EVALUATION OF WEIGHT OF INDICATOR FOR DEVELOPMENT OF PERFORMANCE INDEX OF MUNICIPAL SOLID WASTE IN THE DEVELOPING INDIAN CITIES

Sukrity Bapat[1], R. K. Bhatia[2]

[1]*ME Environmental Engineering, Department of Civil Engineering, JEC, Jabalpur, MP, India*
[2]*Associate Professor, Department of Civil Engineering, JEC, Jabalpur, MP, India*

Abstract - *In developing scenario of India, the concept of smart cities are playing a crucial role. Solid waste management (SWM) is a category among the smart solutions proposed in the development plan by the government. In the critical effort of management of solid waste, it is necessary to develop analytical method to narrate and observe the output from the waste management process. The current paper focuses on developing a performance index for waste management (WM) system. It can benefit in measurement, in terms of investment decisions, public acceptance levels, social participation and environmental needs. It is attempted to keep the process simple, covering the major process from public, governing sectors as well as hospital perspectives. This performance index can also provide an ease in the comparison between the productivity of the two or more smart cities.*

Key Words: **Smart Cities, Solid Waste Management, Performance Index, Analytical Hierarchy Process, Municipal solid waste.**

1. INTRODUCTION:

Marching towards the tag of developed country, Indian government introduced 'the Smart city mission transformation' in 2016. The term 'Smart' itself provides an idea about the contents of the concept. A Smart city is an urban region that is highly advanced in terms of overall infrastructure, sustainable real estate, communications and market viability. In this concept, information technology is the principal infrastructure and the basis for providing essential services to residents. Other technological platforms are also involved, including but not limited to automated sensor networks and data centres. Indian government initially selected 100 cities in India on the culture and tourism, industrial, educational as well as capital centre basis.

Smart cities are equipped with variety of departments viz. adequate water supply, assured electricity supply, e-governance etc. Of these, effective sanitation, including solid waste management focuses on improving the hygienic condition of the urban area. The Ministry of Urban Development, Government of India, and the Central Pollution Control Board (CPCB) of India, annually publish National City Rating under the 'Swachh Bharat Abhiyan scheme'. The rating includes around 500 cities, covering 72 percent of the urban population in India. Until 2017, India was divided into five zones for the purpose of this survey and each city was scored on 19 indicators. The cities were classified into four colors: green, blue, black, and red, green being the cleanest city, and red the most polluted. None of the cities were rated as green—the best category among them.

Municipal solid waste management (MSWM), a critical element towards sustainable metropolitan development, comprises segregation, storage, collection, relocation, carry-age, processing and disposal of solid waste to minimize its adverse impact on environment. Under the Waste Regulations act 2011, one must segregate paper, paper material, plastic, metal and glass at source unless it is technically or economically unfeasible. Under the same regulations, one should implement the waste hierarchy; reduce, reuse, recycle, other recovery and disposal. By law, one should implement this hierarchy and segregation helps with recycling in particular.

2. AIM AND OBJECTIVES:

To develop performance index (PI) for the solid waste management in the Indian smart cities.

3. METHOD OF MEASUREMENT:

At present, many published assessment methods for waste management systems are quite advanced and sophisticated because waste management is considered a strategic sector of public service (Coelho et al., 2012). The high goal to provide sustainability as a balance between society, economy, and ecology requires an integrated approach. Hence, for an evaluation of the many effects of waste management systems, it is necessary to consider all of the processes involved (Diaz and Warith, 2006). The current study is based on a thorough literature search that was composed of articles in journals available.

4. IDENTIFICATION OF KEY PERFORMANCE INDICATORS

The potential PIs that can be used to evaluate the performance of SWM were identified from the literature review. These PIs formed the basis of 2 different sets of questionnaires which targeted: Management officers and experts, health officers, disposal plant officers and citizens. This questionnaires was used to sample the opinions on the degree of importance of the PIs on a 5- point Likert scale, i.e. 1 = not important, 5 = very important. The relative importance of the PIs was identified using the relative importance index (RII) as Eq. (1).

RII= Wi Xi/A×n5i=1 (1)

Where Wi = the weight given to the ith response: I = 1, 2,3,4,5, Xi = frequency of the ith response, A = the highest weight (5 in this study), and n= the number of respondents.

To obtain the KPIs, the cut off value of 90 % for RII was used. These KPIs t formed the SWMI.

5. IDENTIFICATION OF WEIGHT OF INDICATORS USING AHP

AHP stands for Analytic Hierarchy Process. It is a multi-criteria decision making method, originally developed by Prof. Thomas L. Saaty. AHP derives ratio scales from paired comparisons of criteria and allows for some small inconsistencies in judgments. Inputs can be actual measurements, but also subjective opinions. This method is theoretically sound for weighting and selecting individual indicators. In a hierarchical model of a decision problem, broad overall objective (or goal) is the crown of the structure. The lower levels includes the criteria, sub criteria and also alternatives used for evaluation.

Respondent in an AHP survey are less likely to adopt mental short cuts by concentrating disproportionately on one criteria or level. Thus AHP may probably provide an enough discrimination between motivations to make results significant. The AHP decision factors by pairs and assigns weights to reflect their relative importance. Once these hierarchies are established, a matrix is constructed within which elements within each level (and between levels) are compared pair wise. The result is a clear priority statement of an individual or group. The comparisons were made by posing the question. Mathematically the method is based on the solution of an Eigen value problem. The results of the pair-wise comparisons are arranged in a matrix. The first normalized Eigen vector of the matrix gives the ratio scale (weighting), the largest Eigen value determines the consistency ratio.

6. APPLICATION OF AHP

AHP is most useful where teams of people working on complex problems, especially those with high stakes, involving human perceptions and judgements, whose resolutions have long-term repercussions. AHP consists of three main principles, including hierarchy frame work, priority analysis and consistency verification. Formulating the decision problem in the form of hierarchy framework is first step of AHP, while top level present object, and after that criteria and sub-criteria and alternatives. Once a hierarchy framework is constructed, a pair wise comparison matrix is setup at each levels and compare each other according to Saaty's scale

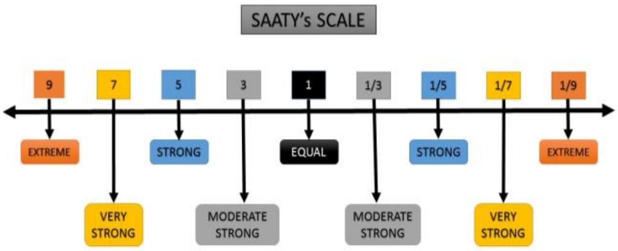

Fig. 1: Saaty's 9 Point Scale

Referring to a questionnaire, an excel sheet is produced doing the calculation for up to 6 criteria. In this study, use of AHP is made considering SWM of cities and the criteria are considered as given in the Fig.2 below.

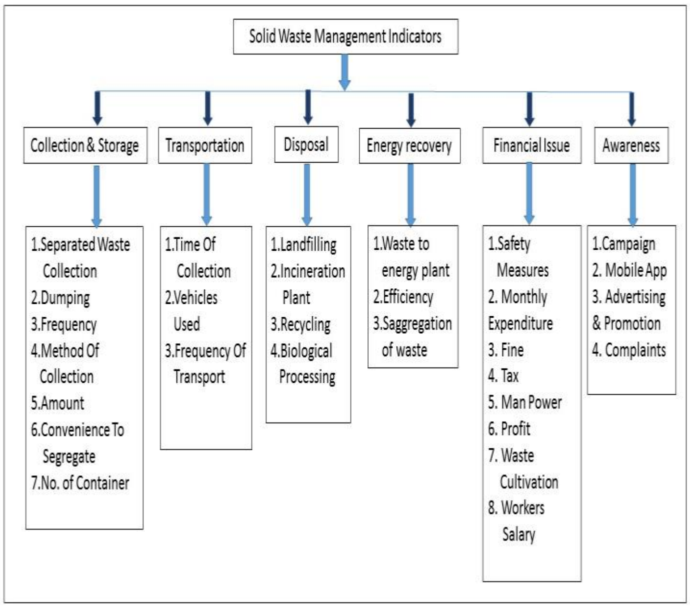

Fig. 2: Three Level Hierarchy Model

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment moderately favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities of 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

Fig. 3: Fundamental Scale for Pairwise Comparisons

Inputs can be actual measurements, but also subjective opinions. Mathematically the method is based on the solution of an Eigen value problem. The results of the pair-wise comparisons are arranged in a matrix. The first normalized Eigen vector of the matrix gives the ratio scale (weighting), the largest Eigen value determines the consistency ratio.

7. PROCESS OF ANALYSIS:

7.1 Defining Objective:

The ultimate goal of research is evaluation of solid waste management process in different cities of India. These may involve the problems of collection, transportation, disposal, energy recovery, recycling, composting of organic waste and factors that affect proper processing of waste i.e. financial, economic, political and technical.

7.2 Structural Elements in Criteria, Sub- Criteria and Alternatives etc.

In this part, different level of hierarchy was developed (as shown in fig: three level hierarchy). In this method the primary or top level of hierarchy is "goal of hierarchy", is established. This level impressions the theme of the study. On the second step of the hierarchy, the sub criteria viz. collection & storage, transportation, disposal, energy recovery, financial, awareness are placed. The second step deals with the associated steps that provides a pivot to carry out the study with different aspects. The third step of the hierarchy is 'sub criteria'. These three steps further assists in obtaining local priorities which indicate the preferred alternative with respect to each criterion. Next part of the study is about calculation of the overall priority (also called final priority), for each alternative; that is, priorities that taken in to account gives preference of alternatives for each criterion but also the fact that each criteria has a different weight. Given that all the values provided in the model are being used, this step is called model synthesis. Initially starting from the calculation of the overall priority using the local priority of each alternative as the starting. Further, the weights of each criteria has to be taken into consideration and for this purpose they are inserted in the table as shown in Table Preparation for weighing of priorities.

7.3 Pair Wise Comparison of Elements in Each Group

A pair wise comparison matrix is constructed for the lower level of hierarchy. Pair wise comparison generates matrix of relative rankings for each level. The number of matrix depends on the number of elements at each level. Table 1 shows matrix of main criteria, by eq. 1 matrix is formed to find Eigen vector. And for Normalized & calculate first normalized principal Eigen vector X1 eq. 2 were followed.

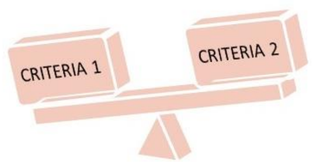

Fig.4 : Comparison Of Elements

7.4 Judgment for Pair Wise Comparison

For the judgement of pairwise comparison performance of two selected items compared. These judgment are used for the formation of matrix in previous step. Fig comparison of elements

7.5 Synthesizing the Pairwise Comparison

To calculate the vectors of priorities, the average of normalized column (ANC) method is used. ANC is to divide the elements of each column by the sum of the column and then add the element in each resulting row and divide this sum by the number of elements in the row (n). This is a process of averaging over the normalized columns.

7.6 Calculation of the weight

The importance of criteria are compared pairwise with respect to the desired goal to derive their weights. Weighting of each criteria and sub criteria were calculated by eq. 2 and in table after the final iteration.

7.7 Calculation of Consistency Ratio

Once judgments have been entered, it is necessary to check that they are consistent. The idea of consistency is best illustrated in the following example: If one prefers an apple twice as much than a pear and a pear twice as much than an orange; how much would one prefer an apple with respect to an orange? The mathematically consistent answer is 4. Similarly, in a comparison matrix criteria, if one provides a value of 2 to the first criterion over the second and assign a value of 3 to the second criterion with respect to the third one, the value of preference of the first criterion with respect to the third one should be $2 \times 3 = 6$. However, if the decision-maker has assigned a value such as 4, 5, or 7, there would be a certain level of inconsistency in the matrix of judgments. Some inconsistency is expected and allowed in AHP analysis.

Since the numeric values are derived from the subjective preferences of individuals, it is impossible to avoid some inconsistencies in the final matrix of judgments. The question is how much inconsistency is acceptable. For this purpose, AHP calculates a consistency ratio (CR) comparing the consistency index (CI) of the matrix in question (the one with our judgments) versus the consistency index of a random-like matrix (RI) given in table. A random matrix is one where the judgments have been entered randomly and therefore it is expected to be highly inconsistent. More specifically, RI is the average CI of 500 randomly filled in matrices. Saaty (2012) provides the calculated RI value for matrices of different sizes as shown in Table.

In AHP, the consistency ratio is defined as CR where CR = CI/RI. Saaty (2012) has shown that a consistency ratio (CR) of 0.10 or less is acceptable to continue the AHP analysis. If the consistency ratio is greater than 0.10, it is necessary to revise the judgments to locate the cause of the inconsistency and correct it. Since the calculation of the consistency ratio is easily performed by computer programs, producing an estimate of this value as follows:

7.7.1 Start with the matrix showing the judgment comparisons and derived priorities (Table 4).

7.7.2 Use the priorities as factors (weights) for each column as shown in eq. 1.

7.7.3 Multiply each value in the first column of the comparison matrix by the first criterion priority; multiply each value in the second column of the second criterion priority; continue this process for all the columns of the comparison matrix.

7.7.4 Add the values in each row to obtain a set of values called weighted sum.

7.7.5 Divide the elements of the weighted sum vector (obtained in the previous step) by the corresponding priority of each criterion. Calculate the average of the values from the previous step; this value is called δ by Eq. 4

7.7.6. Calculation of the consistency index (CI) Eq. 5 as follows:

$$CI = \frac{\delta - n}{n-1}$$

Where n is the number of compared elements in this study n= 6

7.7.7 Now the consistency ratio can be calculated, defined as Eq.6:

$$CR = \frac{CI}{RI}$$

Therefore, CI is the consistency index calculated in the previous step. RI is the consistency index of a randomly generated comparison matrix and is available to the public in tables (Table 1). In other words, RI is the consistency index that would be obtained if the assigned judgment values were totally random. It can be seen that for n = 6, RI =1.24. Using these values for CI and RI, ratio can be calculated.

If CR is less than 0.10, one can assume that our judgments matrix is reasonably consistent so one may continue the process of decision-making using AHP.

7. 8 Evaluation of Alternatives According to Weight:

The third step consists of deriving the relative priorities (preferences) of the alternatives with respect to each criterion. In other words, what are the priorities of the alternatives with respect to collection & storage, transportation, disposal, energy recovery, financial, and awareness respectively? Since these priorities are valid only with respect to each specific criterion, they are called local priorities to differentiate them from the overall priorities to be calculated later. As indicated, one needs to determine the priorities of the alternatives with respect to each of the criteria. For this purpose, a pairwise comparison has to be conducted (using the numeric scale from Table Saaty's pairwise comparison scale) of all the alternatives, with respect to each criterion, included in the decision making model. In a model with two alternatives it is required to make only one comparison (Alternative 1 with Alternative 2) for each criterion; a model with three alternatives would require to make three comparisons (Alternative 1 with Alternative 2, Alternative 2 with Alternative 3, and Alternative 1 2.3 Consistency 15 with alternative 3) for each criterion; and so on. There will be as many alternative comparison matrices as there are criteria.

7.9 Get Priority Ranking

For the priority ranking as per AHP method weight of criteria are used calculated in previous steps.

Once the above steps have been completed, it is now possible to make a decision. This constitutes the last step in AHP analysis. For this, it is necessary to compare the overall priorities obtained and whether the differences are large enough to make a clear choice. It is also necessary to analyze the results of the sensitivity analysis. From this analysis, final recommendation can be drawn out.

8.MATHEMATICAL FORMULATION FOR IDENTIFICATION OF WEIGHT OF INDICATORS USING AHP

Table 1: Matrix of Main Criteria

	Collection & storage	Transportation	Disposal	Energy recovery	Financial Issue	Awareness
Collection & storage	1	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}
Transportation	A_{12}^{-1}	1	A_{23}	A_{24}	A_{25}	A_{26}
Disposal	A_{13}^{-1}	A_{23}^{-1}	1	A_{34}	A_{35}	A_{36}
Energy recovery	A_{14}^{-1}	A_{24}^{-1}	A_{34}^{-1}	1	A_{45}	A_{46}
Financial Issue	A_{15}^{-1}	A_{25}^{-1}	A_{35}^{-1}	A_{45}^{-1}	1	A_{56}
Awareness	A_{16}^{-1}	A_{26}^{-1}	A_{36}^{-1}	A_{46}^{-1}	A_{56}^{-1}	1
Total of column	S_{c1}	S_{c2}	S_{c3}	S_{c4}	S_{c5}	S_{c6}

8.1 Find the Eigen vector of the matrix

$$\text{Matrix N for n(=6)criteria N} = \begin{bmatrix} \frac{1}{1} & \frac{A12}{1} & \frac{A13}{1} & \frac{A14}{1} & \frac{A15}{1} & \frac{A16}{1} \\ \frac{1}{A12} & \frac{1}{1} & \frac{A23}{1} & \frac{A24}{1} & \frac{A25}{1} & \frac{A26}{1} \\ \frac{1}{A13} & \frac{1}{A23} & \frac{1}{1} & \frac{A34}{1} & \frac{A35}{1} & \frac{A36}{1} \\ \frac{1}{A14} & \frac{1}{A24} & \frac{1}{A34} & \frac{1}{1} & \frac{A45}{1} & \frac{A46}{1} \\ \frac{1}{A15} & \frac{1}{A25} & \frac{1}{A35} & \frac{1}{A45} & \frac{1}{1} & \frac{A56}{1} \\ \frac{1}{A16} & \frac{1}{A26} & \frac{1}{A36} & \frac{1}{A46} & \frac{1}{A56} & \frac{1}{1} \end{bmatrix} \quad Eq.\ (1)$$

$$\text{Sum of column} = \quad Sc1 \quad Sc2 \quad Sc3 \quad Sc4 \quad Sc5 \quad Sc6$$

8.2 Normalizing & calculation of the first normalized Principal Eigen vector X1

$$|N| = \begin{bmatrix} \frac{1}{Sc1} & \frac{A12}{Sc2} & \frac{A13}{Sc3} & \frac{A14}{Sc4} & \frac{A15}{Sc5} & \frac{A16}{Sc6} \\ \frac{\frac{1}{A12}}{Sc1} & \frac{1}{Sc2} & \frac{A23}{Sc3} & \frac{A24}{Sc4} & \frac{A25}{Sc5} & \frac{A26}{Sc6} \\ \frac{\frac{1}{A13}}{Sc1} & \frac{\frac{1}{A23}}{Sc2} & \frac{1}{Sc3} & \frac{A34}{Sc4} & \frac{A35}{Sc5} & \frac{A36}{Sc6} \\ \frac{\frac{1}{A14}}{Sc1} & \frac{\frac{1}{A24}}{Sc2} & \frac{\frac{1}{A34}}{Sc3} & \frac{1}{Sc4} & \frac{A45}{Sc5} & \frac{A46}{Sc6} \\ \frac{\frac{1}{A15}}{Sc1} & \frac{\frac{1}{A25}}{Sc2} & \frac{\frac{1}{A35}}{Sc3} & \frac{\frac{1}{A36}}{Sc4} & \frac{1}{Sc5} & \frac{A56}{Sc6} \\ \frac{\frac{1}{A16}}{Sc1} & \frac{\frac{1}{A26}}{Sc2} & \frac{\frac{1}{A36}}{Sc3} & \frac{\frac{1}{A45}}{Sc4} & \frac{\frac{1}{A56}}{Sc5} & \frac{1}{Sc6} \end{bmatrix}$$

Eq. (2)

$$X1 = \begin{bmatrix} \frac{\sum row1}{n} \\ \frac{\sum row2}{n} \\ \frac{\sum row3}{n} \\ \frac{\sum row4}{n} \\ \frac{\sum row5}{n} \\ \frac{\sum row6}{n} \end{bmatrix}$$

Eq. (3)

Square normalized matrix |N| & calculate next iteration of Eigen vector until difference

$X_{k-1} - X\delta$ is negligible $X2 \rightarrow |N|^2$

Calculate largest Eigen value δ =

$S_{c1} X_1 + S_{c2} X_2 + S_{c3} X_3 + S_{c4} X_4 + S_{c5} X_5 + S_{c6} X_6$ **eq. (4)**

Calculate consistency index

$CI = \frac{\delta - n}{n-1}$ **Eq. (5)**

Verify consistency ratio <10%

$CR = \frac{CI}{RI}$ **Eq. (6)**

Table 2: Random Index RI (The Consistency Indices of Randomly Generated Reciprocal Matrices)

Order of the matrix															
Matrix order no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI value	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.59

9. PREPARATION OF QUESTIONNAIRE

For the evaluation of performance of MSWM services a questionnaire of various questions for different departments are developed.

Questions are specific and related to many areas of SWM services. It is divided into two groups 1) for public 2) for Municipal corporation officers, experts, companies who work in this field.

Public group divided into main criteria and sub criteria. Respondent has to choose criteria of relative importance and then decided score depending upon its importance equally, moderate, strong, very strong, extreme important.

Officers, engineers from SWD consultants and contractors are chosen as respondents of these questionnaire to give their experience. Questionnaire was sent to people from random wards. As the common people come only across 'collection and storage' and 'transportation' of the waste collected from their nearby regions, the questions regarding only these two issues were included in the public questionnaire.

Table 3: Benchmarking of Scoring in questionnaire

Analytical criteria	Indicators				
	1	2	3	4	5
Social awareness	No awareness at all	Aware about waste consequences but not following	Aware about waste processes and not following	Aware about process but least followers	Most obedient process followers.
Collection and storage	No collection at all	Nearby municipal waste collection container	Door to door waste collection by vehicle.	Segregated door to door collection.	Segregation of collected waste at all levels.
Transportation	No suitable means of transportation	Unscheduled collection of waste.	Daily transportation of collected waste	Open and separate container carts.	Closed and separate container vehicles.
Disposal	No disposal method implementation	Landfilling	Landfilling and composting method.	Landfilling composting and Reuse by energy recovery	Reuse or recycling (Minimum residual waste production)
Energy recovery	No availability of recovery plants.	Proposed energy recovery plant	Small scale, limited amount recovery plant	Non profitable but efficient energy recovery plant.	Profitable, multiple, futuristic energy recovery plants.
Financial issues	Loss	Minimum profit	Medium profitable	Average profitable system	Well managed profitable system

10. CALCULATION OF SWMI

The Solid Waste Management Index (SWMI) is formed by combination (aggregation) of the several indicators and each one has a weight.

For the evaluation of SWM in this weight of main criteria and sub criteria indicators are used. For the calculation of main criteria weight process explained in previous steps. Similar procedure is used for the calculation of weight of each set of sub criteria of the study.

Weight of sub criteria in each set is multiplied by weight of main of its own criteria to determine its weight in whole system. for example , weight of collection & storage is

15.11/100, now weight of separate waste collection system is 12.56 % hence final weight of % separate waste collection system is = 12.56 × 15.11=1.89/100 . So the weight for all parameters is derived using the same process as described in the study.

11. CONCLUSION

Solid waste management is overall a complicated process when it comes to economical management. In this study, the first step was to develop an AHP model. It included the chief aim of the study, the criteria that divides the study into different platforms viz. collection, segregation etc. and the sub criteria. As the data is differentiated in the AHP method with the help of Saaty's 9 pointer scale. The next step was to calculate the weightage of each criteria with the help of Eigen vector. The consistency ratio has to be <0.1 so as to be acceptable for final judgement. Following this method it will be easier to compare the PI of multiple cities with respect to solid waste management.

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