The Economics of Transporting Solid Wastes

A. ESSAM RADWAN and K. DAVID PIJAWKA

ABSTRACT

The problems associated with the management of solid wastes in today's society are complex and challenging. Transportation of solid waste is an important component of the management system. In this paper an attempt is made to identify the various economic components of transporting solid wastes. A methodology for justifying the construction of transfer stations is suggested, and the impacts of population growth and distance to landfill on the economics of transfer stations are evaluated. The analysis concludes that the location of the transfer station with respect to the waste generators and the landfill has a direct and significant impact on the economic analysis and a detailed approach to the problem is strongly recommended. It is also concluded that the cost saving due to constructing a transfer station increases with the increase in distance between the waste generators and the landfill--a break-even point was observed at around 10 mi. Finally, it was observed that should the population of generators increase unexpectedly, the cost saving would increase.

Solid wastes are wastes that arise from human and animal activities and that are normally solid and discarded as useless or unwanted products. They encompass the heterogeneous accumulations of agricultural, industrial, and mineral wastes. The accumulation of solid wastes is a direct consequence of life, and the management of these wastes is a monumental task.

The problems associated with the management of solid wastes in today's society are complex because of the diverse nature of the wastes and the development of sprawling urban areas. Two critical activities associated with the management of solid wastes from the point of generation to final disposal have been identified: collection, and transfer and transport.

The functional element of collection, generally, includes the gathering of solid wastes and the hauling of these wastes to a location where the collection vehicle is emptied. This location may be a transfer station, a processing station, or a landfill disposal site. Collection accounts for close to 80 percent of the total annual cost of urban solid waste management (1). The functional element of transfer and transport involves the transfer of wastes from the smaller collection vehicle to larger transport equipment and the subsequent transport of the wastes over long distances to the disposal site. In small cities where the final disposal sites are nearby, the hauling of wastes is not a serious problem. In large cities, however, where the haul to the point of disposal is long, the haul may have serious economic implications. The solution to the problem of long-distance hauling is complicated because the motor vehicles that are well adapted to long-distance hauling are not well suited or particularly economical for house-to-house collection. Consequently, supplemental transfer and transport facilities and equipment are needed.

In this paper an attempt is made to identify the various economic components of transporting solid wastes, a methodology for justifying transfer stations is suggested, and the impacts of population growth and the distance to landfill on the economics of transfer stations are evaluated.

A.E. Radwan, Center for Advanced Research in Transportation, Arizona State University, Tempe, Ariz. 85287. K.D. Pijawka, Center for Environmental Studies, Arizona State University, Tempe, Ariz. 85287.

BACKGROUND INFORMATION

Transfer and transport operations become a necessity when haul distances to available disposal sites or processing centers increase to the point that direct hauling is no longer economically feasible. Transfer stations are used to accomplish the removal and transfer of solid wastes from collection and other small vehicles to long-haul transport equipment. Transfer stations may be classified with respect to rate as follows: small, less than 100 tons per day; medium, between 100 and 500 tons per day; and large, more than 500 tons per day. Factors to be considered in the design of transfer stations include type of transfer operation, capacity requirements, equipment requirements, and sanitation requirements (1).

A typical large-capacity transfer station is composed of collection vehicle unloading area, storage pit, platform scales, stationary hydraulic clamshell, auxiliary equipment (cranes and bulldozers), and transfer vehicles. All incoming collection trucks are routed to the platform scales where each truck is weighed. Then the contents of the vehicle are emptied into the storage pit. Bulldozers are used to crush uncompacted wastes and move them through the pit to the loading hoppers. Articulated cranes are used to distribute the load in the transfer vehicles before the vehicles leave their loading position (2).

Transfer stations should be located as close as possible to the weighted center of the individual solid waste production areas to be served, within easy access to major highway routes, and where construction and operation are most economical.

A recent survey, performed jointly by Waste Age and the Association of State and Territorial Solid Waste Management Officials, of 1,278 transfer stations in 42 states reported that only 70 handled more than 300 tons per day (3). Of the total identified transfer stations, the following breakdowns by type were available:

- Enclosed stations with compaction: 396
- Enclosed stations, no compaction: 56
- Open stations with compaction: 103
- Open stations, no compaction: 291

Reports from different cities have revealed small to moderate savings due to the use of transfer stations. In Tucson, Arizona, city administrators claim that their transfer facilities net up to $185,000 per year in direct operating and maintenance savings (4). In Chicago, Illinois, a 900-ton per day transfer station, operated by a private company, reported a successful story. Larry Groot, the owner of C. Groot Disposal, concluded that the direct return on a transfer station investment may be small. However, the indirect benefits should flow in a wide and profitable stream (5). Other reports from Hempstead, New York, Tampa, Florida, and Montgomery County, Maryland, indicated that a well-designed and managed facility could result in a profitable operation (6-8). The question that remains unanswered at this juncture is: At what level of long-haul distance and solid waste generation rate may a transfer station be justifiable? This study will attempt to answer that question.

FEASIBILITY OF TRANSFER STATIONS

In this section, an incremental economic analysis is presented to evaluate the feasibility of transfer stations. Five major components of the economic analysis were identified, and the proposed analysis was applied to five localities within the Phoenix metropolitan area in Arizona.

The five major components of the economic analysis include:

1. Transportation costs without a transfer station from the waste generation area to the candidate landfill site;
2. Transportation costs with one transfer station from the local waste generators to the transfer station; these are called short-haul costs;
3. Transportation costs with a transfer station from the transfer station to the candidate landfill; these are called long-haul costs;
4. Capital costs for constructing the facility; and
5. Operation and maintenance costs of the transfer station.

Transportation Costs Without a Transfer Station

A review of the literature related to collection trucks showed that their capacity ranges between 6 and 45 yd^3 per loading. For this study, it was assumed that the average truck has a hauling capacity of 35 yd^3 at a waste compaction rate of 1,000 lb per cubic yard. The average number of trips per year was calculated from

No. of trips per year = (total tonnage x 2,000)/(1,000 x 35)

Trip mileage to a candidate site was measured from the center of each locality to the landfill site. Multiplication of number of trips per year times trip length gave the average annual mileage for any given landfill site. A cost per mile factor of $3.91 was used to calculate the annual transportation cost from the average annual mileage. This cost per mile factor was determined on the basis of data collected in Phoenix, Arizona, and the following assumptions:

- A typical collection truck costs $80,000 and has a life mileage of 65,000 mi; the replacement cost, therefore, amounts to $1.23 per mile;
- Collection trucks travel at an average speed of 30 mph, and an average operator wage of $12.40 per hour amounts to $0.41 per mile; and
- A typical collection truck costs around $2.27 per mile in operation and maintenance.

Although the $3.91 per mile cost rate includes replacement costs, it does not include the collection down time for waste trucks while they are traveling to a distant landfill. A separate analysis was conducted to estimate the annual cost for down time using the following assumptions:

- 250 working days per year;
- 20-min loading and unloading period;
- 8 working hours per day with 3 hr covering the peak period;
- Average running speed of 30 mph; and
- The cost per mile rate increases by an inflation rate of 6 percent annually, and capitalization was financed at 8 percent over a 30-year period.

Short-Haul Transportation Costs

Short-haul transportation represents the transportation of solid waste from the generation area to the transfer station. The assumptions made for the transportation cost without a transfer station were applied to the short-haul analysis. The only difference is that short-haul movements have relatively shorter hauling distance than does direct haul from the collection area to landfills. It is critical to locate transfer stations at strategic sites close to major waste generators to minimize the total short-haul transportation cost.

Long-Haul Transportation Costs

Long-haul transportation represents the transportation of compacted waste from the transfer station to the landfill using appropriate transfer trucks. The following assumptions were made for this analysis:

- Transfer trucks, of 72 yd^3, are used, each at a cost of $110,000 and with a life mileage of 65,000 mi;
- Waste is compacted at a rate of 1,000 lb per cubic yard;
- Because transfer trucks travel mostly on highways, their maintenance and fuel consumption cost is significantly lower per unit traveled than is that of collection pick-up waste trucks; a cost rate of $2.00 per mile was used for replacement, labor, and maintenance of trucks; and
- An inflation rate of 6 percent and an interest rate of 8 percent were used over the 30-year analysis period.

Capital Costs of Transfer Stations

The capital cost of a transfer station generally consists of four components: (a) land cost, (b) building cost and other related components, (c) in-station equipment, and (d) transfer trucks. The land cost is assumed to be $50,000 per acre, and the area needed is a function of the daily activities of the station. The second cost category includes administration building, scale, scale house, storage pit, transfer building, earthwork, landscaping, paving, fencing, insurance, and contingency. In-station

TABLE 1 Capital Cost ($000s) Categories for Six Levels of Facility Output

	Facility Output (TPD) of					
	600	1,100	1,400	1,800	2,200	3,200
Building and other costs	2,500	2,500	2,500	3,500	3,500	7,000
Land cost	500	750	750	1,000	1,000	1,000
In-station equipment cost	120[a]	160	160	160	320	320

Source: Information provided by the Sanitation Divisions of the cities of Phoenix and Glendale.

[a]Two bulldozers and one crane at $40,000 each.

equipment includes bulldozers and cranes, and the number of these is also a function of the ton per day (TPD) rating of the station. Table 1 gives the first three capital cost categories as a function of six levels of TPD (600, 1,100, 1,400, 1,800, 2,200, and 3,200).

For the fleet size determination, the following assumptions were made:

- 250 working days per year, 20 percent for peak day higher than the average day, and 3 peak hours per day and
- Average operating speed of 35 mph.

Cost of Transfer Station Operation and Maintenance

The cost of operating and maintaining a typical transfer facility normally includes the following items:

- Labor costs for crane operators, bulldozer operators, scale operators, clerks, and supervisors;
- Maintenance and parts;
- Fuel and oil;
- Utilities;
- Building and site maintenance;
- Insurance; and
- Contingency.

The cost of operation and maintenance is a direct function of the total TPD. Surveying transfer stations currently in operation and making appropriate assumptions resulted in operating costs of $480,000, $750,000, $800,000, $900,000, $1,140,000, and $1,440,000 for the same six TPD levels listed in Table 1 (namely: 600, 1,100, 1,400, 1,800, 2,200, and 3,200 TPD). These estimates were developed using personnel costs and other information provided by the Sanitation Divisions of the cities of Phoenix and Glendale, Arizona.

Application of Model to Arizona Sites

A feasibility study for constructing a transfer station to serve five localities in Arizona (El Mirage, Surprise, Peoria, Youngtown, and rural county) was conducted. These localities are located within the Phoenix metropolitan area.

The first step in the analysis was to develop waste projections for the five localities. The 1980 Maricopa Association of Government (MAG) projections on waste generation for Maricopa County were used to develop population projections and waste projections (Table 2). These projections were based on a generation rate of 4.10 lb per capita per day increasing annually at a rate of 0.10 lb per capita per day until reaching 6.10 lb per capita per day.

For purposes of the study, two sites were considered for constructing a transfer station. The

TABLE 2 Population Projections and Waste Production

Year	El Mirage	Surprise	Peoria	Youngtown	Rural[a]	Total
Population						
1985	6,050	5,670	23,480	2,310	51,110	88,620
1990	8,390	7,600	35,740	2,400	62,420	116,550
1995	10,540	9,380	51,270	2,500	73,840	147,530
2000	12,900	11,430	71,230	2,500	82,940	181,000
2005	15,050	13,420	92,620	2,500	90,990	214,580
2010	17,420	15,350	117,100	2,500	99,500	251,870
2015	20,240	17,170	146,430	2,500	109,400	295,740
Waste (tons)						
1985	4,527	4,243	17,569	1,728	38,243	66,310
1990	7,043	6,380	30,004	2,015	52,402	97,844
1995	9,810	8,730	47,720	2,327	68,727	137,314
2000	13,184	11,681	72,797	2,555	84,765	168,466
2005	16,754	14,940	103,109	2,783	101,295	199,720
2010	19,393	17,088	130,362	2,783	110,768	280,394
2015	22,532	19,115	163,013	2,783	121,790	329,233

[a]Sun City and Sun City West.

first site (TS 1) is located in El Mirage, and the second site (TS 2) is located in Sun City West. Land cost, zoning constraints, and the location of the landfill were the main criteria used in selecting the sites. Table 3 gives the hauling distances between the collection sites and both the landfill and transfer stations.

TABLE 3 Haul Distances (mi) Between Collection Sites and Both the Landfill and the Transfer Stations

	El Mirage	Surprise	Peoria	Youngtown	Rural
Landfill	14.50	14.00	23.00	17.50	19.00
Transfer station (TS 1)	3.00	3.50	8.50	1.50	4.75
Transfer station (TS 2)	5.25	2.75	4.75	2.75	2.00

Note: TS 1 to landfill = 10.75 mi and TS 2 to landfill = 9.00 mi.

All the costs estimated in the analysis were annualized over a 30-year analysis period (1985-2015) and discounted at 8 percent to present worth. The short-haul transportation cost, long-haul transportation cost, transfer station capital cost, and operating costs were summed using the appropriate economic factors to determine the equivalent discounted annual cost associated with the two station alternatives. The net annual cost, namely the equivalent annual cost without the transfer station minus the equivalent annual cost with the transfer station, was used as the justification measure. It was assumed that the station is designed for the year 2015.

Microcomputer spreadsheet software (LOTUS 123) was used to conduct the analysis. This program permitted a fast and easy assessment of different planning scenarios that will be discussed in the next sections of the paper.

Impact of Station Location

Economic analysis was conducted first for site TS 1. The hauling distances were measured from an approximate location in the center of the locality to either the transfer station or the landfill depending on the cost category. For short haul, as an example, the distance is measured to the transfer station. The results of this analysis are given in Tables 4-6. Table 4 gives the results of the transportation cost without a transfer station. The first line in

TABLE 4 Transportation Cost Without Transfer Station

Year	Item	El Mirage	Surprise	Peoria	Youngtown	Rural	Total
1985	Yd^3/yr	9,053.83	8,485.16	35,137.82	3,456.92	76,486.12	132,620
	Loads/yr	258.68	242.43	1,003.94	98.77	2,185.32	3,789
	Distance (mi)	12.50	12.00	21.00	15.50	17.00	17.39
	Cost ($)	25,286	22,750	164,867	11,972	290,516	515,391
1990	Yd^3/yr	14,086.81	12,760.40	60,007.46	4,029.60	104,803.16	185,637
	Loads/yr	402.48	364.58	1,714.50	115.13	2,994.38	5,591
	Distance (mi)	12.50	12.00	21.00	15.50	17.00	17.55
	Cost ($)	39,342	34,212	281,555	13,955	398,072	767,137
1995	Yd^3/yr	19,620.21	17,460.87	95,439.11	4,653.75	137,453.16	274,627
	Loads/yr	560.58	498.88	2,726.83	132.96	3,927.23	7,846.49
	Distance (mi)	12.50	12.00	21.00	15.50	17.00	17.73
	Cost ($)	54,796	46,815	447,800	16,117	522,086	1,087,615
2000	Yd^3/yr	26,367.60	23,362.92	145,594.12	5,110.00	169,529.36	369,964
	Loads/yr	753.36	667.51	4,159.83	146.00	4,843.70	10.570
	Distance (mi)	12.50	12.00	21.00	15.50	17.00	17.92
	Cost ($)	73,641	62,639	683,128	17,697	643,921	1,481,025
2005	Yd^3/yr	33,508.83	29,879.63	206,218.43	5,566.25	202,589.24	477,762
	Loads/yr	957.40	853.70	5,891.96	159.04	5,788.26	13,650.35
	Distance (mi)	12.50	12.00	21.00	15.50	17.00	18.08
	Cost ($)	93,585	80,112	967,577	19,277	769,492	1,930,042
2010	Yd^{3}yr	38,785.63	34,176.78	260,723.15	5,566.25	221,536.75	560,798.56
	Loads/yr	1,108.16	976.48	7,449.23	159.04	6,329.62	16,022.53
	Distance (mi)	12.50	12.00	21.00	15.50	17.00	18.23
	Cost ($)	108,323	91,633	1,223,313	19,277	641,460	2,284,005
2015	Yd^3/yr	45,064.36	38,229.01	326,026.39	5,566.25	243,579.10	658,465.11
	Loads/yr	1,287.55	1,092.26	9,315.04	159.04	6,959.40	18,813.29
	Distance (mi)	12.50	12.00	21.00	15.50	17.00	18.37
	Cost ($)	125,858	102,497	1,529,716	19,277	925,183	2,702,531

Note:

N	PWF	PW ($)
0	1.000	515,391
5	1.000	3,627,782
10	0.681	3,500,453
15	0.463	3,244.087
20	0.315	2,877,259
25	0.215	2,317,339
30	0.146	1,866,144

Total present worth $17,948,455
Annual transportation cost $1,594,315
Adjustments for down time

Year	RTT	EDS	EHS	EFS	EFS5Y	PW
1990	1.84	7.21	0.90	1.65	0.56	30,394.48
1995	1.85	9.02	1.13	2.08	0.71	24,327.39
2000	1.86	10.90	1.36	2.53	0.87	22,025.18
2005	1.87	12.32	1.54	2.88	1.00	17,204.55
2010	1.88	9.49	1.19	2.23	0.78	9,140.20
2015	1.89	11.16	1.40	2.64	0.93	7,411.57

PW down time cost $112,503
Annual down time cost $9,993

RTT = round-trip time (hr), EDS = extra daily shipment, EHS = extra hourly shipment, EFS = extra fleet size, EFS5Y = extra fleet size over 5 years, PW = present worth, RTT = (one-way distance/30 + 0.33) · 2, EDS (forecast yd^3 - original yd^3/(250 · 35), EHS = EDS/8, EFS = RTT · EHS, and EFS5Y = EFS · (one-way distance · 250 · 5)/65,000.

the table represents the total annual waste in cubic yards taken from Table 2. The second line shows the number of loads per year calculated from line 1 (line 1 divided by 35). The distances shown in the third line are taken from Table 3, and the distance shown under the heading "Total" represents an average weighted distance. This average weighted distance was used only in the down time calculation as will be discussed later. The annual cost was simply calculated by multiplying the number of loads times the distance times $3.91. PWF stands for series present worth factor, and PW is the present worth of cost.

For the adjustments for down time, the round-trip time was calculated knowing the distance (average weighted distance), the speed, and the extra time at either end for loading and unloading. The extra daily shipments (EDS) were calculated for 5-year increments of yearly yardage. For example, the extra daily shipment for 1990 is calculated from the difference between 1990 and 1985 divided by 35 cubic yards per shipment and by 250 working days per year. Furthermore, it was assumed that a typical day contains 8 working hours and that the truck should be replaced every 65,000 miles. These parameters were used to calculate the extra fleet size needed over a 5-year period.

Transfer station capital and operations costs, in dollars, are as follows:

Total yd^3	132,620
Daily peak	8.84
Hourly peak	2.95
Speed (mph)	35
Round trip (mi)	0.64
Fleet size	2
Building cost	2,500,000
Land cost	750,000
In-station equipment	160,000
Trailer cost	206,550
Total capital	3,616,550
Annual cost	321,249

TABLE 5 Transportation Cost with Transfer Station (short haul)

Year	Item	El Mirage	Surprise	Peoria	Youngtown	Rural	Total
1985	Yd^3/yr	9,053.83	8,485.16	35,137.82	3,456.92	76,486.12	132,620
	Loads/yr	258.68	242.43	1,003.94	98.77	2,185.32	3,759
	Distance (mi)	3.00	3.50	8.50	1.50	4.75	5.46
	Cost ($)	6,069	6,635	66,732	1,159	81,174	161,768
1990	Yd^3/yr	14,086.81	12,760.40	60,007.46	4,029.60	104,803.18	195,687
	Loads/yr	402.48	364.58	1,714.50	115.13	2,994.38	5,591
	Distance (mi)	3.00	3.50	8.50	1.50	4.75	5.63
	Cost ($)	9,442	9,979	113,963	1,350	111,226	245,960
1995	Yd^3/yr	19,620.21	17,460.87	95,439.11	4,653.75	137,453.16	274,627
	Loads/yr	560.58	498.88	2,726.83	132.96	3,927.23	7,846.49
	Distance (mi)	3.00	3.50	8.50	1.50	4.75	5.79
	Cost ($)	13,151	13,654	181,252	1,560	145,877	355,495
2000	Yd^3/yr	26,367.60	23,362.92	145,594.12	5,110.00	169,529.36	369,964
	Loads/yr	753.36	667.51	4,159.83	146.00	4,843.70	10,570
	Distance (mi)	3.00	3.50	8.50	1.50	4.75	5.98
	Cost ($)	17,674	18,270	276,504	1,713	179,919	494,079
2005	Yd^3/yr	33,508.83	29,879.63	206,218.43	5,566.25	202,589.24	477,762
	Loads/yr	957.40	853.70	5,891.96	159.04	5,788.26	13,650.35
	Distance (mi)	3.00	3.50	8.50	1.50	4.75	6.13
	Cost ($)	22,460	23,366	391,638	1,865	215,005	654,335
2010	Yd^3yr	38,785.63	34,176.78	260,723.15	5,566.25	221,536.75	560,788.56
	Loads/yr	1,108.16	976.48	7,449.23	159.04	6,329.62	16,022.53
	Distance (mi)	3.00	3.50	8.50	1.50	4.75	6.26
	Cost ($)	25,997	26,726	495,151	1,865	235,114	784,853
2015	Yd^3/yr	45,064.36	38,229.01	326,026.39	5,566.25	243,579.10	658,465.11
	Loads/yr	1,287.55	1,092.26	9,315.04	159.04	6,959.40	18,813.29
	Distance (mi)	3.00	3.50	8.50	1.50	4.75	6.39
	Cost ($)	30,206	29,895	619,171	1,865	258,507	939,644

Note:

N	PWF	PW ($)
0	1.00	161,768
5	1.00	1,163,142
10	0.68	1,144,148
15	0.46	1,082,248
20	0.32	975,467
25	0.21	796,308
30	0.15	648,840

Total present worth $5,971,921
Annual transportation cost $530,470

Adjustments for down time

Year	RTT	EDS	EHS	EFS	EFS5Y	PW
1990	1.03	7.21	0.90	0.93	0.10	5,469.06
1995	1.04	9.02	1.13	1.17	0.13	4,849.67
2000	1.05	10.90	1.36	1.43	0.16	4,156.77
2005	1.07	12.32	1.54	1.64	0.19	3,318.62
2010	1.08	9.49	1.19	1.28	0.15	1,794.62
2015	1.08	11.16	1.40	1.51	0.19	1,477.29

PW down time cost $21,066
Annual down time cost $1,871

For explanation of abbreviations see Table 4.

Operating and maintenance (O&M) costs of the facility are as follows:

Year	Total O&M ($)
1985	480,000
1990	480,000
1995	480,000
2000	480,000
2005	480,000
2010	750,000
2015	750,000

PW of first 15 yr	$4,108,550
PW of second 15 yr	$1,295,187
PW of last payment	$74,533
Total present worth	$5,478,270
Annual O&M cost	$486,621

Cost without transfer station = $1,604,309. Cost with transfer station = $1,578,308. Cost savings = $26,001.

It was concluded from the analysis that a cost saving of around $26,000 can be achieved with site TS 1. The analysis of the second site, TS 2, revealed that the cost savings can amount to $298,800. As expected, the second site is centrally located with respect to the five localities; consequently, the total hauling distance is shorter. Two observations can be made: (a) down time cost is small compared with the transportation cost (Table 3) and (b) the analysis is sensitive to the location of the transfer station. The second observation brings out the need for a refined and detailed approach to determining the optimal location of transfer stations. Such an approach would require detailed data with respect to the collection routes in each locality and more information related to traffic flow in the region.

Impact of Landfill Location

To assess the impact of landfill location on the justification of the transfer station, the analysis

TABLE 6 Transportation Cost with Transfer Station (long haul)

Year	Item	El Mirage	Surprise	Peoria	Youngtown	Rural	Total
1985	Yd^3/yr	9,053.83	8,485.16	35,137.82	3,456.92	76,486.12	132,620
	Loads/yr	125.75	117.85	488.03	48.01	1,062.31	1,842
	Distance (mi)	10.75	10.75	10.75	10.75	10.75	
	Cost ($)	5,407	5,068	20,985	2,065	45,679	79,204
1990	Yd^3/yr	14,086.81	12,760.40	60,007.46	4,029.60	104,803.18	185,687
	Loads/yr	195.65	177.23	833.44	55.97	1,455.60	2,718
	Distance (mi)	10.75	10.75	10.75	10.75	10.75	
	Cost ($)	8,413	7,621	35,838	2,407	62,591	116,869
1995	Yd^3/yr	19,620.21	17,460.87	95,439.11	4,653.75	137,453.16	274,627
	Loads/yr	272.50	242.51	1,325.54	64.64	1,909.07	3,814.27
	Distance (mi)	10.75	10.75	10.75	10.75	10.75	
	Cost ($)	11,718	10,428	56,998	2,779	82,090	164,013
2000	Yd^3/yr	26,367.60	23,362.92	145,594.12	5,110.00	169,529.36	369,964
	Loads/yr	366.22	324.48	2,022.14	70.97	2,354.57	5,138
	Distance (mi)	10.75	10.75	10.75	10.75	10.75	
	Cost ($)	15,747	13,953	86,952	3,052	101,247	220,951
2005	Yd^3/yr	33,508.83	29,879.63	206,218.43	5,566.25	202,589.24	477,762
	Loads/yr	465.40	414.99	2,864.14	77.31	2,813.74	6,635.59
	Distance (mi)	10.75	10.75	10.75	10.75	10.75	
	Cost ($)	20,012	17,845	123,158	3,324	120,991	285,330
2010	Yd^3yr	38,785.63	34,176.78	260,723.15	5,566.25	221,536.75	560,788.56
	Loads/yr	538.69	474.68	3,621.15	77.31	3,076.90	7,788.73
	Distance (mi)	10.75	10.75	10.75	10.75	10.75	
	Cost ($)	23,164	20,411	155,710	3,324	132,307	334,915
2015	Yd^3/yr	45,064.36	38,229.01	326,026.39	5,566.25	243,579.10	658,465.11
	Loads/yr	625.89	530.96	4,528.14	77.31	3,383.04	9,145.35
	Distance (mi)	10.75	10.75	10.75	10.75	10.75	
	Cost ($)	26,913	22,831	194,710	3,324	145,471	393,250

Note:

N	PWF	PW ($)
0	1.00	79,204
5	1.00	552,671
10	0.68	527,872
15	0.46	483,978
20	0.32	425,363
25	0.21	339,803
30	0.15	271,546

Total present worth $2,680,437
Annual transportation cost $238,096.

was repeated assuming different long-haul distances. For site TS 1, the distance between the transfer station and the landfill was increased and decreased on either side of the original value by 1-mi increments. The new distances caused changes in the long-haul transportation cost and the transportation cost without a transfer station, and all other cost items remained essentially unchanged. Table 7 gives the results of this analysis. Closer examination of the results reveals that, as expected, as the landfill moves farther from the transfer station, the net saving increases. A break-even point does exist between distances of 9.75 and 10.75 mi. This is because, as the landfill moves farther away, the total cost without the transfer station increases faster than the increase in the long-haul cost. Furthermore, it is observed that the capital cost increase due to moving farther out. This is due to the increase in down time experienced by transfer trucks. It is interesting to conclude that a break-even distance of about 10 mi exists for this case study.

Impact of Unexpected Population Growth

The last analysis was conducted to evaluate the impact of unexpected population growth. Rural county was assumed to have growth factors of 1.25, 1.50, 1.75, 2.25, and 2.50 with respect to the forecast population as reported by the MAG. It was concluded that, as the population of this locality increases, the cost saving due to constructing a transfer station increases and the results are given in Table 8. The savings are attributed to the sharp increase in the cost without a transfer station. It was assumed that population growth will take place within the existing land use pattern and that the hauling distance from the localities to the landfill will remain essentially unchanged.

SUMMARY AND CONCLUSIONS

A review of the different economic components of transporting solid wastes was attempted. An incre-

TABLE 7 Landfill Location Results—Annual Cost Items ($)

Distance Between Transfer Station and Landfill (mi)	Without Transfer Station	Short Haul	Long Haul	Capital Cost	Operating and Maintenance Cost	With Transfer Station	Cost Saving
7.75	1,334,508	532,341	171,651	318,781	486,621	1,509,394	−174,885
8.75	1,424,402	532,341	193,799	319,603	486,621	1,532,365	−107,963
9.75	1,514,335	532,341	215,948	320,426	486,621	1,555,336	−41,001
10.75[a]	1,604,309	532,341	238,096	321,249	486,621	1,604,309	26,001
11.75	1,694,322	532,341	260,245	322,072	486,621	1,601,279	93,044
12.75	1,784,376	532,341	282,393	322,894	486,621	1,624,250	160,126

[a]Base case.

TABLE 8 Results of Population Growth Impact

Unexpected Population Growth Factor	Cost Without a Transfer Station ($)	Cost With a Transfer Station ($)	Cost Saving ($)
1.0	1,604,309	1,578,308	26,001
1.25	1,780,644	1,658,145	122,499
1.50	1,956,984	1,802,258	154,725
1.75	2,133,326	1,881,660	251,666
2.00	2,363,670	2,072,979	290,691
2.25	2,486,017	2,164,367	321,650
2.50	2,662,365	2,243,772	418,592

mental economic analysis to justify transfer stations was formulated, and a computer program utilizing LOTUS 123 was developed. The proposed approach was applied to five localities and two proposed station sites. The following conclusions were drawn:

1. The results of the analysis are highly sensitive to the location of the transfer station.
2. As the landfill gets farther away from the localities, the cost savings due to constructing a transfer station increase. A break-even point was observed at a distance of around 10 mi.
3. As the population unexpectedly increases, the cost saving due to constructing a transfer station increases.

REFERENCES

1. M.R. Greenberg et al. Solid Waste Planning in Metropolitan Regions. The Center for Urban Policy Research, Rutgers University, New Brunswick, N.J., 1976.
2. G. Tchobanoglous, H. Theisen, and R. Eliassen. Solid Wastes: Engineering Principles and Management Issues. McGraw-Hill Book Co., New York, 1977.
3. ASTSWMO/Waste Age Survey Finds Nearly 1,300 Transfer Stations. Waste Age, Feb. 1985, pp. 69-70.
4. Two Transfers Work for City of Tucson. Waste Age, Dec. 1984, pp. 70-71.
5. J. Salimando. When You Add It All Up a Transfer Station Can Make a Lot of Sense. Waste Age, Dec. 1984, pp. 30-34.
6. J. Salimando. Hempstead Transfer Station Up and Running in 92 Hours! Waste Age, Dec. 1984, pp. 47-50.
7. Potential Crisis Avoided with New Transfer Station. Waste Age, March 1985, pp. 16-17.
8. D. Dilworth. Community Interest Inspires Transfer Station's Success. Waste Age, March 1985, pp. 12-14.

Publication of this paper sponsored by Committee on Application of Economic Analysis to Transportation Problems.