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Evaluation of Alternatives For Solid Waste Systems

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ABSTRACT

A method is presented which incorporates environmental, social, and engineering factors into the selection of a solid waste system from among several alternatives. The methodology relies upon the establishment of a data matrix for the criteria and alternatives under consideration and upon the assignment of weights to the various criteria. A stochastic procedure takes account of the inherent uncertainty in the quantitative values assigned to subjective criteria and for the uncertainty in the assigned weightings. An example is included which demonstrates the use of the method.

Introduction

Cost-benefit analysis is a standard tool for engineers and economists in introducing order into decision-making processes.[1] This method is restrictive because monetary values must be assigned to the benefits. More general methods for approaching multiple-criteria decisions have been developed. These methods require the assignment of weights to the factors which enter into a decision. Drobney, Qasim, and Valentine[2] utilized cost-effectiveness in evaluating the attributes of waste treatment systems and in choosing the most desirable system. Similar methods were employed by Odum et al.[3] and Niemann and Miller[4] to determine the optimum highway route from a set of proposed alternative routes. The criteria used in the selection of the

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optimum route included environmental and social factors, in addition to the economic and engineering considerations.

Until recently, solid waste management practices relied upon disposal of wastes in landfills or by incineration. Open dumping is still a widespread practice.[5] However, the environmental hazards and the public nuisances of these policies are now very much recognized. Government agencies are adopting stricter standards related to the disposal of solid waste. Communities and municipalities are confronted with these realities as well as pressures from environmentally concerned citizens who call for programs that are oriented toward recycling and reclamation. In all of this it is important that decision-makers and community leaders be able to establish and maintain rational decision-making procedures. Environmental and social factors must be brought into these procedures.

In this paper, the method of Odum et al.[3] is adapted for use as a tool to evaluate municipal solid waste processing and disposal alternatives. The key feature of the method is the ability to consider environmental and social factors in addition to cost and engineering aspects. The details of the method and an illustrative example are discussed in the main part of the paper.

Methodology

The method of analysis for comparing solid waste management alternatives requires the delineation of all alternatives which offer potential solutions to the problem and of the factors which are important in the decision-making process. The factors should involve physical, social, environmental, and economic considerations. The factors may include economic considerations such as capital, collection, and operating costs; environmental factors such as acreage required to dispose of solid residuals; social factors such as the number of trucks converging each day to a neighborhood where a processing plant is located; and administrative or political implications such as the anticipated public cooperation or support measured as a per cent of the population which is served by the solid waste system. The minimum requirement is that there be a consistent means of measuring the factor, even if only in a very general sense.

Technological feasibility presents a special problem since it will probably be of paramount importance in the final choice of alternatives. This issue can be handled in one of two ways:

1. Include only alternatives which are technologically feasible at the

present time. Then technological feasibility needs no further consideration. This conservative approach would be utilized by a municipality which is intent upon finding a solution from among those systems which have been tried and found to be reliable.

2. Include among the set of alternatives those which offer promise on the basis of research or demonstration projects, in addition to those which are technologically feasible at the present time. If this approach is taken and if the analysis should reveal that an alternative which is experimental and not thoroughly tried is superior on the basis of the factors in the decision model, technological feasibility can be used as a veto mechanism. The next lower ranking feasible alternative could then be chosen for implementation. The advantage in knowing the superior alternative, even though it is not chosen for implementation, is that it provides insight and guidance for research efforts.

The decision model is outlined with the aid of Figure 1. The alternatives to be evaluated are A_1, A_2, A_3, ..., A_m. The factors which will be considered in the evaluation of the alternatives are C_1, C_2, C_3, ..., C_n. The matrix entry, d_{ij}, measures factor C_i for alternative A_j. In addition, weights are assigned to each of the n factors to indicate their relative importance in determining the best of the alternatives; w_i, is the weight

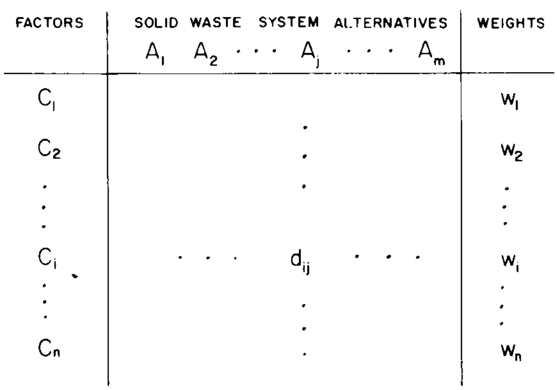

Figure 1. Matrix of alternatives, factors, and weights.

assigned to factor C_i. After the matrix entries, d_{ij}, and the weights, w_i, are determined, index I_j is computed for alternative A_j according to the equation

$$I_j = \sum_{i=1}^{n} \frac{w_i}{W} \frac{d_{ij}}{D_i} \tag{1}$$

in which $W = \max |w_i|$, $1 \leqslant i \leqslant n$, so that $-1 \leqslant w_i/W \leqslant 1$ for all w_i; and $D_i = \max d_{ij}$, $1 \leqslant j \leqslant m$, so that $0 \leqslant d_{ij}/D_i \leqslant 1$ for all d_{ij}. The number W is introduced for scaling purposes only. Thus the index I_j is obtained by multiplying the scaled matrix entry, d_{ij}/D_i, by the scaled weight, w_i/W, then summing over all factors.

If the indices of the alternatives are ordered, a basis exists for choosing the best alternative. It is important to note that the introduction of multipliers for scaling purposes in no way destroys the relative positions of the alternatives. Only the absolute positions on a scale are modified.

The opportunity to incorporate error analysis due to the uncertainty of data entered into the matrix or the uncertainty in the assigned weights is provided in a stochastic procedure utilizing a computer program to generate random numbers. The computer chooses a random number e_i, $1 \leqslant i \leqslant n$, from a uniform distribution, $-1/2 \leqslant e_i \leqslant 1/2$, then computes I_{jk} of the form

$$I_{jk} = \sum_{i=1}^{n} \left[\frac{w_i}{W} \frac{d_{ij}}{D_i} + e_i \frac{w_i}{W} \frac{d_{ij}}{D_i} \right] \tag{2}$$

The subscript k is used to indicate the k^{th} calculation from a predetermined number, r, of repetitive calculations for alternative A_j. The average index, $\bar{I}_j$, where

$$\bar{I}_j = \frac{1}{r} \sum_{k=1}^{r} I_{jk} \tag{3}$$

and its 95% confidence interval are calculated. The average indices can be ordered and used to rank the alternatives. The confidence intervals indicate whether the differences in the average indices are significant. If the confidence intervals of the indices of two alternatives overlap, the methodology provides no justification for choosing one of these alternatives in preference to the other.

Example Problem

SOLID WASTE MANAGEMENT ALTERNATIVES

Specific alternatives must be defined for consideration. The components of a waste system, such as processing equipment and disposal sites, should be specified as accurately as possible. Variations in handling, processing, or materials reclamation may produce distinct alternatives. Since the enumeration and description of possible alternatives is not germane to this paper only 11 alternatives will be considered in this example. The alternatives are listed in Table 1. Data for representative hardware and equipment needed for a given process are utilized in the matrix; detailed engineering specifications are not employed.

FACTORS

The decision model is designed so that all of the criteria or factors which are important to a problem may be considered; consequently, a complete list of factors relevant to solid waste management systems is

Table 1. Components of Solid Waste System

Alternative	*Processing*	*Recovery*	*Disposal*
A_1	None	None	Sanitary landfill
A_2	Hammermilling	None	Sanitary landfill
A_3	Hammermilling	None	Sanitary landfill incorporated with land-use plan for parks, recreational areas, etc.
A_4	Hammermilling	Ferrous metals	Residues to sanitary landfill
A_5	Hammermilling	Metals, glass and mixed paper	Residues to sanitary landfill
A_6	Incineration	None	Residues to sanitary landfill
A_7	Incineration	Heat	Residues to sanitary landfill
A_8	Pyrolysis	Char, acids, oil and tars	Residues to sanitary landfill
A_9	Composting by high rate digestion and windrowing	Ferrous metals	Rejects to sanitary landfill
A_{10}	Black Clawson hydrapulping	Metals, glass and fibers	Rejects to sanitary landfill
A_{11}	Incineration of combustibles	None	Incinerator residue and non-combustibles to sanitary land-fill

constructed. The authors have found it useful to group these factors into the following categories:

1. Engineering, cost, and administrative factors;
2. Environmental factors;
3. Social factors; and
4. Recovery and reclamation factors.

Numerical values must be assigned as a measurement of each factor for each alternative. This can be done in obvious ways for the objective factors. The more subjective factors are not readily quantifiable, particularly those factors of a social or environmental nature. For the subjective factors, numbers can be assigned to each alternative on the basis of predetermined scales. In assigning the numbers, it is crucially important that the numbers reflect the relative standings of the alternatives with respect to the factor under consideration. Since the entries in a given row are scaled, the actual values assigned are unimportant in an absolute sense. Errors of judgment in the values assigned to subjective factors will inevitably occur, but one of the purposes of the stochastic procedure with the assumption of 50% uncertainty is to allow the decision-maker to take them into account when ranking the alternatives. Table 2 displays the complete set of factors considered and the numerical values assigned to each alternative for each factor. The assigned values are based on the assumptions that 300 tons of municipal waste is generated per day and that the composition of the waste is the same as that of typical municipal solid waste.[6] A detailed discussion of the factors follows.

Engineering and Administrative Factors

The foremost factors in this category are capital, operating, and collection costs. Collection costs enter the analysis only if for at least one alternative more than one collection is required. An example of such an alternative is a system in which burnables and non-burnables are collected separately. Rather than assigning actual dollar values to the collection process it is easier to introduce the number of collections as the unit which measures the cost of collection.

Capital cost and operating cost estimates are obtained from the literature for hammermilling,[7] landfilling,[8] incineration,[9] pyrolysis,[10] composting,[11] and the Black Clawson hydrapulping process.[12] It is assumed that environmental standards for air and water pollution are met.

The costs involved in the processing of the solid waste, in the reclamation of materials or heat, and in the disposing of residuals are totaled to obtain the operating costs. These costs are measured in dollars per ton. Hauling costs are omitted because specific locations of landfill sites are not included in the problem. If in a given problem specific landfill sites are being considered, then hauling costs should be included in the operating costs.

The adaptability or flexibility of a system to accommodate future technological improvements or improved concepts in solid waste handling, processing, or disposal is an engineering factor which differs among alternatives. Numbers from 1 to 5 are assigned. Alternatives with the smallest investment in buildings, equipment, and land were considered to be the most flexible. The least adaptable system has major investments in specialized equipment and in single-purpose buildings which are not easily modified.

If an alternative requires more than passive support or participation of the public, such as for the segregation of burnables and non-burnables for separate collection, public participation should be included as a factor. Public participation can be examined from two viewpoints depending upon the alternatives which are considered: 1) Willing participation such as occurs in the separation of newsprint from other refuse in Madison, Wisconsin.[13] The public participation is approximately 30%. 2) Enforced participation such as occurs when collection crews do not collect waste which is not sufficiently segregated. The former viewpoint more accurately reflects freedom from administrative difficulties and is used in this example. It is assumed that alternatives in which solid waste is collected in unsegregated form will have 100% participation. It is assumed that 50% of the public willingly participates in the alternative which requires the segregation of burnables and non-burnables.

Environmental Factors

The rodent or vector problem is a subjective factor which is measured on a scale with an arbitrarily chosen range of 0 to 4. A number is assigned to each alternative which reflects the standing of that alternative relative to the others. Of all the alternatives in the example, sanitary landfill has the greatest potential for harboring rodents or vectors and it was assigned the value of 4. Hammermilling prior to landfill reduces the rodent problem[14] and the value of 3 reflects this fact. The Black Clawson process is considered to have less potential for attracting rodents and vectors than hammermilling and is assigned a value of 2. Composting of the hammer-milled refuse by high-rate digestion prior to windrowing further reduces the rodent-vector problems and is assigned a value of 1. The processes which utilize incineration or pyrolysis were given the value of 0 since the residues from these processes are sterile.

Table 2. Tabulation of the Matrix Entries

	Alternatives										
Factors	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}
(a) Engineering, Cost, and Administrative Factors											
(1) Capital Costs, in millions of dollars	0.43	0.76	0.77	0.75	0.83	3.24	5.24	8.67	4.19	0.94	1.43
(2) Operating Costs, in dollars per ton	1.5	3.5	3.5	4.5	6.0	8.5	10	8.5	9	7	6.5
(3) Collection Costs, in number of collections	1	1	1	1	1	1	1	1	1	1	2
(4) Adaptability, in arbitrary units	5	4	4	4	4	2	2	2	3	1	2
(5) Public Participation, in per cent of population	100	100	100	100	100	100	100	100	100	100	50
(b) Environmental Factors											
(6) Rodent or vectors, in arbitrary units	4	3	3	3	3	0	0	0	1	2	1
(7) Air Pollutants, in lbs/ton	0	0	0	0	0	8	8	0	0	0	8
(8) Solid Residuals, in tons per day	300	300	300	273	120	75	75	69	36	90	86
(9) Liquid Pollutants, in gallons per day	0	0	0	0	0	4	4	3	0	60	4
(10) Acreage Required, in acres	250	125	125	114	50	38	38	38	14	38	100
(11) Power input, in megawatt-hours per day	6.5	8.7	8.7	8.9	9.0	7.8	7.8	7.8	8.1	9.4	6.3

(c)	Social Factors											
(12)	Traffic Interference, in trucks per day	60	90	90	91	90	68	68	77	83	81	61
(13)	Land Value Deterioration, in arbitrary units	4	2	1	2	2	3	3	3	3	3	3
(14)	Visual Disturbance, in arbitrary units	3	4	2	4	4	3	3	3	4	3	3
(15)	Noise, in arbitrary units	2	3	3	3	3	2	2	2	3	3	2
(16)	Odor, in arbitrary units	3	2	2	2	2	2	2	1	2	3	2
(d)	Recovery and Reclamation											
(17)	Paper, in tons per day	0	0	0	0	120	0	0	0	0	60	0
(18)	Ferrous Metal, in tons per day	0	0	0	27	27	0	0	0	27	27	0
(19)	Aluminum, in tons per day per day	0	0	0	0	3	0	0	0	0	3	0
(20)	Glass, in tons per day	0	0	0	0	30	0	0	0	0	30	0
(21)	Compost Produced, in tons	0	0	0	0	0	0	0	0	164	0	0
(22)	Char Produced, in tons per day	0	0	0	0	0	0	0	72	0	0	0
(23)	Acids, Oil, and Tars Produced, in gallons per day	0	0	0	0	0	0	0	30	0	0	0
(24)	Energy Generated, in megawatt hours per day	0	0	0	0	0	0	12	0	0	0	0
(25)	Income from Materials, in dollars per day	0	0	0	135	1080	0	180	672	135	1080	0
(26)	Land Value Improvement, in arbitrary units	2	2	4	2	1	1	1	1	3	1	1

The air pollutants are measured by the amount of particulates emitted each day by a given process. It is assumed that the incineration process employs air pollution control equipment and produces very low emissions. The amount of particulates emitted is assumed to be of the order of 8 lbs/ton.[15] The other processes do not produce any appreciable air pollutants.

Solid residuals are the solid materials which remain after processing has taken place. It is assumed that all materials which are recovered can be utilized and do not contribute further to the solid residuals load which must be landfilled. The number of tons of solid residuals generated each day is used as a measure of this factor.

Several of the alternatives produce waste water either in direct processing or in air pollution control equipment which should be treated before discharge. The impact of this factor is measured by calculating the number of gallons of waste water generated each day which requires treatment.

In many metropolitan areas the scarcity of land for sanitary landfill operations is a critical problem. The total acreage required for landfills and for the processing operations is used to measure this factor.

The final environmental factor is a recognition that power needs of society are met at the expense of a depletion of fossil fuels. The electrical energy and fuel required to operate collection trucks, processing equipment, and heavy machinery at the disposal site is estimated in megawatt-hrs/day and used to measure the energy input factor.

Social Factors

Heavy truck traffic is a social factor in that it is frequently considered undesirable by those who are exposed to it. The factor, Traffic Interference, is entered to account for this nuisance in the decision process. The factor is measured for a given alternative by tallying the number of trucks which enter the area of a processing plant with solid waste or leave the same area with reclaimed materials and those which enter a disposal area.

Processing buildings, incinerators, and landfill operations influence property and land values in the area where they are located. The sanitary landfill alternative is arbitrarily given a value of 4. The incineration, pyrolysis, and composting processes are given a value of 3 because the volume of waste is reduced considerably. A lower value is not assigned because the processing plants also contribute to land value deterioration. If hammer-milling is used, the volume of waste is reduced by approximately 50%[7] and a more desirable fill material is obtained. This alternative and those which recover materials are given a value of 2. The alternative utilizing short-term landfills within an overall land use plan is given a value of 1.

Landfill operations and processing areas tend to mar the landscape. This subjective factor is measured on a scale with a range from 1 to 4. The alternatives employing both extensive landfilling and processing operations are given a value of 4. Composting is also given a value of 4 because the windrowing operation requires a large area. Those alternatives in which the landfill or processing operation is small are assigned a value of 3. The alternative in which the landfilling is incorporated within a land-use plan is given a value of 2.

A fourth social factor is the noise associated with an alternative. This factor includes noise heard by the workers and by the nearby residents. Noise is generated by trucks and other heavy equipment and by processing equipment, such as the hammermills. A value of 2 was assigned to sanitary landfill to account for noise of collection trucks and heavy equipment at landfill sites. If, in addition, hammermilling is employed, the value is increased to 3. Additional processing equipment needed to recover materials increases the noise slightly. The incineration process and pyrolysis are given the value of 2 since less material is landfilled and therefore less noise is generated at this stage. The separate collection of burnables and non-burnables produces more neighborhood noise than a single collection, but less noise at the disposal site. This alternative is given a value of 2.

Odor is also a subjective factor. The sanitary landfill and the hydrapulping processes are judged to have the greatest odor associated with them and are assigned a value of 3. The smallest value of 1 is given to pyrolysis. The other alternatives are assigned the intermediate value of 2.

Recovery and Reclamation

Solid waste processing systems may be designed to recover resources in the form of materials or heat. A factor is included for each type of material recovered and for the electrical energy generated by heat recovery. The types of materials which may be recovered in a given system are: paper, glass, ferrous metals, aluminum, compost, char, acids, oil, and tars. Other types of material recovery are theoretically possible and if in a given study these should be under consideration, additional factors can be employed in the matrix. The units used to measure the factors for a given alternative are tons/day for the materials and megawatt-hrs/day for the electrical energy generated.

The net income realized from the sale of reclaimed materials or electrical power is measured in dollars per day. Expenses incurred in transporting the materials to the market location are subtracted from the gross sale price to obtain a more realistic measure of income.

Engineering capabilities provide an opportunity for using solid waste for the purpose of reclaiming degraded land areas such as abandoned strip mines or quarries. In addition, it is possible to go beyond merely alleviating eyesores. Solid waste has been used for the construction of ski slopes, tobaggan runs, or golf courses. Compost can be used to assist in the restoration of land for agricultural purposes. The factor which is called Potential Land Improvement is included to consider these aspects and it is measured for a given alternative on a scale of 1 to 4. Alternatives which involve long term landfill operations are assigned values of 2. The potential for using waste for land improvement is decreased for the alternatives in which processing reduces the volume of waste. These alternatives were given a value of 1. The alternative A_3 incorporates land-use planning. It has the greatest potential for land value improvement and is assigned a value of 4.

WEIGHTS

To implement the method, judgments are required which reflect the decision-makers' evaluation of the relative importance of the factors in arriving at a "best" alternative. The weights must be assigned as objectively and consistently as possible. A study of Eckenrode[16] demonstrated that the ranking of factors on a continuous scale, paired comparison of factors, or successive comparison of factors produced essentially the same results; however, as the number of factors increases, ranking becomes the most efficient method. Ranking is used in this example. In practice, a team representing divergent backgrounds or viewpoints might provide the best judgment of the relative importance of the factors.

In order to complete this illustrative example, several assumptions will be made concerning the hypothetical region to be served: 1) The soil is marginal for use as landfills. The region is largely rural but there is a rapidly expanding urban area; 2) The area is served by adequate liquid waste treatment facilities; 3) Paper mills which can utilize reclaimed paper are located in this region; 4) Reclaimed glass and metal would require shipping for large distances in order to be utilized by the manufacturers.

A typical ranking of the factors and the assigned weights are shown in Table 3. Weights are assigned from the interval 0-50. The weights which are assigned to factors that are liabilities are negative and weights which are assigned to factors which are assets are positive. In order to provide insight into the reasoning used to determine the weights, brief justifications for the weights follow.

Costs—Public money is in critically short supply. There is severe competition for money among education, public services, etc. Consequently collection costs, capital costs, and operating costs are weighted 50.

Table 3. The Ranking of the Factors With Their Assigned Weights

Ranking	*Factor*	*Weight*
1	Collection Costs	-50
2	Operating Costs	-50
3	Capital Costs	-50
4	Adaptability to Other Systems	+40
5	Public Participation	+40
6	Solid Residuals to be Landfilled	-35
7	Visual Disturbance	-30
8	Noise	-30
9	Land Value Deterioration	-25
10	Acreage Required	-25
11	Potential Land Improvement	+25
12	Traffic Interference	-20
13	Reclamation of Ferrous Metals	+20
14	Reclamation of Aluminum	+20
15	Reclamation of Paper	+20
16	Reclamation of Glass	+10
17	Electrical Energy Generated	+10
18	Net Income from Reclaimed Materials	+10
19	Production of Compost	+10
20	Rodent and Vector Problems	-5
21	Odor	-5
22	Generation of Air Pollutants	-5
23	Generation of Liquid Pollutants	-5
24	Energy Input (Electrical and Fuel)	-5
25	Production of Acids, Oils, and Tars	+2
26	Production of Char	+2

Adaptability—At a time when solid waste management practices are undergoing considerable change, community leaders are hesitant to implement systems which cannot be readily adapted to other systems as changes occur. Consequently this factor is considered very important and assigned a value of 40.

Energy Input—The energy required for the operation of any of the alternatives is very low compared to the energy required by an industrial plant. It is rated at 5.

Traffic Interference—This factor is considered to be important for processing plants and in rural areas where roads are not planned for truck traffic. It is rated 20.

Land Value Deterioration—Greatest deterioration of land value is the result of utilizing a large area of farmland for a landfill, since this eliminates its future use for agriculture and lowers its value as future building sites. Deterioration of land values may also be expected for residential areas located near processing plants.

Visual Disturbance—This is a subjective judgment related to the annoyance produced by seeing land in the process of being filled, truck traffic, processing plants or incinerators. Visual disturbance affects a moderately large number of people.

Noise—This factor is judged to be approximately as important as visual disturbance. It directly affects fewer people but for them it can produce a greater annoyance than visual disturbance. It is rated at 30.

Odor—In all the processes considered this nuisance would be confined to relatively few people and therefore is not an important consideration. It is rated 5.

Paper Reclamation—Since the region under consideration is assumed to have paper industries, it is reasonable to consider recovery of paper fiber from the wastes.

Public Participation—If any component of a solid waste system is not willingly supported by a majority of the public, difficult administrative and implementation problems will occur. A value of 40 is given.

Rodents or Vectors—The most serious problems with rodents or vectors are judged to occur for sanitary landfills. For properly operated sanitary landfills it is not a great problem. The importance of this factor may be judged to be greater in the warmer climates. A value of 5 is given.

Air Pollutants—The alternatives with greatest likelihood to produce air pollution, namely incineration and pyrolysis, are assumed to have appropriate pollution abatement equipment and are well below acceptable limits. Therefore air pollution should not be a significant factor in deciding among alternatives.

Solid Residuals—It is assumed that soil conditions are marginal for landfills. In addition, transporting materials contributes to air pollution. The amount of material which must be transported to a final landfill site is an important consideration and is weighted at 35.

Liquid Pollutants—If it is assumed that the community is served by adequate waste water treatment facilities, such that liquid pollutants can be effectively treated, the weighting should be low. If treatment facilities are not present this would be ranked considerly higher.

Acreage Required—At present, land is available; however, the land is in a rapidly growing area. Any large amounts of land will be obtained at the expense of removing it from agricultural use.

Ferrous Metals—Since iron is a nonrenewable resource, its recovery is important. The distance to market and the fact that detinning is required for the cans decreases the value of the rating.

Aluminum—The importance of reclaiming aluminum is weighted at 20, the same as ferrous metal recovery. In areas where aluminum cans are not prevalent, a lower weight may be assigned.

Glass Reclamation—Glass does not have an intrinsically high value; however, it has a value in that the raw materials for manufacture of glass, currently cost approximately 3/4 cent/lb. Melts utilizing reclaimed glass liquify at a lower temperature, save fuel, and also produce less wear on furnace linings.[17] From the assumption that the region under consideration is not near glass manufacturers, large transportation expenses would be incurred. This makes reclamation of glass less attractive.

Compost Produced—The compost does not qualify as a fertilizer but does have value as a soil conditioner. The value may be higher or lower depending upon soil type and availability of other fertilizers or animal wastes in the region being considered.

Char Obtained—The char has a low value. It could be used for building road beds, etc., however, the amount produced would be low and could not contribute significantly.

Acids, Oil, and Tars Obtained—The amounts of acids, oil, and tars which could be recovered are low. This factor is judged to be about the same importance as obtaining char.

Energy Generated—The amount of electrical energy generated relative to the energy currently available from other sources is small. The 300 tons of available waste does not furnish sufficient fuel to provide for full-time operation of a power generating station, but may be a fuel supplement. It could, perhaps, supply sufficient energy for a private industrial operation. The factor is rated 10.

Net Income From Reclaimed Material—Receiving a net profit for recovery of materials should not be an important consideration. Certainly, the past practice of disposing of wastes in a dump did not provide a profit for a municipality either.

Potential Land Improvement—The potential of solid waste for land value improvement is considered to be moderately important and is given a value of 25. In areas where the need for improving deteriorated land or the development of recreation opportunities is great, a higher value could be assigned.

RESULTS OF EXAMPLE

The result of the computer calculations using 50 repetitions for each alternative are shown in Figure 2. The alternative A_5, which utilizes extensive recovery of materials emerges as the preferable alternative based

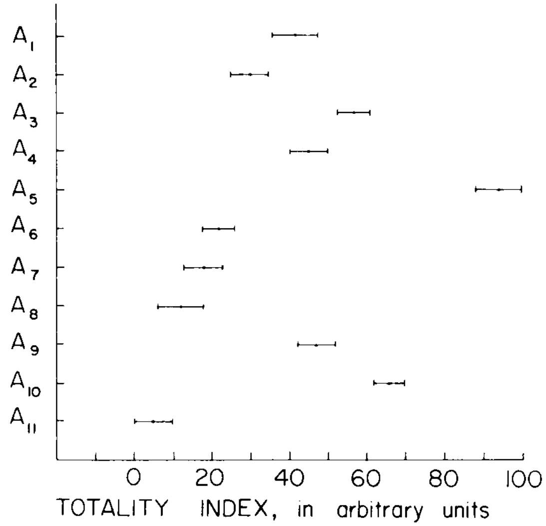

Figure 2. Average totality indices, $\overline{I}_j$, and confidence intervals.

on the authors' assigned weights. The second and third choices are the hydrapulping process, A_{10}, and the short-term landfill alternative, A_3, respectively. These choices are clear-cut because there is no overlap of the confidence intervals. The fourth choice is not clearly distinguished because the confidence intervals for alternatives A_1, A_4, and A_9 overlap.

SENSITIVITY OF RESULTS

Sensitivity analyses can easily be performed to obtain insight into the meaning of the results. For example, if only cost factors are considered, with all other factors weighted 0, the traditional solutions should emerge as the favorable choices. The results confirm this observation as shown in Figure 3. The results obtained when the cost factors are weighted 0 and all others assume the weights assigned previously are shown in Figure 4.

Summary

The methodology presented provides a consistent quantitative decision-making procedure for analyzing alternatives in solid waste management problems. The decision model incorporates social, environmental, reclamation, and engineering considerations. The mathematical operations employed in the computer program are relatively simple. The value of the methodology presented has these advantages: 1) The methodology forces

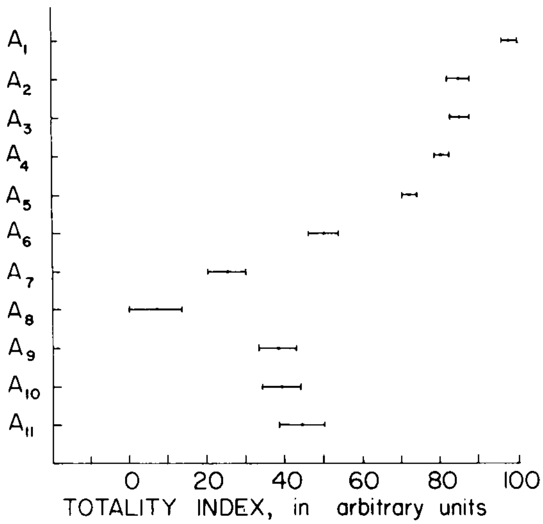

Figure 3. Average totality indices, $\overline{I}_j$, and confidence intervals when only costs are considered.

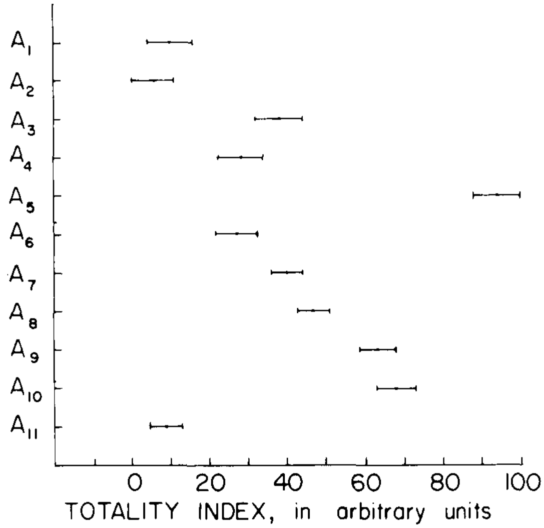

Figure 4. Average totality indices, $\overline{I}_j$, and confidence intervals using all factors except cost

the decision-makers to formalize their thinking and concisely state their assumptions and evaluations of the relative importance of the factors; 2) The methodology incorporates the inherent uncertainty of some of the factors and assigned weights into the calculations; 3) The methodology allows the decision-maker to investigate the sensitivity of the results with respect to the importance of certain factors.

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Appendix Notation

The following symbols are used in this paper:

A_j = solid waste processing and disposal alternative;
C_i = decision-making factor;

d_{ij} = value of factor C_i for alternative A_j;
D_i = maximum d_{ij}, $1 \leqslant j \leqslant m$;
e_i = random number chosen from a uniform distribution, $-1/2 \leqslant e_i \leqslant 1/2$;
i, j, k = index coordinates;
I_j = totality index for alternative A_j;
$\bar{I}_j$ = average totality index obtained in the stochastic evaluation of alternative A_j;
I_{jk} = k^{th} totality index used in the stochastic evaluation of alternative A_j;
m = number of alternatives;
n = number of factors;
r = number of repetitions in the stochastic evaluation of A_j;
w_i = weight assigned to factor C_i; and
W = maximum $|w_i|$, $1 \leqslant i \leqslant n$.

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