AN ANALYTIC HIERARCHY PROCESS FRAMEWORK FOR DETERMINING THE APPROPRIATE NUMBER OF MUNICIPAL WASTE BINS

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ABSTRACT

Making decisions on issues related to provision of social amenities such as solid waste management is tasking and the judgment of various governments at setting priorities over these issues differs. This study applied Analytic Hierarchy Process (AHP) as a multi-criteria decision making tool to determine the optimal number of waste bins to be sited for a study area in Ilorin, North Central, Nigeria. The social, economic and environmental impacts of several waste bin quantities were structured as decision elements and seven possible tradeoffs (scenarios) between these impacts with respect to the overall solid waste management goal were considered for sustainable service delivery. In six scenarios, the level of importance of the three impacts was varied while one scenario assumed equal importance of the impacts. The waste bins were then ranked by summing their respective weight under each scenario. The AHP model ranked the use of a single waste bin highest in "Eco (Economic) >Soc (Social) >Env (Environmental)", "Eco>Env>Soc", "Env>Eco>Soc", "Env>Soc>Eco", and "Soc=Eco=Env" scenarios while the use of five waste bins was ranked highest in "Soc>Eco>Env" and "Soc>Env>Eco" scenarios. The AHP framework presented in this paper will be useful for improving the provision of solid waste management services for sustainable development.

Keywords: Analytic Hierarchy Process, model, solid waste, municipal waste bins, impact

1.0 INTRODUCTION

The Analytic Hierarchy Process (AHP) is a multi-criteria decision making approach in which factors are arranged in a hierarchic structure as a means of modeling the problem. The AHP begins with choosing all the factors that are important to the decision, and arranging them in a hierarchic manner, descending from the overall goal/objective to criteria, subcriteria and alternatives (scenarios) in successive levels (Saaty, 1990). The hierarchy is a convenient way to decompose a complex problem into steps which form a linear chain and the objective of the hierarchy is to assess the contribution of elements in the lower level to the fulfillment of the elements in the upper level (Saaty, 2006). Setting priorities in the hierarchy requires a form of measurement and synthesis throughout the structure. Elements at a lower level are compared in pairs with respect to an element at the upper level. A scale of numbers is used to indicate how important or relevant elements of the same level are to one another with respect to an element at the upper level. The priorities obtained from the comparison in an upper level are used to weigh the priorities in the level below, and it is added until the final priorities in the last level are obtained.

The prime use of AHP is in the resolution of choice problems such as selecting among competing alternatives in a multi-objective environment, making choice decisions, prioritization/evaluation, allocation of scarce resources, benchmarking, quality management, public policy formulation, strategic planning and forecasting (Forman and Gass, 2001). The AHP has over the years been applied in many areas of human endeavor such as selection of best vendor by North Carolina State, allocation of funds and portfolio by the Nuclear Regulatory Commission of the United States, analyses of conflicts and the most appropriate action to be taken, student admissions, promotions and hiring decisions, and match prediction (Saaty, 2008). It has equally been applied to solid waste management in areas such as technology selection, facility siting, and optimization (Nasrabadi et al., 2006; Alshammari et al., 2008; and Ramjeawon and Beerachee, 2008).

How to determine the number of waste bins to be placed at a municipality has been a challenge to municipal authorities because too many waste bins result in under utilization of waste bins and increased collection cost. On the other hand, fewer waste bins result in reduction of public satisfaction and increase in environmental problems such as overflowing of waste bins and litter. Therefore, the choice of the optimal number of waste bins to be sited entails tradeoff between cost and quality of service. Setting up tradeoff between cost and quality of service was described by Kao and Lin (2002) as a decision making problem. In this regard, the use of AHP seems promising in municipal solid waste management because of its ability to solve complex problems involving diverse preferences which feed into one another.

2.0 METHODOLOGY

In order to illustrate the application of AHP to determine the appropriate number of municipal waste bins to be sited within a municipality, a study area was chosen within Ilorin metropolis, Kwara State, Nigeria. The study area is bounded by Latitude 8028'45" and 8028'55" North, and Longitude 4032'50" and 4033'20" East. The digitized map of the study area is shown in Figure 1. The waste bins utilized in this study are fabricated metal roll on-roll off waste bins of capacity 7.54m3 which are required to be placed along the shoulders of publicly accessible roads. Medium-duty collection vehicles (Iveco Euro Cargo 100E18) are used to haul these waste bins to and from the disposal site. Field study was carried out to obtain data on demography, solid waste, and collection operation. These data are the baseline variables required for the AHP model. By using the spatially processed data from field study, the Facility Location Function in TransCAD v.5.0 (Caliper, Corp.) software was used to determine the optimal location of one to ten waste bins along the road network of the study area.

Figure 1 Digitized map of the study area showing solid waste generation points and the road network

The social, economic and environmental impacts of placing these waste bins at optimal points were then evaluated from the output of the TransCAD solution. The issues of sustainable development examined under these impacts for various locations and quantities of waste bins are:

Social impact: The amount of solid waste generation points served, the quantity of solid wastes collected, and waste bin utility.

Economic impact: The cost of purchasing the waste bins and the costs associated with its collection.

Environmental impact: Emissions of Greenhouse Gases (N_2O, CH_4 and CO_2) and Criteria Air Pollutants (NO_x, CO, and PM_{10}) from collection vehicles.

The decomposition of the problem into different levels of hierarchy is shown in Figure 2. The decision's goal is topmost (Level 1) on the hierarchy and it is to find the optimal number of waste bins for the study area given a set of waste bins and locations. The criteria for the decision is at Level 2 and it is an evaluation of the social, economic and environmental impacts of placing one to ten waste bins within the study area. At the bottom of the hierarchy (Level 3) is a set of the various quantities of waste bins which are potential alternatives for reaching the final decision.

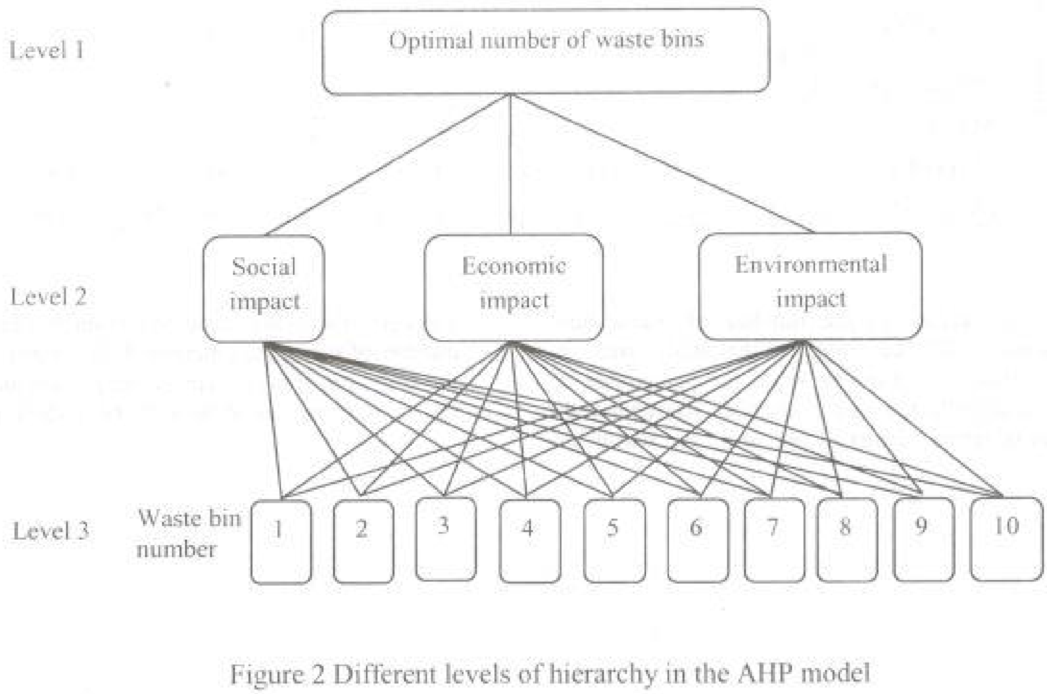

Figure 2 Different levels of hierarchy in the AHP model

The impacts were scaled using the scale of measurements contained in Saaty (1980). A program was written and coded using Microsoft Office Excel 2007 syntax to perform paired comparison of a matrix of elements, find the Eigen value of the matrix, check for consistency in judgment, and rank the alternatives for each scenario that was considered.

3.0 RESULTS AND DISCUSSION

From field studies, a total of 187 solid waste generation points and 269 potential waste bin locations were identified within the study area after eliminating unsuitable sites. The output of solid waste from different land use types was 843.38 kg/day and it was dispersed across 113 residential, 30 commercial and 44 mixed dwellings. The different waste bin quantities and associated social, economic and environmental impacts are presented in Table 1. The percentage of the solid waste generation points served (solid waste generation points within 200m walking distance to the waste bin) was found to increase from 50.27% when one waste bin was placed to 100% when six wastes bins were placed.

Table 1: Waste bin quantities and associated impacts

Impact	No. of waste bins	1	2	3	4	5	6	7	8	9	10
Social	% solid waste generation points served	50.27	74.87	86.63	94.12	99.47	100	100	100	100	100
	% solid waste collected	55.83	62.64	78.09	93.5	98.2	100	100	100	100	100
	No. of waste bins underutilized	0	0	0	0	0	2	2	3	6	7
Economic	Cost of fuel per week (₦ x10^3)	1.72	2.20	3.01	3.06	3.08	3.10	3.53	3.94	3.94	4.40
	Cost of waste bin (million ₦)	1.2	2.4	3.6	4.8	6	7.2	8.4	9.6	10.8	12
Environmental	Greenhouse gas emissions (g/week)										
	N_2O	1.37	1.76	2.41	2.45	2.46	2.48	2.82	3.15	3.10	3.52
	CH_4	0.22	0.29	0.39	0.40	0.40	0.40	0.46	0.51	0.51	0.57
	CO_2 (x10^3)	46.89	59.96	82.08	83.55	84.05	84.62	96.25	107.59	107.48	120.01
	Criteria Air Pollutant emissions (g/week)										
	NO_x (x10^3)	0.55	0.71	0.96	0.99	1.00	1.01	1.14	1.27	1.27	1.42
	CO (x10^3)	1.39	1.78	2.43	2.48	2.49	2.51	2.85	3.19	3.19	3.56
	PM_{10}	12.17	15.63	21.30	21.83	22.00	22.19	25.56	28.11	28.09	31.36

A further increase in the number of waste bins maintained 100% coverage of the study area. A similar trend was observed when the percentage of solid waste collected was evaluated. The economic impacts in terms of cost of procuring the waste bin and cost of fuel for waste collection increased as the number of waste bins increased. In a similar manner, the emissions from the collection vehicle increased as the number of waste bins to be picked increased.

3.1 Comparison of waste bin quantities with respect to impacts

The absolute weight of different number of waste bins under social, economic and environmental impact is shown in Tables 2, 3 and 4 respectively. The priority vector derived from paired comparison of the number of waste bins with respect to the three impacts is presented in Table 5.

Table 2: Average absolute weight of waste bins under social impact

No. of waste bin	1	2	3	4	5	6	7	8	9	10
Solid waste generation points served	1	4.96	6.85	8.05	8.91	9	9	9	9	9
Amount of solid waste collected	1	2.23	5.03	7.82	8.67	9	9	9	9	9
Waste bin underutilization	9	9	9	9	9	6.72	6.72	5.57	2.15	1
Average weight	3.67	5.40	6.96	8.29	8.86	8.24	8.24	7.86	6.72	6.33

Table 3: Average absolute weight of waste bins under economic impact

No. of waste bin	1	2	3	4	5	6	7	8	9	10
Cost of fuel per week	9	7.56	5.15	5	4.94	4.88	3.59	2.37	2.37	1
Cost of waste bin	9	8.11	7.22	6.34	5.45	4.56	3.67	2.78	1.9	1
Average weight	9	7.835	6.185	5.67	5.195	4.72	3.63	2.575	2.135	1

Table 4: Average absolute weight of waste bins under environmental impact

No. of waste bin	1	2	3	4	5	6	7	8	9	10
N_2O	9	7.55	5.13	4.98	4.94	4.87	3.6	2.38	2.56	1
CH_4	9	7.4	5.11	4.87	4.87	4.87	3.52	2.37	2.37	1
CO_2	9	7.57	5.15	4.99	4.93	4.87	3.6	2.36	2.37	1
NO_X	9	7.53	5.23	4.95	4.86	4.77	3.57	2.38	2.38	1
CO	9	7.56	5.17	4.98	4.95	4.87	3.62	2.37	2.37	1
PM_{10}	9	7.55	5.19	4.97	4.9	4.82	3.42	2.36	2.37	1
Average weight	9	7.53	5.16	4.96	4.91	4.85	3.56	2.37	2.40	1

Table 5: Priority vectors for the comparison matrix of waste bins with respect to each impact

Number of waste bins	Priority vector with respect to social impact	Priority vector with respect to economic impact	Priority vector with respect to environmental impact
1	0.0520	0.1877	0.1968
2	0.0765	0.1634	0.1646
3	0.0986	0.1290	0.1129

4	0.1175	0.1183	0.1084
5	0.1256	0.1084	0.1073
6	0.1167	0.0984	0.1060
7	0.1168	0.0757	0.0777
8	0.1113	0.0537	0.0518
9	0.0952	0.0445	0.0526
10	0.0898	0.0209	0.0219

3.2 Comparison of impacts with respect to goal

The matrix developed for paired comparison of the impacts with respect to the goal of the AHP model assumed equal and a combination of unequal weights. The weights of the three impacts with respect to the goal of AHP (choice of the optimal number of waste bin for the study area) were evaluated under the following combination of impacts:

1. Social impact is of importance over other impacts
   - **Soc>Eco>Env**: Social impact is slightly favored more than economic impact and economic impact is favored more than environmental impact.
   - **Soc>Env>Eco**: Social impact is slightly favored more than environmental impact and environmental impact is favored more than economic impact.

2. Economic impact is of importance over other impacts
   - **Eco>Soc>Env**: Economic impact is slightly favored more than social impact and social impact is favored more than environmental impact.
   - **Eco>Env>Soc**: Economic impact is slightly favored more than environmental impact and environmental impact is favored more than social impact.

3. Environmental impact is of importance over other impacts
   - **Env>Soc>Eco**: Environmental impact is slightly favored more than social impact and social impact is favored more than economic impact.
   - **Env >Eco> Soc**: Environmental impact is slightly favored more than economic impact and economic impact is favored more than social impact.

4. **Soc=Eco=Env**: Social, economic and environmental impacts are of equal importance

3.3 Overall weight of waste bins

The priority vector matrix of the number of waste bins with respect to the impacts is a 10 x 3 matrix while the priority vector matrix of the impact with respect to goal is a 3x1 matrix as shown in Table 5 and Table 6 respectively. The overall weight of the waste bins under each scenario is presented in Table 7.

Table 6: Priority vectors for the comparison matrix of impacts with respect to goal

Impacts	Priority vector of unequal impact with respect to goal	Priority vector of equal impact with respect to goal
1	0.6443	0.3318
2	0.2824	0.3318
3	0.0733	0.3318

Table 7: Overall weight of different number of waste bins under each scenario

Scenario	1	2	3	4	5	6	7
No. of waste bins	Soc>Eco>Env	Soc>Env>Eco	Eco>Soc>Env	Eco>Env>Soc	Env>Soc>Eco	Env >Eco> Soc	Soc=Eco=Env
1	0.0999	0.1019	0.1512	0.1829	0.1567	0.1864	0.1458
2	0.1135	0.1141	0.1432	0.1610	0.1448	0.1620	0.1391
3	0.1108	0.1075	0.1213	0.1240	0.1122	0.1182	0.1151
4	0.1133	0.1087	0.1087	0.1014	0.0960	0.0934	0.1031
5	0.1221	0.1256	0.1237	0.1280	0.1331	0.1340	0.1272
6	0.1130	0.1151	0.1058	0.1037	0.1114	0.1072	0.1089
7	0.0989	0.0969	0.0787	0.0650	0.0732	0.0615	0.0786
8	0.0817	0.0816	0.0660	0.0567	0.0655	0.0564	0.0677
9	0.0820	0.0838	0.0611	0.0510	0.0662	0.0542	0.0661
10	0.0646	0.0649	0.0403	0.0264	0.0409	0.0268	0.0438

A waste bin number with a higher weight is preferred to a waste bin number with a lower weight. These weights denote the order of choice of waste bins by the Analytic Hierarchy Process model under each scenario. For example in the Soc>Eco>Env scenario, the use of five waste bins was ranked topmost (weight of 0.1221), followed by the use of four waste bins (weight of 0.1133). Other waste bin numbers also have various ranks based on their overall weight. Therefore, if priority is identified or available resources are known, the result presented in Table 7 would be a valuable guide to municipal solid waste managers in a bid to decide on the most appropriate number of waste bins to be sited within the study area.

4.0 CONCLUSION

The research has demonstrated how the AHP could be applied as a multi-criteria decision making tool for siting a public facility. Several tradeoffs between quality of service, cost and negative impacts were fused together to determine the choice of the number of waste bins to be sited. In the Soc>Eco>Env and Soc>Env>Eco scenario, the AHP model ranked the use of five waste bins topmost. With this choice, service coverage and public satisfaction was guaranteed while economic and environmental impacts were moderate. In the Eco>Soc>Env, Eco>Env>Soc, Env>Eco>Soc, Env>Soc>Eco, and Eco=Env=Soc scenario, the use of only one waste bin was ranked topmost by the AHP model. This choice has the least cost and environmental impact; however, it has the lowest service coverage and public satisfaction. Several other waste bin numbers and locations have varying impacts and ranks under each management scenario. Hence, municipal authorities can choose the most appropriate number of waste bins based on identified priority or available resources for sustainability of solid waste management services.

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