Fuzzy AHP- Goal Programming Technique for Selecting the Best Plastic Waste Management Method

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Abstract—*As the population increases the amount of waste created is also increases. The significant portion of the total solid waste is plastic waste. Plastics are used by all sector people. They are non-biodegradable and so it cannot be returned to carbon cycle. Plastic wastes become threat to the environment. Waste plastic management is a large area of study. Numbers of methods are available to dispose the waste plastic. In this paper the best plastic waste management method is determined using Fuzzy AHP – Goal programming method. For this the criteria are selected and based on it the alternatives are evaluated by Fuzzy AHP methodology. Goal programming technique is used to derive weight vectors. Based on the weight vectors the alternatives are ranked and best one is identified.*

Keywords — *Solid waste, Plastic waste, Fuzzy AHP, Goal programming technique.*

I. INTRODUCTION

Plastics are the most useful invention of this era. Because of its light weight, low cost, reusable properties it is used by all.Production of plastic is increasing almost 10 percentage every year globally. The annual production of plastics raised from 1.5 million ton in 1950 to 322 Million ton in 2015. The total consumption of plastics in India at 2016 is 21.9 Million tons. The amount of plastic waste generated in India is 15,342 tons/ day. Based on their origin plastic wastes are classified as Municipal plastic waste and Industrial plastic waste. Large part of plastic waste are disposed in Landfills, some of them are recycled and some are recovered as energy. Landfill space is becoming scarce and expensive and landfilled waste plastics produces greenhouse gases. So it is not a desirous option. Selecting a best waste management method is an important area of study.

David Lazaveric et al [1] studied waste plastic management in the European context and they compared results and uncertainties in a life cycle perspective. EboTawianQuartey et al [2] studied the waste plastic management in Ghana through extended produces responsibility. AchyutK.Panda [3] introduced a process of producing liquid fuel using waste and justified in their paper that this option is a best one. S.Vinodh et al [4] have done a case study using Fuzzy AHP- TOPSIS methodology for selecting the best plastic recycling method. N.Othmen et al [5] discussed about the research conducted on electronic plastic wastes potential as a source of energy. S.M.Al-salem et al [6] in their paper discussed about different methods of recovery routes and recycling of plastic solid waste.

To select a best plastic waste management method many criteria and experts opinion are to be considered. So this problem can be modelled as Multi criteria decision making (MCDM) problem. AHP is one of the most used approach of MCDM problem. In AHP decision maker's ambiguity and uncertainty cannot be modelled effectively. The possible solution is to extend AHP in the Fuzzy environment. FAHP has been studied by many authors. Extent analysis method [7], fuzzy priority theory [8], Fuzzy preference programming method [9], Goal programming method [10], Fuzzy hierarchical analysis [11] are the available methods to evaluate weights from the comparison matrices in FAHP.

S.Chakraborthy et al [12] studied the different plastic recycling methods and its barriers through Fuzzy-AHP method, MohdArmiabusamah et al [13] studied the solid waste management techniques using AHP in Malaysia.

In this paper the best plastic waste management technique is identified using FAHP – Goal programing technique. To do so this paper is arranged as follows. Section-1 introduces the problem and provides the literature survey. Section-2 explains the possible plastic waste management method. Methodology used in this problem to select the best plastic waste management method suitable in India. Section-4 solves the problem by FAHP and goal programming technique. Conclusion is given in the final section.

II. PLASTIC WASTE MANAGEMENT METHODS

As the population increases the demand for plastic product also increases. The total consumption of plastic in India at 2015 is 21.9 million tons. The amount of plastic waste generated in India is 15,342 tons/day. The lifecycle of the plastic waste ends at disposal facilities. There are multiple methods available to dispose the plastic wastes. Land filling, Mechanical recycling, Incineration, Feedstock recycling, Biological recycling are some of the methods.

A. Land filling:

Largest amount of plastic wastes are subjected to landfill. It is becoming undesirable due to increase of land cost and population. Land filling of waste creates ground water contamination and it produces harmful gases like methane. Landfill space is very expensive. In America this gas is collected from the landfills and it is used instead of coal and other fuels.

In India the current per day per capita waste generation in cities in average is 300-600 kg. 43 million tonnes of solid waste are collected annually, out of which 31 Million are dumped at landfills.62 million tons of waste are generated in India each year. In this 5.6 million are plastic wastes. This creates serious health issues including breathing problems, bacterial infection.

B. Mechanical Recycling:

Mechanical recycling is the process of making products from used plastics with same or less performance level. Using waste plastics, the process of laying roads are designed and implemented successfully at several places in India. Also efforts are taken to convert plastic wastes to concrete or wood substitute in manufacturing of benches, fence posts, boats etc. In constructional works waste plastics are added as modifier in the 5% level in the cement concrete. It is found that the strength of the concrete is two times greater than the plain cement concrete. But if the plastic waste is contaminated the cost of cleaning up is high. Large amount of energy is required to segregate the plastic waste that can be recycled mechanically. The performance level of the recycled one from the waste plastics are very low.

C. Incineration:

Recovery of energy by incinerating waste plastic is called incineration. The heating value of plastics exceeds 40 MJ/Kg because of its high content of hydrogen and carbon. So plastic wastes are partially used instead of fossil fuels and also it is used as co-incinerator. This has the financial gain. Hence it is a preferred option for local authorities. In India in the state of Madhya Pradesh plastic waste is used as alternate fuel in the cement plant.

But the disadvantage of this method is it produces highly toxic pollutants and greenhouse gases which is highly a threat to the environment.

D. Feedstock recycling:

It is the method of forming valuable chemicals or original monomers from the waste polymers. From these recycled monomers a new plastic product can be formed with same or less performance level. This final product from the feedstock recycling can be used also as transportation fuels. In cost and ecological perspective it would be better alternative.

In India at Nagpur, Maharashtra a research plant was set up to convert waste plastic in to liquid fuel in the presence of catalyst. In most of the world this process of depolymerisation is practiced.

E. Bio degradable plastics production

The plastic that degrades naturally by biological process are made up of plant materials are used successfully in many countries. They are used mostly in packaging, food and catering industries. The disadvantage of this is, it is decomposed only when it is exposed to the sunlight. It is very difficult to segregate this kind of plastic from the other plastic waste. Cost of making biodegradable plastics is high compared to the others.

III. METHODOLOGY

The aim of this research is to select a best plastic waste management method using Fuzzy AHP and Goal programming technique.

A. Fuzzy AHP:

AHP is a methodology to solve a decision making problems by evaluating the weightages for a set of alternatives of that problem. In AHP the decision maker's uncertainty cannot be expressed. So Fuzzy set theory is introduced in AHP. In this paper Triangular fuzzy numbers are used to express decision maker's opinion. The steps are Fuzzy AHP are explained below.

Step: 1 the problem is divided into multi-level hierarchical structures which consist of goal, criteria, sub criteria and alternatives.
Step: 2 at each level of the hierarchy the elements are compared with each other with other with respect to the previous level with the help of Fuzzy scale given in Table-1.

Table-1 Judgment scale

Linguistic Variable	Triangular Fuzzy number (TFN)	Reciprocal TFN
Equally Preferred	(1,1,1)	
Weakly Preferred	(2/3,1,3/2)	(2/3,1,3/2)
Strongly preferred	(3/2,2,5/2)	(2/5,1/2,2/3)
Very Strongly preferred	(5/2,3,7/2)	(2/7,1/3,2/5)
Absolutely preferred	(7/2,4,9/2)	(2/9,1/4,2/7)

The judgment values are taken in the form of matrices. The elements of the matrices are Triangular fuzzy Numbers (TFN).The definition of triangular fuzzy numbers is as follows:

Def: 1

TFN is defined by $\tilde{A}$ = (l, m, u) whose membership function is defined as follows.

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x-l}{m-l} & l \le x \le m \\ \dfrac{u-x}{u-m} & m \le x \le u \\ 0 & otherwise \end{cases}$$

In a comparison matrix $\tilde{a}_{ij} = (\tilde{a}_{ji})^{-1} = \left(\dfrac{1}{u_{ij}}, \dfrac{1}{m_{ij}}, \dfrac{1}{l_{ij}}\right)$ for all i<j. So it is enough to find $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$

Step: 3 Weightages which are triangular fuzzy number (TFN) are evaluated from these comparison matrices using Goal programming technique which is explained in the next section.
Step: 4 the weight values are fused from top level of the hierarchy to bottom level and weight vectors are evaluated for the alternatives.

Step: 5 the weights which are TFN are defuzzified using the formula $w_i = \dfrac{(l_i + m_i + u_i)}{3}$ and made it as a crisp vectors. Based on the weights, the alternatives are ranked and the best plastic waste management is selected.

B. Goal programming Technique:

Goal programming is an extension of linear programming problem. This is also called as branch of Multi Criteria Decision Making problem. This handles with the conflict, multiple goal subject to the constraints. In this paper, from the comparison matrices the weight vectors are evaluated using goal programming technique. Goal programming formulation of comparison matrices with Triangular Fuzzy Number is given in [15] which is as follows:

If $\tilde{A} = (\tilde{a}_{ij})_{n \times n}$ be the comparison matrix where $\tilde{a}_{ij} = (\tilde{l}_{ij}, \tilde{m}_{ij}, \tilde{u}_{ij})$ then

$$\min = \sum_{i=1}^{n} (d_i^+ + d_i^- + \gamma_i^+ + \gamma_i^- + \delta_i)$$

$$\sum_{j=2}^{n} l_{ij} w_j^u - (n-1) w_i^l - d_i^- + d_i^+ = 0 \quad for\ i = 1,2,\ldots,n.$$

$$\sum_{j=2}^{n} u_{ij} w_j^l - (n-1) w_i^u - \gamma_i^- + \gamma_i^+ = 0 \quad for\ i = 1,2,\ldots,n.$$

$$(m_{ii} - n) w_i^m + \sum_{j=2}^{n} m_{ij} w_j^m - \delta_i = 0 \quad for\ i = 1,2,\ldots,n.$$

$$w_i^l + \sum_{j=1,\, j\neq i}^{n} w_j^u \geq 1 \quad for\ i = 1,2,\ldots,n$$

$$w_i^u + \sum_{j=1,\, j\neq i}^{n} w_j^l \leq 1 \quad for\ i = 1,2,\ldots,n$$

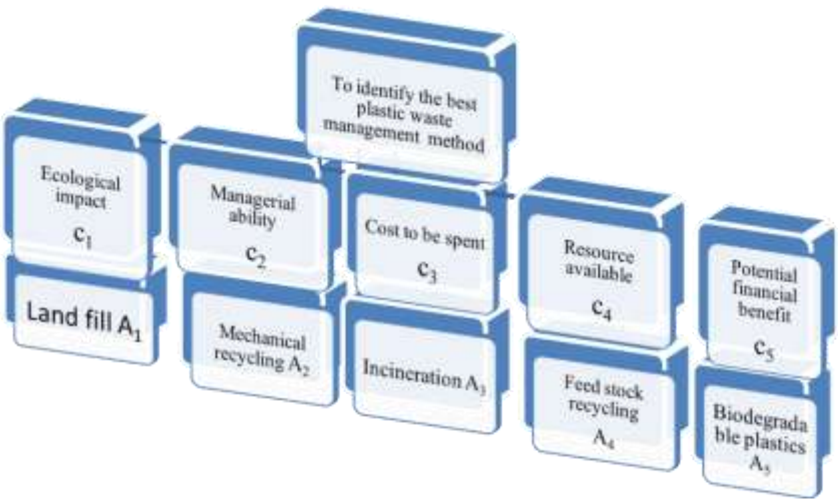
$$w_i^u - w_i^m \geq 0$$

$$w_i^m - w_i^l \geq 0$$

$$w_i^l, d_i^+, d_i^-, \gamma_i^+, \gamma_i^-, \delta_i \geq 0 \quad for\ i = 1,2,\ldots,n.$$

IV. CASE STUDY

This research aims to identify best waste plastic management in India. For this the alternatives are Land filling (A_1), Mechanical recycling (A_2), Incineration (A_3), Feedstock recycling (A_4), and Biodegradable plastic production (A_5). The criteria by which the alternatives selected are Ecological impact (c_1), the managerial ability (c_2), Cost to be spent (c_3), resources available (c_4), and Potential financial benefits (c_5). These criteria are selected by having discussion with decision makers. They are group of three persons who are experts in the field of polymer technology. The hierarchical structure of the problem is given below.



Initially, criteria are compared with each other with respect to goal and judgment values are given in Table-2.

Table-2 Criteria comparison matrix

	C_1	C_2	C_3	C_4	C_5
C_1	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)	(5/2,3,7/2)
C_2	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(5/2,3,7/2)
C_3	(2/5,1/2,2/3)	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)
C_4	(2/3,1,3/2)	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(5/2,3,7/2)
C_5	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(3/2,2,5/2)	(2/7,1/3,2/5)	(1,1,1)

By using Goal programming technique the weight vectors are given below:

W_{c1}= (0.28, 0.31 ,0.31), W_{c2}=(0.22,0.25,0.27), W_{c3}=(0.06, 0.14, 0.18), W_{c4}= (0.21,0.23,0.25), W_{c5}=(0.07,0.08,0.11).

Likewise all the matrices are evaluated and weight vectors are calculated. Overall weights are given in the following Table.

Table-3 Overall weights

Criteria weights	(0.28, 0.31, 0.31)	(0.22,0.25,0.27)	(0.06, 0.14, 0.18)	(0.21,0.23,0.25)	(0.07,0.08,0.11)
Alternative weights with respect to criteria	C_1	C_2	C_3	C_4	C_5
A_1	(0.048,0.048,0.048)	(0.14,0.17,0.21)	(0.11,0.11,0.14)	(0.25,0.29,0.35)	(0.35,0.37,0.39)
A_2	(0.41,0.43,0.43)	(0.22,0.225,0.227)	(0.122,0.14,0.16)	(0.13,0.135,0.15)	(0.035,0.07,0.12)
A_3	(0.43,0.47,0.47)	(0.21,0.25,0.25)	(0.122,0.13,0.154)	(0.105,0.105,0.105)	(0.029,0.037,0.0625)
A_4	(0.35,0.37,0.37)	(0.21,0.22,0.24)	(0.17,0.22,0.28)	(0.137,0.138,0.14)	(0.023,0.05,0.07)
A_5	(0.156,0.167,0.17)	(0.46,0.462,0.462)	(0.16,0.16,0.2)	(0.07,0.07,0.11)	(0.11,0.11,0.15)

From the above table, overall alternative weights are calculated and given as
A_1 = (0.13,0.17,0.22), A_2 = (0.20,0.25,0.27),
A_3 = (0.198,0.25,0.27), A_4 = (0.19,0.24,0.27),
A_5 = (0.18,0.22,0.26).

Defuzzifying and making this as crisp vector, the weight vectors are A_1 = 0.18, A_2 = 0.28, A_3 = 0.24, A_4 = 0.23, A_5 = 0.22.

From this it can be concluded that the best plastic waste management method is Mechanical recycling followed by Feed stock recycling.

V. Conclusion

In this paper, the best plastic waste management method is identified using Fuzzy AHP and Goal programming technique. For this five criteria and five alternatives are selected. The comparison matrices are formed by comparing the criteria with respect to goal and alternatives are compared with respect to criteria. Weight values are evaluated from the comparison matrices using Goal programming technique. It is found that Ecological impact is the most important criteria whereas Mechanical recycling is the most preferred waste plastic management method. Since this paper uses Goal programming technique the inconsistency of the comparison matrix is resolved and weight values are accurate.

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