,000	100 to 120	20,000 to 22,500
50-130	100 to 130	25,00 to 32,500	110 to 130	20,000 to 25,000	120 to 150	22,500 to 27,500
130-250	150 to 190	32,500 to 45,000	150 to 180	30,000 to 35,000	150 to 190	27,500 to 35,000
250-500	Combination of machines		250 to 280	47,500 to 52,000	Combination of machines	
500-plus						

TABLE B-5. APPLICABILITY OF LANDFILL EQUIPMENT TO SPECIFIC TASKS[a]

Equipment	Solid Waste		Cover Material			
	Spreading	Compacting	Excavating	Spreading	Compacting	Hauling
Crawler dozer	E	G	E	E	G	NA
Crawler loader	G	G	E	G	G	NA
Rubber-tired dozer	E	G	F	G	G	NA
Rubber-tired loader	G	G	F	G	G	NA
Landfill compactor	E	E	P	G	E	NA
Scraper	NA	NA	G	E	NA	E
Dragline	NA	NA	E	F	NA	NA

[a]Basis of evaluation: Easily workable soil and cover material haul distance greater than 1,000 ft.
E = Excellent; G = Good; F = Fair; P = Poor; NA = Not applicable.

Source: Wilcomb, M. J. and H. Hickman, Jr , Sanitary Landfill Design and Operation, U.S.E.P.A. Report, 1972.

APPENDIX C

COMPARISON OF SOLID WASTE SYSTEMS CHARACTERISTICS FOR FOUR AIR FORCE BASES

As indicated in the Introduction, the optimization methodology described in this report was originally applied to four Air Force bases: Kelly Air Force Base (KAFB), Texas; L. G. Hanscom Air Force Base (HAFB), Bedford, Massachusetts; Vandenberg Air Force Base (VAFB), Lompoc, California; and Charleston Air Force Base (CAFB), Charleston, South Carolina. The following selected information resulted from that four-base study and is presented for relative comparisons and sources of reference for other bases conducting comprehensive waste management studies. Not all results of the original study are included here because many parameters are too site/base-specific to be generalized.

SOLID WASTE EMISSION FACTORS

Solid waste emission factors are solid waste generation rates, each expressed in terms of source characteristics (Table C-1). Data on solid waste volume in cubic yards and weight in pounds per week were obtained during the base surveys for typical sources and activities representative of Air Force base functions and operations. Included types are office, commissary, BX, motor pool, aircraft maintenance, sheet metal shop, bowling alley, golf course, and other facilities.

Source characteristics were defined for each base function in terms of readily obtainable source parameters. Source parameters commonly available from normal base records were number of personnel, services performed, dollars of sales, and floor space of facilities. The following parameters were used for the major source groups: residential units; commercial - area in square feet, number of employees, dollars of sales, number of meals served; industrial type activities - number of workers, area in square feet; special type activities - hospitals by number of patients; and street and runway sweeping in square yards.

Presentation of Factors. Emission factors are presented based on weekly weights and volume of waste per defined unit. The tabulated information includes the major base functions normally tested by the Air Force for use in preparing environmental impact reports, designing waste systems for new facilities, as well as evaluating other existing bases. Table C-1 presents the average emission factors and range for the four bases. This data summarizes emission factors and indicates the observed ranges. The factors are derived from actual volumes and either measured or derived weights of storage bins. Thus, only facilities with their own storage containers, not shared with other facilities, were used to establish emission factors for each type of facility.

Evaluation of Factors. Residential emission factors were in close agreement among HAFB, VAFB, and CAFB for single family housing units: 64 to 69 pounds per unit per week. At KAFB, single family housing varied among areas from 89 to 51 pounds per unit according to the rank of personnel residing in the housing areas.

Residential emission factors for multiple family housing varied from 49 to 75 pounds per unit at KAFB and HAFB, respectively. Wide variation can be explained by the difference in rank and the difference in regions. Other bases had no high-density family housing.

Commercial and Industrial Emission Factors Varied Greatly Between Bases. No consistent errors biasing the measurements were noted. Instead, random differences occur among the types of facilities on any one base and between bases. Basic differences are attributable to different building construction, efficiency of each building's occupants, materials handled, and regional differences.

The waste generation per person varies significantly among the defined types of sources. The weight of waste per dollar sales varied among commissaries from 63 pounds per $10,000 sales at HAFB to 233 pounds per $10,000 sales at KAFB. Variations also showed up between sources at Offutt Air Force Base, as reported in a previous study (AFWL TR-73-4, Air Force Base Solid Waste Management Study). These large variations in emission factors makes their application to other bases questionable except for single family residences.

SOLID WASTE DENSITIES

Solid waste densities are presented by types of sources in Table C-2. The basic procedure used to develop densities was to divide weekly weight by weekly volume. There is reasonably close agreement among bases, but the defined types of sources varied in density.

TABLE C-1. SUMMARY OF SOLID WASTE EMISSION FACTORS BY TYPE OF SOURCE

Type of Source	Lbs/1000 sq ft/wk			Cy/1000 sq ft/wk			Other		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
1. Family Housing							Lbs/unit . wk		
a. Single Family							66.7	69	64
b. Multiple Family							56.3	76	48.6
2. Dorms	16.95	22.5	11.4	0.42	0.9	0.2			
							Cu yd/$10,000 sales		
3. BX	244.5	451.5	37.5				3.3	7.5	0.004
							Lbs/$10,000 sales		
4. Commissary	568.6	850	344	1.7	4.3	0.2	128.06	232.7	62.9
							Cu yd/$10,000 sales		
5. Food Service	261.3	645.6	26.5	2.34	4.76	0.8	6.53	16.0	0.004
6. Service Stations	278.6	359.0	181.3	3.5	4.5	2.3			
7. Offices	36.3	51.6	25.4	0.8	1.3	0.3			
8. Warehouses	36.5	92.8	4.8	.5	1.5	0.03			
9. Hospitals	101.5	140	37.6	1.0	1.29	0.5	Lbs/patient		
							2.6	4.8	0.08
10. Laboratories	125.2	245.3	5.1	0.3	0.52	0.06			
11. Utilities	448.9	HAFB only		0.9	1.6	0.2			
12. Roads & Grounds	0.49	1.02	0.14	0.11[a]	--	--			
13. Recreation	93.4	131.0	68.8	0.9	3.4	0.1			

[a]Only Charleston AFB.

TABLE C-1. SUMMARY OF SOLID WASTE EMISSION FACTORS BY TYPE OF SOURCE (Concluded)

Type of Source	Lbs/1000 sq ft/wk			Cy/1000 sq ft/wk			Other		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
14. Aircraft Support									
a. Flightline	19.3[a]	27.1[a]	14.1[a]	0.27	1.1	0.02			
b. Shops	34.2[a]	60.4[a]	0.5[a]	0.54	1.4	0.08			
15. Motor Vehicle Support	93.9	208.6	17.7	0.5	1.5	0.05			
16. Radar & Range	54	VAFB only		0.65	0.6	0.7			
17. Industry	16.1	KAFB only		0.26	KAFB only				
18. Computer	169.0	KAFB only		1.16	1.6	0.9			
19. CE Shops	344.1	677.2	13.2	2.5	4.5	0.08			
20. Other:									
Chapel	40.9	77.0	4.8	0.4	0.93	0.03			

[a] Kelly and Hanscom AFBs.

TABLE C-2. SOLID WASTE DENSITY RANGES

Type of Source	Density (lb/cu yd) Average	Maximum	Minimum	Type of Source	Density (lb/cu yd) Average	Maximum	Minimum
1. Family Housing				12. Roads & Grounds[a]	102	--	--
a. Single Family	143	151	138	13. Recreation	87	157	23
b. Multiple Family	117	139	94	14. Aircraft Support			
2. Dorms/Barracks	27	72	6	a. Hangers	100	188	65
3. BX	29	40	10	b. Shops & Overhaul	80	133	7
4. Commissary	81	101	61	15. Motor Vehicle Support	100	150	63
5. Food Service	95	267	28	16. Radar and Range[b]	76	80	72
6. Service Stations	73	80	66	17. Industry[a]	61	--	--
7. Offices	79	158	30	18. Computer[a]	103	--	--
8. Warehouses	77	153	29	19. Other			
9. Hospitals	85	117	63	a. C. E. Shops	104	150	55
				b. Chapel	133	183	83
10. Laboratories	83	120	59	c. Printing Office[a]	105	--	--
				d. P.O.L.	40	--	--
11. Utilities	93	120	64	e. School	94	96	92

[a]One building, one base.

[b]One base, two buildings.

Waste Composition. Table C-3 presents overall waste composition for residential, commercial, industrial, and roads and grounds. The table summarizes data presented in the four base reports. Differences are expected due to the same local conditions that affect the emission factors. The variation in residential solid waste is apparent. Care is needed when applying emission data to new locations since generation data seem to be only partially transferable due to climatic, technical activity, and other local variations.

PRODUCTIVITY

A number of time and dollar measures of productivity exist. While these measures are only superficial descriptions, their emphasis on labor time and dollar costs make them the main interest of management. They present information on present efficiency and give activities needing future improvement.

Residential Collection Productivity. Residential productivity is presented in Table C-4. On the four bases different types of collection have been described, and two municipal system productivities are also presented. Containers per stop and pounds per stop are given and basis for comparing the systems listed in the table. The collection methodology at the areas were generally similar. One difference is due to the fact that the Air Force bases and municipality number one collect twice a week, while municipality number two collects once a week. The Air Force base collection systems are relatively expensive and have low productivity. This results from backyard collection, the twice-a-week collection frequency, and lack of incentives.

Front Loading Collection. Table C-5 presents productivity for front loading units. The high man-minutes per ton at Kelly and Vandenberg Air Force Bases stem largely from three factors: (1) The use of two-man crews, (2) the lack of task incentive systems, and (3) the condition of the collection equipment and the old storage bins. Conversely, the contractor at Charleston Air Force Base used newer bins, employed one-man collection crews, and provided a work task incentive by allowing the workers to leave when finished.

Hoist Bin Collection. Table C-5 presents productivity measures for hoist bin collection. Travel time is not included so that measured operations are uniform at the bases. The collection cost per ton is for all hoist collection operations. A major conclusion is that hoist collection costs were uniformly greater than alternative front-loading collection.

TABLE C-3. SOLID WASTE WEIGHT COMPOSITION SUMMARY FOR FOUR BASES
(Percent by weight)

	Corrugated			Other Paper			Ferrous			Aluminum			Other Nonferrous			Wood		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Residential	9.2	19.1	0.7	35.1	55.7	18.5	8.3	12.6	1.8	0.45	0.9	0	8.1	32.3	0	1.1	1.7	0
Commercial	26.3	34.8	20.5	41.3	66.9	27.6	5.5	7.3	2.4	0.6	1.2	0.1	4.2	16.8	0	6.6	18.4	0.9
Industrial	22.5	37.3	15.0	42.0	49.5	33.2	15.7	42.2	3.4	0.47	2.8	0	0.6	2.4	0	10.5	35.7	1.5

	Clear			Glass Green			Brown			Textiles			Plastics			Rubber		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Residential	3.3	4.4	0	0.8	2.9	0	0.08	0.3	0	2.25	4.9	0.5	12.6	21.8	8.8	0.6	1.8	0
Commercial	1.5	2.5	0.4	0.1	0.5	0	1.75	5.3	0	0.75	2.1	0.1	1.8	3.1	1.1	1.0	1.8	0
Industrial	0.1	0.3	0	0.25	1.0	0	0	0	0	2.8	8.3	0	2.5	5.3	0.8	1.6	2.7	0

	Leather			Food			Lawn and Light Trimmings			Wood and Heavy Trimmings			Other		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Residential	0.08	0.3	0	10.5	15.8	7.5	3.9	8.2	0	1.8	3.7	0	0.05	0.2	0
Commercial	1.5	5.3	0	1.8	4.4	0.1	0.4	1.8	0	0	0	0	4.7	18.2	0
Industrial	0	0	0	0.6	1.2	0.1	0	0	0	0	0	0	0.06	0.25	0

TABLE C-4. COMPARISON OF COLLECTION PRODUCTIVITY AND COST

Productivity Item	Air Force Base				
	KAFB	CAFB	VAFB	HAFB	Municipal
Residential[a] (man-min./ton)					
Backyard	186	80	98	96	--
Curbside	83	--[b]	--	--	38
Cost ($/ton)					
Backyard	117.40	20.30	24.78	37.00	--
Curbside	117.40	--	--	--	13.48
Front Loading Bin (man-min./ton)	50	7.7	22	None	None
Cost ($/ton)	14.42	50.17[c]	26.43	--	--
Rear Hoist Bin (man-min./ton)	20.5	None	16.9	24.0	None
Cost ($/ton)	35.84	None	43.8	28.11	None

[a] G.I. cans.

[b] Indicates this method not used.

[c] Based on the contract cost.

TABLE C-5. BIN COLLECTION PRODUCTIVITIES

Base	Front Loading		Hoist		
			Man-Min/ton		
	Man-Min/ton[a]	$/ton	Excl.Haul[b]	Incl.Haul[c]	$/ton
Kelly	50	14.42	4.9	20.5	35.84
Charleston	7.70	50.17[d]	--	--	--
Vandenberg	220	26.43	6.3	16.9	43.80
Hanscom	--	--	7.7	24.0	28.11

[a] Excludes time hauling to/from disposal site, downtime, idle.

[b] Excludes time hauling to/from disposal site downtime and breaks.

[c] Excludes time for downtime and breaks.

[d] This high cost is found by dividing the annual contract cost for commercial/industrial service by the number of tons collected per year, and so it includes storage container waste.

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INITIAL DISTRIBUTION

HQ USAF/PREE	1	Defense Resch & Engrg/AD(E&LS)	1
HQ USAF/PREV-P	1	OASD/(I&L)ES	1
HQ USAF/PREV-X	1	Ch of Engrg/ENGMC-RD	1
HQ USAF/RDPS	2	USA WW Exp Sta	1
HQ USAF/SAFOI	1	AFRCE/Eastern Region	1
HQ COMD USAF/DEE	1	AFRCE/Central Region	1
CINCAD/DEV	1	AFRCE/Western Region	1
CINCAD/DEECV	1	Environ Protection Div, OP-45	1
AFCS/DEEE	1	NCEL, Code 25111	1
AFLC/DEPV	1	Nav Ship R&D Ctr (Code 3021)	1
AFLC/MAUT	1	Univ of New Mexico	1
AFSC/DE	1	Tech Transfer Staff (EPA)	1
AFSC/DEV	1	Office of R&D (EPA)	1
AFSC/SGB	1	National Science Foundation	1
ATC/DEPV	1	SGRD-UBG	1
AAC/DEV	1	AFCEC/SUL	1
MAC/DEEE	1	AFCEC/EV	7
MAC/DEMP	1	USA CERL	1
CINCPACAF/DEMU	2	USA Eng R&D Lab/MERDC	1
CINCSAC/DEPV	1	DARD/ARE-E	1
TAC/DE	1	5010 CSG/DE	1
USAFSS/DEE	1	21 ABG/DE	1
TAC/DEEV	1	5073 ABG/DE	1
USAFSS/DEMM	1	46 ADW/DE	1
CINCUSAFE/DEPV	2	4756 ABG/DE	1
AFISC/SES	2	USAFA/DE	1
AFRES/DEEE	1	AFAFC/DE	1
USAFA/DEV	1	3800 ABS/DE	1
3800 ABW/DEE	1	3345 ABG/DE	1
AFIT/DEM	1	14 ABG/DE	1
AU/LDG	1	29 ABG/DE	1
AUL	1	3380 ABG/DE	1
AFOSR	1	3700 ABG/DE	1
AFML/DO	1	47 ABG/DE	1
OEHL/CC	1	3415 ABG/DE	1
OEHL/OL-AA	1	323 ABG/DE	1
OEHL/OL-AB	1	347 CSG/DE	1
AFWL/SUL	1	12 ABG/DE	1
AFGL/XOP	1	64 ABG/DE	1
AFRPL/Library	1	3750 ABG/DE	1
RADC/DOT	1	71 ABG/DE	1
AEDC/DEE	1	78 ABG/DE	1
SAMSO/DEC	1	82 ABG/DE	1
ADTC/DLOSL	2	1840 ABG/DE	1
DDC/TCA	12	508 CSS/DE	1
USAFSO/DEE	1	2851 ABG/DE	1

2852 AFB/DE	1
5 Combat Comm Gp/DE	1
2854 ABG/DE	1
2750 ABW/DE	1
4960 ABS/DE	1
6570 ABG/DE	1
6510 ABG/DE	1
3201 ABG/DE	1
4900 ABW/DE	1
3245 ABG/DE	1
6550 ABG/DE	1
1 ABW/DE	1
1100 ABW/DE	1
443 ABG/DE	1
437 ABG/DE	1
314 CSG/DE	1
62 ABG/DE	1
438 ABG/DE	1
63 ABG/DE	1
317 CSG/DE	1
375 ABG/DE	1
349 ABS/DE	1
15 ABW/DE	1
1843 Elect Cngr Sq/DE	1
1978 CG/DE	1
24 CSG/DE	1
43 CSG/DE	1
2 CSG/DE	1
17 CSG/DE	1
97 CSG/DE	1
7 CSG/DE	1
93 CSG/DE	1
803 CSG/DE	1
96 CSG/DE	1
44 CSG/DE	1
90 CSG/DE	1
92 CSG/DE	1
321 CSG/DE	1
416 CSG/DE	1
410 CSG/DE	1
449 CSG/DE	1
42 CSG/DE	1
341 CSG/DE	1
452 CSG/DE	1
381 CSG/DE	1
91 CSG/DE	1
3902 ABW/DE	1
509 CSG/DE	1
380 CSG/DE	1
301 CSG/DE	1
4392 ASG/DE	1
351 CSG/DE	1
379 CSG/DE	1
56 CSS/DE	1
67 CSG/DE	1
27 CSG/DE	1
23 CSG/DE	1
35 CSG/DE	1
58 CSG/DE	1
49 CSG/DE	1
31 CSG/DE	1
57 CSS/DE	1
4500 ABW/DE	1
58 CSG/DE	1
56 CSG/DE	1
366 CSG/DE	1
354 CSG/DE	1
57 CSG/DE	1
4 CSG/DE	1
363 CSG/DE	1
6940 ABG/DE	1
AFCEC/SU	1
436 ABG/DE	1