

January 01, 2004

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Recommended Citation

Gupta, Surendra M. and Pochampally, Kishore K., "Evaluation of recycling programs with respect to drivers of public participation: a fuzzy TOPSIS approach" (2004). Paper 53. <http://hdl.handle.net/2047/d10013866>

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Bibliographic Information

Pochampally, K. K. and Gupta, S. M., "Evaluation of Recycling Programs with respect to Drivers of Public Participation: A Fuzzy TOPSIS Approach", ***Proceedings of the 2004 Northeast Decision Sciences Institute Conference***, Atlantic City, New Jersey, pp. 226-228, March 24-26, 2004.

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EVALUATION OF RECYCLING PROGRAMS WITH RESPECT TO DRIVERS OF PUBLIC PARTICIPATION: A FUZZY TOPSIS APPROACH

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ABSTRACT

Evaluating the performance of a recycling program is equivalent to evaluating how well the program is driving the public to participate in the program. Studies are conducted in numerous cities around the world, in order to assess the level of participation of the public in their respective recycling programs. The officials of each program painstakingly approach many homes in the city, with questions regarding how convenient the program is to them and how the program can be improved. This paper lists some important drivers of public participation, and proposes a fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) approach to evaluate recycling programs with respect to those drivers. Application of the fuzzy TOPSIS approach is detailed through a numerical example.

MOTIVATION

The success of a recycling program is very heavily dependent on the level of public participation. Hence, evaluating the performance of a recycling program is equivalent to evaluating how well the program is driving the public to participate in the program. Studies have been conducted in numerous cities around the world, to assess the level of public participation in their respective recycling programs (see, for example, [4], [6]). The officials of each program painstakingly approach many homes in the city, with questions regarding how convenient the program is to them and how the program can be improved. While the drivers for governments and/or companies to implement these programs and evaluate the programs' performances are environmental consciousness [2] and profitability [1], the drivers for the public to participate in the programs are numerous and often conflicting with each other (for example, the more regularly a recycling program offers to collect used products from consumers, the more taxes the consumers will have to pay; high regularity of collection and low tax levied on the consumers are conflicting drivers, here). What's lacking in the literature is the identification of all the important drivers of public participation and a systematic method to evaluate a recycling program's performance with respect to those drivers. This paper attempts to fill that void.

DRIVERS OF PUBLIC PARTICIPATION

The following is a fairly exhaustive list of self-explanatory drivers for the public to participate in a recycling program:

- i. Knowledge of drivers of implementation of the recycling program (KD)
- ii. Awareness of the recycling program being implemented (AR)
- iii. Simplicity of the recycling program (SR)
- iv. Convenience for disposal of used products at collection centers (CD)
- v. Incentives for disposal of used products (ID)
- vi. Effectiveness of collection methods (EC)
- vii. Information supplied about used products being collected (IU)
- viii. Regularity of collection of used products (RC)
- ix. Design of special methods for abusers of the recycling program (AB)
- x. Good locations of centers where refurbished goods are sold (LR)
- xi. Incentives to buyers of refurbished goods (IB)
- xii. Cooperation of the program organizers with the local government (CL).

EVALUATION OF RECYCLING PROGRAMS

While fuzzy set theory [7] facilitates converting linguistic weights of criteria for evaluation of alternatives (such as, "very good", "poor", etc) into numerical weights, the basic concept of the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [3] is that the rating of the alternative selected as the best from a set of different alternatives, should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution in a geometrical (i.e., Euclidean) sense. See [5] for a detailed theoretical explanation of the fuzzy set theory as well as the TOPSIS approach. In this paper, due to space limitation, the fuzzy TOPSIS (combination of fuzzy set theory and TOPSIS) approach to evaluate recycling programs is only detailed using a numerical example

Suppose that there are three representatives of a community to weigh the drivers of public participation, based on which drivers greatly motivate them to participate and which drivers are not so important to them. Since it is difficult for them to assign numerical weights to the drivers, they give linguistic weights like

“very high”, “low”, “medium”, etc. Table 1 depicts the linguistic weights given by the three representatives. Using fuzzy set theory, these linguistic weights are then converted into triangular fuzzy numbers (TFNs). A TFN has three parameters, each representing a quantity that describes the linguistic weight – the smallest possible quantity, the most promising quantity and the largest possible quantity (see [5] for more details on TFN). Table 2 shows the TFN equivalents (i.e, fuzzy weights) of the linguistic weights.

Table 1. Linguistic weights of drivers

Driver	Rep.1	Rep.2	Rep.3
KD	Low	Medium	High
AR	Medium	High	Very High
SR	Low	Low	Very High
CD	Very High	Very High	Medium
ID	Low	High	Low
EC	High	Medium	Very High
IU	Low	Low	High
RC	Medium	Low	Low
AB	Medium	Low	Medium
LR	Very High	High	High
IB	High	High	Medium
CL	Medium	High	Low

Table 2. Conversion table for weights of drivers

Linguistic weight	TFN
Very High	(0.7, 0.9, 1.0)
High	(0.5, 0.7, 0.9)
Medium	(0.3, 0.5, 0.7)
Low	(0.1, 0.3, 0.5)
Very Low	(0.0, 0.1, 0.3)

The average fuzzy weight and hence the normalized fuzzy weight are calculated for each driver of public participation. The normalized fuzzy weights that we obtain in this example are as follows: KD - (0.03, 0.07, 0.16); AR - (0.06, 0.10, 0.20); SR - (0.03, 0.07, 0.16); CD - (0.06, 0.11, 0.21); ID - (0.03, 0.06, 0.12); EC - (0.07, 0.10, 0.20); IU - ((0.03, 0.06, 0.15); RC - (0.02, 0.05, 0.13); AB - (0.02, 0.06, 0.15); LR - (0.06, 0.11, 0.22); IB - (0.05, 0.09, 0.20); CL - (0.03, 0.07, 0.16).

Suppose that we evaluate recycling programs of two different companies. Now that we have the weights (normalized TFNs) of the drivers of public participation, we rate the two recycling programs with respect to each driver. Assuming that the three representatives come to a consensus about the linguistic rating (In this paper, we use the term, “weight”, for a driver of public participation, and the term “rating”, for a recycling program) of each recycling program with respect to each driver, we arrive at the decision matrix shown in Table 3 (S1 and S2 are the

recycling programs). Table 4 is used for conversion of linguistic ratings into TFNs.

Table 3. Decision matrix

Driver	S1	S2
KD	Very Good	Very Poor
AR	Fair	Very Good
SR	Fair	Fair
CD	Very Poor	Very Good
ID	Very Good	Good
EC	Good	Fair
IU	Poor	Fair
RC	Very Poor	Very Good
AB	Fair	Good
LR	Good	Good
IB	Poor	Very Good
CL	Very Poor	Good

Table 4. Conversion table for ratings of recycling programs

Linguistic rating	Triangular fuzzy rating
Very Good	(7, 10, 10)
Good	(5, 7, 10)
Fair	(2, 5, 8)
Poor	(0, 3, 5)
Very Poor	(0, 0, 3)

The normalized decision matrix $\{r_{ij}\}$ is then constructed using Equation 1.

$$r_{ij} = \frac{z_{ij}}{\sqrt{\sum_{j=1}^m z_{ij}^2}} \quad (1)$$

where z_{ij} represents each element of the decision matrix shown in Table 3 after conversion of its elements to TFNs, and m represents the number of drivers of public participation. $\{r_{ij}\}$ is shown in Table 5.

The weighted normalized decision matrix defined by $V = (v_{ij}) = (r_{ij}w_j)$, is then constructed. Here, w_j represents the weight (normalized TFN) of each driver. Table 6 shows the matrix V . For each row i in the matrix V , the maximum TFN is represented as p_i and the minimum one is represented as q_i . Then, the positive Euclidean distance (separation from the ideal solution) D_{j+} and the negative Euclidean distance (separation from the negative-ideal solution) D_{j-} for each recycling program is calculated using Equations 2 and 3 respectively.

$$D_{j+} = \sqrt{\sum (v_{ij} - p_i)^2} \quad \text{for } j = 1, 2, 3, \dots, m \quad (2)$$

$$D_{j-} = \sqrt{\sum (v_{ij} - q_i)^2} \quad \text{for } j = 1, 2, 3, \dots, m \quad (3)$$

Then, using Equation 4 given below, the relative closeness of the performance of each recycling program to the ideal solution is calculated.

$$C_{j+} = \frac{D_{j-}}{D_{j+} + D_{j-}} \quad (4)$$

In this example, C_{1+} is 0.31, and C_{2+} is 0.69. Therefore, S2 is better than S1 because C_{2+} is higher than C_{1+} .

Table 5. Normalized decision matrix

Driver	S1	S2
KD	(0.67, 1.00, 1.43)	(0.00, 0.00, 0.43)
AR	(0.16, 0.45, 1.10)	(0.55, 0.89, 1.37)
SR	(0.18, 0.71, 2.83)	(0.18, 0.71, 2.83)
CD	(0.00, 0.00, 0.43)	(0.67, 1.00, 1.43)
ID	(0.50, 0.82, 1.16)	(0.35, 0.57, 1.16)
EC	(0.39, 0.81, 1.86)	(0.16, 0.58, 1.49)
IU	(0.00, 0.51, 2.50)	(0.21, 0.86, 4.00)
RC	(0.00, 0.00, 0.43)	(0.67, 1.00, 1.43)
AB	(0.16, 0.58, 1.49)	(0.39, 0.81, 1.86)
LR	(0.35, 0.71, 1.41)	(0.35, 0.71, 1.41)
IB	(0.00, 0.29, 0.71)	(0.63, 0.96, 1.43)
CL	(0.00, 0.00, 0.60)	(0.48, 1.00, 2.00)

Table 6. Weighted normalized decision matrix

Driver	S1	S2
KD	(0.67, 1.00, 1.43)	(0.00, 0.00, 0.43)
AR	(0.16, 0.45, 1.10)	(0.55, 0.89, 1.37)
SR	(0.18, 0.71, 2.83)	(0.18, 0.71, 2.83)
CD	(0.00, 0.00, 0.43)	(0.67, 1.00, 1.43)
ID	(0.50, 0.82, 1.16)	(0.35, 0.57, 1.16)
EC	(0.39, 0.81, 1.86)	(0.16, 0.58, 1.49)
IU	(0.00, 0.51, 2.50)	(0.21, 0.86, 4.00)
RC	(0.00, 0.00, 0.43)	(0.67, 1.00, 1.43)
AB	(0.16, 0.58, 1.49)	(0.39, 0.81, 1.86)
LR	(0.35, 0.71, 1.41)	(0.35, 0.71, 1.41)
IB	(0.00, 0.29, 0.71)	(0.63, 0.96, 1.43)
CL	(0.00, 0.00, 0.60)	(0.48, 1.00, 2.00)

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