Measuring Internal and External Costs of Sanitary Landfill Sites in Chicago Metropolitan Area

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I. Introduction

A recent national survey shows that an average of over a ton per person of various types of solid wastes is collected in the United States. This amounts to more than five pounds per capita per day (American Public Work Assn, 1970).

The term "solid waste" generally refers to garbage and other forms of solid residuals generated by all residential, commercial, industrial and municipal sources. Waste generation may be considered as the function of the rise in per capita purchases for all nondurable and durable goods, which represents approximately four percent of annual growth in the past few years. If the quantity of solid wastes generated per capita increases at a conservative rate of four percent annually, the amount of wastes to be collected by private and municipal agencies will rise to approximately eight pounds per day by 1980.

Growing quantities of solid wastes are beginning to produce social, economic, and environmental problems of significant pro-

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portions. These problems are particularly acute in the Chicago metropolitan area where intensive urbanizaion and population concentration increases solid wastes and decreases relatively the availability of spatial area suitable for disposal.

The purpose of this paper is to discuss how one can empirically measure both internal and external costs of sanitary landfill sites.

II. Direct Costs of a Sanitary Landfill

An estimate by the Energy and Environmental System Division (EES), Argonne National Laboratory shows that the domestic and industrial solid waste collection rates in the Chicago Metropolitan area totaled 8,731,269.2 tons in 1970. Using the land area and consistent population values for 1970, the EES projected 10,402,215.2 tons of solid wastes collection rates in 1990. The 1990 collection rates were estimated from population and density data and by the formula:

$$C = \frac{((\log d \times 1.54) - 0.68) \times p \times 52 \text{ weeks}}{285.7}$$

where d = population density = (population/area-square mile)
p = population
c = collection rate in tons per year.

The group (log d x 1.54 - 0.68) is referred to as the generation factor in units of pounds per person per day, and 285.7 is a conversion factor producing units of tons per week: (ton/2000 pounds) (7 day/week) (Argonne Nat'l Lab. 1974). The quantities estimated above do not include solid wastes induced by installment of control devices for air and water pollution, which would also amount to a considerable volume.[1]

The collection of wastes is about equally divided between municipal agencies and private facilities. Practically all of the solid wastes collected by companies is disposed of mostly in landfill sites, while the majority of refuse collected by municipal agencies is burned in incinerators.

1 For example, amounts of particulate collected by nine electric plants in the Chicago Metropolitan area was estimated to be 1,413,000 tons in 1970, which accounted for 11.5% of total coal consumption by these plants whose total capacities are 7,314 MW. Also about 262,035 tons of ashes, about 8% of coal consumed in tons, collected by all manufacturing industries in the area in 1970. This quantity was estimated under the assumption of 99.5% efficiency of electric precipators used. It is very important to note that with existing technology, reduction in airborne or waterborne residual discharges increase solid or liquid wastes.

The direct cost of collecting and disposing of solid waste is estimated to be over \$23.00 per ton; eighty percent of which represents collection and transport cost (Shaffer and Tolley 1971). The transport costs vary widely depending upon the daily volume handled and the vehicle employed and distance traveled. All of the cost expressions in this paper are in 1970 dollar value.

Disposal costs (which do not include collection and transportation) generally range from \$1 to \$4 per ton for sanitary landfills and from \$3 to \$12 per ton for incineration, depending upon the size of the operation. Actually, every solid waste disposal system is unique, and no two system have exactly the same cost structure. Such differences in costs can be attributed, in the case of disposal at a sanitary landfill, to soil characteristics, cover materials availability, site topography, types of solid waste received, differences in labor cost and other factors. Assuming other factors are the same, the daily quantity of solid waste affects costs significantly. As the daily quantity of solid waste is increased, more efficient use of labor and equipment would make lower unit cost possible. There are definite economies of scale possible with facilities serving populations of approximately 100,000 or more. As an example, the average annual per ton cost of disposal for a daily quantity of 100 tons of solid waste is just over \$2. The average cost for a quantity of 600 tons per day, by comparison, is less than \$1 per ton.

The total annual internal cost of operating a sanitary landfill should include (1) planning and designing costs, (2) initial site development costs, (3) land expenses, (4) the owning and operating expenses of equipment, (5) wages and salaries, (6) annual amortization costs and (7) administration and overhead costs. This cost can be expressed in a reduced form:

$$TC = FC + VC(V)$$

where TC is total annual cost of disposal at a sanitary landfill. FC is the total annual fixed cost. VC is the total annual variable cost. And V is the daily volume of solid waste in tons. The statistical result of a recent study by Clayton and Hui produced the following cost function in its empirical form (Clayton and Hui (1973)):

$$TC = \$28010.87 + 255.920(V) - 0.148(V^2) + 0.00005(V^3).$$

The preceding expression of total annual cost is further converted to yield average annual cost per ton. The average cost expression for a sanitary landfill is of the form:

$$AC = \$1.024 + \frac{112.043}{V} - 0.0006(V) + 0.0000002(V^2).$$

An estimate of the per ton sanitary landfill cost for solid waste disposal can be obtained by inserting the appropriate daily volume of solid waste in tons into the above expression.

According to landfill inventory reported by the Northeastern Illinois Planning Commission (NIPC), there were 55 landfill sites in the Chicago Metropolitan Area in 1972. However, recent information from EES of the Argonne National Laboratory indicates that 35 out of 55 sites are still receiving refuse. Information about average daily volume received by each site is inconsistent with wide variance ranging from 21 tons to 4,200 tons. Probably, the average 500 ton per day per site might be assumable, allowing for inconsistencies among individual reporting system.

Substituting this assumed figure (500 tons per day per site) into the average cost function will produce about $1 of average annual per ton cost of disposal at a sanitary landfill in the long run. Further, assume 275 working day per year. Then, the quantities of solid waste received by 35 active landfill sites would be 4,812,500 tons per year. Multiplying this quantity data by the average per ton cost ($1 per ton) gives 4,812,500 dollars in 1970 value for total annual landfill costs (excluding collection and transportation cost) in the Chicago Metropolitan area. If the average daily volume received per site is less than 500 tons, for example, the cost would be a little higher.

Given the availability of lands within economic transportation distance, landfilling is usually the least costly method of disposing of solid wastes. Landfills require sizable amounts of land that is economically important to a community or region, particularly if the pressure for land demand is great. Acreage requirements depend on a wide variety of factors, including the configuration of the initial site, the nature and density of the incoming refuse, the compaction to be provided, the prescribed amounts of cover materials and the planned elevation of the completed fill above natural ground.

The American Public Works Association has estimated that approximately two cubic yards of landfill space are needed each year for each person served (American Public Work Assn, 1970). This rule of thumb was based on a 5.5 pounds per capita per day, that is 2,000 pounds/capita/year, generation rate, and an in-place refuse density of 1,000 pounds per cubic yard. Two cubic yards of refuse space per person per year equates to about 1.25 acre-feet per 1,000 population per year. Information obtained from a recent federally funded demonstration project indicates that in-place refuse densities of 1,200 to 1,300 pounds per cubic yard can be achieved in well compacted landfills (U.S. Dept. HEW 1968).

As the quantities of solid waste increase, the acquisition of disposal land is important. The sanitary landfill is generally considered a nuisance free method of refuse disposal characterized by competent and continuing engineering planning and control. But there are apparent forces which make the acquisition by a public body or private individual of sites for solid waste disposal locations difficult. First, the physical quantity of suitable sites is limited. Second, there is generally strong adverse reaction of communities to having any type of solid waste facility located nearby. One of the major objections raised against having a disposal site located nearby is that the value of surrounding properties will be adversely affected. Such objections may not be without basis since generally no provision is made to compensate those in a community who may suffer loss or bear risk or loss because of externalities which emanate from the solid waste facility. In rare instances there is little or no opposition to the opening of a landfill or the landfill is welcomed by the people living near the site. This may occur if the present use of the site is creating such undesirable conditions that shifting its use to a sanitary landfill immediately improves the conditions. Such could be true for a site where uncontrolled dumping and open dump burning had previously been permitted. Also, in situations where the sanitary landfill is truly a land reclamation activity with a rapid realization of benefits compatible to the personal goals of individuals near the site, the landfill is opened with little or no opposition. This has been the case with the filling of ravines and gullies where not only more usable space is created, but the completed landfill may add stability to the surrounding terrain.

III. External Effects of a Landfill Site

Little is known about the neighborhood effects of sanitary landfill sites on property value. What is the magnitude and distribution of such external effects?

An externality arises wherever an economic action affects parties not directly involved in the activities, thereby falling outside the reach of the price system. A negative externalty exists where a person incurs costs for which he receives no compensation.

A positive externality occurs when a person benefits from the action of another without being required to make compensation.

To empirically examine the external effects of landfills on surrounding property values, a regression model was set up based on the classical assumptions and with data obtained from Wayne County, Indiana.[2]

The price of residential property is hypothesized to be functionally related to three general categories of variables - physical attributes of the residential property, general level of cost of housing, and other factors representing amenities and nonamenities associated with solid waste disposal sites and neighborhood characteristics. The housing unit and accompanying land are considered together with no attempt to separate the value of the housing service from site value. The basic relationship underlying the regression was assumed as follows:

$$Y = f(x_1 x_2 x_3 \ldots x_9 x_{10} x_{11} x_{12})$$

where:

- Y = the transaction price in current dollars
- x_1 = the size of the house in square feet
- x_2 = the number of bathrooms
- x_3 = the age of the house to the nearest whole year
- x_4 = the size of lot in square feet
- x_5 = the amount of encumbrance in dollars
- x_6 = the year of sale measured in terms of the last two digits of the year
- x_7 = the absolute degrees that the residential property is away from downwind (prevailing) of the landfill site
- x_8 = the distance in feet that the residential property is from the nearest landfill site
- x_9, x_{10}, x_{11}, x_{12} = zero one dummy variables representing four landfill sites.

Based on the 183 observations, the regression was computed in the linear form. The estimated coefficient ($\hat{B}$), normalized regression coefficients (Beta), elasticities at mean values (E) and standard errors of $\hat{B}$ are represented in Table 1. The proportion of explained variation of residential property prices (R^2) is 76.

2 The original work was done by Havlicek, Richardson and Davies (1971). However, the original version of regression result was modified in a subsequent run, whose estimated coefficients are used in this paper.

The absolute angle variable, x_7, and the distance that the residential property is from the nearest solid waste disposal site, x_8, are variables which represent measures of the external effects of landfills if such external effects exist. The information on the land value surrounding a sanitary landfill is also available from annual Olcott's Land Value Statistics. Externality is observed to exist to the maximum distance of three blocks, that is approximately 1,980 feet, from a site. This externality continues for a considerable length of time, even after a site is closed. The activities of aerobic and anerobic decomposition in a landfill containing such a heterogeneous mixture of materials last sometimes about seven to ten years. During the decomposition process carbon dioxide, odor and methane gas produce external problems to its neighborhood.

To calculate the external effects of landfill sites on surrounding properties, the first step was to obtain residential values by blocks

Table I

COEFFICIENTS, ELASTICITIES, AND STANDARD ERRORS FOR RESIDENTIAL PROPERTY PRICE MODEL

	Estimated Coefficients ($\hat{B}$)	Elasticity (E_i)	Normalized Regression (Beta)	Standard Error of $\hat{B}_i$
Intercept	-24265.39951			
x_1	7.3435	.61209	.43882	.88516
x_2	3169.40579	.26302	.21246	814.24884
x_3	-114.90433	-.11967	-.24115	25.68251
x_4	.00934	.01693	-.07173	.00595
x_5	.08206	.03368	.06926	.05137
x_6	348.16172	1.42306	.11136	124.48304
x_7	24.56366	.09852	.14304	11.37872
x_8	.6222	.16626	.09449	.28842
x_9	-1319.92955	-.01106	-.06161	1159.40771
x_{10}	-848.88157	-.00939	-.04436	1264.74205
x_{11}	-6700.15105	-.02921	-.23394	1664.11163
x_{12}	1568.46675	.04470	.10632	1009.88203

$\bar{Y} = 16297.1311$

$R^2 = .75743$

from each site facing west, north, east and south. This data was obtained from 1970 Census of Housing, Block Statistics, Chicago, Illinois - Northwestern Indiana Urbanized Area. A survey on surrounding properties of each landfill site indicates that about 30 sites out of 55 sites as of 1970 produce external effects. The other sites are mostly located in such places as betwen either highways, river, canals or forests, so their externality is not economically felt. The prevailing wind direction of the Chicago area is observed from west to east. Using the estimated regression coefficients of absolute angle variable (x_7) and distance variable (x_8) and direction of wind from west to east, we did calculate the external effects as follows:

Facing	0 block	1 block	2 blocks
West	-1200	-800	-400
North	-3360	-2960	-2560
East	-5520	-5120	-4720
South	-3360	-2960	-2560

Dividing the external effects of landfill site on surrounding properties by the estimated mean price of property sold for $16,300, a measure for the external effects as a percentage of mean sale price is obtained for each block and for each direrction. Then, multiplying this value for each block and direction by the property value (residential value) obtained from 1970 Census data gives the total external value of each landfill site on its neighborhood properties:

$$\sum_{i=1}^{4} \left[\left(\begin{matrix}\text{Effects of each landfill} \\ \text{site on property value}\end{matrix} \right) \div \left(\begin{matrix}\text{Estimated Mean Sale Price} \\ \text{of residential site}\end{matrix} \right) \times \left(\begin{matrix}\text{Property value obtained for} \\ \text{Census data for each block}\end{matrix} \right) \right] = \begin{matrix}\text{Total external effect of a landfill} \\ \text{site on property value}\end{matrix}$$

The total external effect averaged to be about $60,500 per site. The number of operation days of each site is assumed to be 275 days per year. Multiplying daily receiving volume of solid wastes in tons by each site by yearly operation days (275 days) and then dividing into ten percent of total external effect of individual site (assuming average ten life years for the existence of externalities) gives external cost per ton per year. It was already mentioned that 31 sites out of 55 landfills were observed producing externality.

Among these 31 landfills only 19 operators provide data on their daily volume of solid wastes while the other 12 operators refuse to give information on daily volume received for some confidential reasons. The external cost estimated from the available data of 19 sites is about 13 to 14 cents per ton, but this is overestimated because total externalities are divided only by a little less than half of quanities of total solid wastes going to landfills in the Chicago Metropolitan Area. In order to obtain average per ton external cost in the area, therefore, it may be appropriate to divide this again by approximately 2 or 2.3. This produces about 5 to 7 cents of external cost per ton. The estimated total external cost, daily volume and external cost per ton per year of each available site is shown in Table 2.

Combining a dollar of average direct cost per ton at a sanitary landfill site[3] with this 5 to 7 cents external cost gives about $1.05 to $1.07 as a total internal and external cost per ton at a sanitary landfill location in the Chicago Metropolitan area. Multiplying this cost data to the estimated quantities (4,812,500 tons) of solid wastes gives 5,053 thousand to 5,149 thousand dollars as a total annual cost at all landfill sites. Now, assume an average of 22 dollars for collection and transport cost per ton. Then, total cost for collection and transport and disposal would be approximately 111 million dollars annually in terms of 1970 price base in the Chicago Metropolitan area.[4]

IV. Conclusion

The external costs associated with sanitary landfill were estimated via changes in property values adjacent to a landfill site. Changes in property values around a landfill are attributed to the presence of the landfill site. In calculating the environmental costs of landfills, it was found that property values varied with (1) the number of degrees a house is from the prevailing downwind direction from the landfill site and (2) distance from the site. The downwind direction is significant because the concentration of odor and dust from a landfill site would most likely be greater in the downwind direction. Housing values were found to increase with distance from a landfill site, for a distance equivalent to three city blocks.

3 Note that one dollar direct cost is derived by assuming that each site receives more than 55 tons of solid wastes per day and this one dollar cost does not include collection and transport cost. See page 6.

4 This includes external costs.

Table 2
Total Cost of Landfills, Daily Volume Received, and Average Cost Per Ton

Map No.	Site Name	Total External Effect($)	Daily Volume Received (tons) Per Year ($)	Estimated C Cost Per Ton
C 5	Chicago Ridge Landfill, Inc.	47,644.4	700.0	0.0247
C 10	Doetsch Pit	52,333.5	105.0	0.1812
C 11	Industrial Building Operations	16,247.1	1081.5	0.0054
C 15	Lake Landfill, Inc.	78,032.0	2500.0	0.0081
C 19	Stearns Quarry	25,135.0	399.0	0.0305
C 20	Twin Hills Solid Waste	60,355.4	525.0	0.0418
C 21	Morton Grove	59,277.3	157.5	0.1368
C 22	Winnetka	114,094.5	158.2	0.2622
K 11	Elgin Landfill Co.	35,656.6	140.0	0.0926
K 2	Midway	49,351.8	1050.0	0.0170
K 4	Great Lakes	10,792.0	49.7	0.0789
L 5	Lake Bluff	95,027.9	21.7	1.5924
L 7	Landfill Engineering	47,454.3	700.0	0.0246
L 9	North Chicago	66,502.9	227.5	0.1062
L 10	Fort sheridan	5,502.6	140.0	0.0142
L 11	T-K City Disposal	37,281.2	689.5	0.0196
L 12	Wauconda Sand and Gravel	39,365.7	584.5	0.0244
L 13	City of Zion	19,167.9	215.6	0.0323
W 3	ESL, Inc.	33,778.0	584.5	0.0244
C 1	American Grading Co.	22,603.3	Not Available	Not Available
C 12	John Sexton Blue Island	30,806.6	"	"
C 13	John Sexton Maryville	41,394.6	"	"
C 14	John Sexton 31st St. and Tri-State	48,921.7	"	"
C 18	South Suburban Land Development	49,515.2	"	"
C 23	Winnetka	8,755.3	"	"
K 3	Tri-county	35,656.6	"	"
D 1	Ajak Sand and Gravel	70,441.6	"	"
D 2	E & E Disposal	51,574.4	"	"

Note: See "Landfill Inventory Map," appendix, Solid Waste Report, Technical Report No. 7, Northeastern Illinois Planning Commission, Chicago, April 1973.

External costs were estimated to average $60,500 per landfill site. Since the other costs (investments, operating, transportation) are on a per-ton-of-solid-waste basis, the environmental costs were converted to an annual per-ton basis, resulting in an annual environmental cost of five to seven cents per ton depending on the daily volume that a landfill handles.

Combining a dollar of average direct cost per ton at a sanitary landfill site with this 5 to 7 cents external costs gives about $1.05 to $1.07 as a total internal and external cost per ton at a sanitary landfill location in the Chicago Metropolitan area.

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