Using Fuzzy Based Multiple Criteria Decision Making for Selecting Private Firm for Waste Management PPP Contract Arrangement

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Abstract. In Municipal Solid Waste Management (MSWM), intervention and participation of private sector is increasing day by day and various Public Private Partnership (PPP) arrangement is applied to enhance services across different parts of world. In Indian context new initiatives and policies like Swachh Bharat Mission(SBM), Smart City Mission (SCM) and Solid Waste Management(SWM) Rules, 2016 are launched recently to promote more integration of private actors in the MSWM system. Selecting a suitable private firm for PPP arrangement is crucial stage and needs careful assessment and feasibility study. The selection process is complex and decision making is often based on many conflicting attributes under uncertain environment. Therefore, selection of private firm for PPP contract arrangement is Multiple Criteria Decision Making (MCDM) problem. This paper with the aim of aid decision making presents a study of the selecting optimal company for the Design-Build-Finance-Operate-Transfer (DBFOT) contract model of MSWM operations by using Fuzzy based TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) Method. The numerical example for the MSWM planning problem of 4 selectable alternatives based on 10 evaluating criteria is also provided to illustrate the approach. The result revealed that approached used in the study can easily applied to any practical case of selection of private firm for PPP arrangement required for SWM services by the cities.

1. Introduction

Today, the incremental infrastructural needs and demands of urban India are posing a new threat to future urban planning. According to the population census 2011 of India, 31 percent of the overall population of the country lives in cities [1]. As per another forecast, by the year 2050, cities population score will be half of the total population of the country[2].This incremental population growth trends in cities added tremendous pressure on the government to lay down infrastructure, which will help to meet the services demand like energy supply, land requirement, waste management, education, health, and water supply. The one the biggest challenge emerged today in front of government is proper management of solid waste and need urgent attention.

The private sector participation for waste management has now become a trend worldwide for providing improved services for the citizens. The private sector participation has brought transformation and modernization into the system, which in turn demands more and newer models of integration with government bodies. The pressing call today especially in the context of smart city development across various parts of the world is finding the right framework for Public-Private Partnership(PPP) for sustainable waste management. The Indian government, especially in the context of waste management are pushing new mechanisms for cities to aid more integration of private
stakeholders into the system. In the past, many initiatives were launched by the government but were utilized to the full extent [3]. The weak competencies of municipal authority in India are the main reason for the underutilization of the PPP model for cities [4]. The competencies required are different from the traditional way of integration. To create a more suitable environment for the private actor, few programs like Swachh Bharat Mission (SBM) and Smart City Mission (SCM) are launched by the government. These initiatives are launched to provide significant pace to infrastructural transformation and transition for cities, enhancing the living quality of citizens. This has given a new opportunity for city planners and city authority officials to create their planning area a new market base for the private investor. Sustainable waste management is a key challenge, which is to address while planning for smart city development projects. The constraint like institutional weakness, continuously changing lifestyle, migration, technological choices, the financial burden has the mammoth task of decision-makers for sustainable waste management. Effective decision making is the most necessary step required for the successful integration of private actors into the MSWM system, especially considering the experience of weak competencies of municipal authority with private companies. The important decision making of selecting suitable contract models and private actors is highlighted in guidelines of Solid Waste Management Rules, 2016. This paper with the aim of aid decision making presents a novel study of the selecting optimal company for the Design-Build-Finance-Operate-Transfer (DBFOT) contract model of MSWM operations by using Fuzzy based TOPSIS Method. The one reason for taking fuzzy-based MCDM is uncertainty involved in decision making. The other reason behind the study is that the PPP model may not suitable and viable in all situations and needs effective decision making. Their selection often based on so many conflicting criteria, hence complex analysis is required for optimal selection. The application example is used in the study to present the computational analysis and application of method into public administration planning associated with contract company selection.

2. Literature Review
Developing countries' waste management is criticized mostly, due to insufficient infrastructure assets [5]. The services and infrastructure assets of the public sector are not up to the standard required [6]. The PPP arrangements deliver the economic, technical, and mechanical infrastructural resources to the system [7]. The inclusion of private actors in public brings skills and competency to manage and build infrastructure resources [8]. PPP arrangements swiftly provide scope for infrastructural needs and growing demand [6]. Due to innovative methods selection freedom with the integration of commercial emphasis, PPP arrangements reduce overall cost and provides a check on the overrun of project cost [9]. The public sector administration cost-related service facility can be reduced by PPP usage [10]. This PPP arrangement associated with several challenges and risks which may lead to significant renegotiations and withdrawals. The significant cancellation rates of PPP arrangements are seen [11]. The mitigation of risks depends on sound decision making by properly evaluating criteria like economic viability, feasibility, tariff system, skill, and human resource requirement of private partners. Hence selection of optimal private firms is the MCDM problem.

In traditional MCDM methods, the evaluating weights and ratings of the criteria are defined by certain or precise values. One of the famous classical methods is TOPSIS developed by Hwang and Yoon 1981 [12]. The method is based simple concept that optimal alternative will have the shortest distance from the ideal solution (positive ideal solution) and maximum distance from an anti-ideal solution (negative ideal solution). The anti-ideal solution is a solution that minimizes the benefit criteria and maximizes the cost criteria, whereas the ideal solution minimizes the cost criteria and maximizes the benefit criteria. This method uses a certain or precise number for performance evaluation. The use of a certain number for performance evaluation is insufficient for tackling the imprecise or vague nature of linguistic assessment in real situations. C.T. Chen [13], for decision making in a fuzzy environment, extended this method. To handle ambiguity and impreciseness of human judgments and knowledge, Zadeh [14] introduced a fuzzy set theory. Since then many studies in different fields used this theory for tackling uncertainty in decision making. The fuzzy-based MCDM methods use a fuzzy number instead of a certain number. The different fuzzy numbers can be used as per the situation. The triangular fuzzy number due to their simplicity in computation is often used. These triplet (a, b, c) is a
fuzzy set, where \( a \) represents the smallest possible value, \( b \) represents the most possible value and \( c \) largest possible value.

Many authors have applied fuzzy-based TOPSIS for waste management studies. But most of the studies applied method for landfill site selection [15,16], waste treatment and disposal technology selection [17,18,19], waste collection system selection [20], selection of the best plastic recycling method [21], and selection of treatment alternatives of hazardous waste [22]. The selection of PPP partners in a fuzzy environment, especially in context waste management is not much unexplored. With the help of this study we are trying to present an application example of a private firm selection problem for waste management under the DBFOT contract model arrangement.

3. Methodology

The previous discussion on PPP arrangements benefits, risks, challenges and government recent initiatives to support integration, especially in waste management sector suggests that for sustainable waste management practices, private firm selection is important and needs careful decision making on planning issues. In this context of a need for selection the right private firms, the study presents a case by using MCDM computation technique to aid local municipal authority in decision making. In this attempt of selecting the optimal private firm alternative, a hybrid methodology is used. The systematic and comprehensive literature review of existing empirical studies mainly on PPP arrangements, solid waste management and MCDM methods is the first phase of study. The literature review of governments report documents on MSWM toolkit for public-Private Partnership frameworks, SCM and SBM is done for the first phase of this study. The second phase of study is computation part of finding selectable alternative for PPP arrangement. With the aim of developing a practical model of selection problem, academicians, municipal authority officials, city planners, experts and consultants are informedly consulted for evaluating the criteria and alternatives. The computation methodology is based on fuzzy based MCDM method. The basic steps used for computation by fuzzy TOPSIS method for case of private firm selection is divided into two parts, finding the importance of weight and ranking the alternatives. The methodology [13,23,24,25] used can be described as follows:

**Step 1: Form a committee of decision makers and then identify the evaluation criteria.**

a. Assume for \( k \) decision makers, DM={ DM\(_1\), DM\(_2\),…,DM\(_k\) }

b. A set \( m \) possible alternatives A={a\(_1\),a\(_2\),…,a\(_m\)} of private firm

c. A set of \( n \) criteria, C={c\(_1\),c\(_2\),…c\(_n\)} of private firm. These \( n \) criteria are divided into cost criteria and benefit criteria.

**Step 2: Determine the weighting of evaluation criteria**

Choose the appropriate linguistic variables given in Table 1 for the importance weight of the criteria.

The aggregated fuzzy weight by integrating the opinions of experts can be calculated as:

\[
\tilde{w}_j = \left[ \tilde{w}_{j1} + \tilde{w}_{j2} + \cdots + \tilde{w}_{jk} \right]
\]

\( \tilde{w}_j^k \) to represent the fuzzy weight assessed by \( k^{th} \) decision makers of \( j^{th} \) criterion

**Step 3: Evaluate the ratings of alternatives**
Choose the appropriate linguistic variables given in Table 2 for evaluating the all alternatives ratings corresponding to each criterion.

| Linguistic variables | Triangular fuzzy number |
|----------------------|-------------------------|
| Very poor (VP)       | (1, 1, 3)               |
| Poor (P)             | (1, 3, 5)               |
| Fair (F)             | (3, 5, 7)               |
| Good (G)             | (5, 7, 9)               |
| Very good (VG)       | (7, 9, 9)               |

**Table 2: Linguistic variables for the fuzzy rating of each criterion**

**Step 4: Integrate the opinions of Decision Makers**

The calculation of alternatives aggregated fuzzy ratings ($\tilde{x}_{ijk}$) of alternatives with respect to each criterion is shown below:

$$\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$$

Where,

$$a_{ijk} = \min_k a_{ijk} \quad b_{ijk} = \frac{1}{k} \sum b_{ijk} \quad c_{ijk} = \max_k c_{ijk}$$

$\tilde{x}_{ijk}$ are the rating of kth decision maker.

**Step 5: Construct decision matrix**

$$\tilde{D} = \begin{bmatrix} \tilde{d}_{11} & \cdots & \tilde{d}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{d}_{m1} & \cdots & \tilde{d}_{mn} \end{bmatrix}$$

**Step 6: Compute the normalized fuzzy decision matrix**

$$\tilde{R} = \begin{bmatrix} \tilde{r}_{11} & \cdots & \tilde{r}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{r}_{m1} & \cdots & \tilde{r}_{mn} \end{bmatrix}$$

where $\tilde{R} = [\tilde{r}_{ij}]_{m \times n}$ is normalized fuzzy decision matrix obtained by linear scale transformation and its obtained by using following equation:-

$$\tilde{r}_{ij} = \left( \frac{a_{ij}}{c_{ij}}, \frac{b_{ij}}{c_{ij}}, \frac{c_{ij}}{c_{ij}} \right) \quad \text{and} \quad c_i^* = \max_i c_{ij} \quad \text{(Benefit Criteria)}$$

$$\tilde{r}_{ij} = \left( \frac{a_i}{a_{ij}}, \frac{a_i}{b_{ij}}, \frac{c_i}{c_{ij}} \right) \quad \text{and} \quad a_i^* = \min_i a_{ij} \quad \text{(Non-benefit Criteria)}$$

**Step 7: Compute the weighted normalized matrix.**

The weighted normalized decision matrix is computed by multiplying the values in the normalized decision matrix and the importance weight of evaluation criteria.

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \quad i = 1, 2, \ldots, m \quad \text{and} \quad j = 1, 2, \ldots, n$$

Where, $\tilde{v}_{ij} = \tilde{r}_{ij}(\cdot)\tilde{w}_j$

**Step 8: Compute the fuzzy negative ideal solution (FNIS) and the fuzzy ideal solution (FPIS).**

The FNIS and FPIS of the alternatives are calculated by using equation shown below:

$$A^- = (\tilde{v}_{i1}, \tilde{v}_{i2} \ldots \tilde{v}_{in}) \quad \text{where} \quad \tilde{v}_{ij}^- = \min_i \{\tilde{v}_{ij}\} \quad i = 1, 2, \ldots, m \quad \text{and} \quad j = 1, 2, \ldots, n$$

$$A^+ = (\tilde{v}_{i1}, \tilde{v}_{i2} \ldots \tilde{v}_{in}) \quad \text{where} \quad \tilde{v}_{ij}^+ = \max_i \{\tilde{v}_{ij}\} \quad i = 1, 2, \ldots, m \quad \text{and} \quad j = 1, 2, \ldots, n$$

**Step 9: Calculate the distance of each alternative from FNIS and FPIS.**

The distance of each alternative from FNIS and FPIS calculated by equation shown below:

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_{ij}^-), i = 1, 2, \ldots, m$$

$$d_i^+ = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_{ij}^+), i = 1, 2, \ldots, m$$

**Step 10: Calculate the closeness coefficient of each alternative**

The closeness coefficient of each alternative is calculated by using equation shown below:-
\[ CC_i = \frac{d_i^-}{d_i^- + d_i^+} \quad i = 1, 2, \ldots, m \]

Where, \( CC_i \) is the distance fuzzy positive ideal solution \( (A^+) \) and the fuzzy negative ideal solution \( (A^-) \) simultaneously.

**Step 11: Rank the alternatives**

According to their closeness coefficient, rank the alternatives. The best alternative is farthest from the FNIS and closest to the FPIS

**4. Application Example**

The selection of private partner for PPP arrangements is a part of planning which directly affects the level of services and sustainable planning for smart city development. The selection of private firm for Design-Build-Finance-Operate-Transfer (DBFOT) contract model needs pre-feasibility test before implementation. These pre-feasibilities are based on critical factors which private actor needs to qualify for the project. This research aims to fill the gap of decision-making tool needed for selection of prospective partners. The selection of prospective partners is complex process due to long run risk associated with both the quality of services and environmental effects. Also, selection process associated broad range of uncertainty like future regulations, urbanization and future needs.

**Table 3: Criteria for private firm selection for DBFOT contract model**

| Criteria                                      | Criteria Type     |
|-----------------------------------------------|-------------------|
| Time required for delivering project (C_1)    | Cost (the less the better) |
| Compliance with MSW 2016 rules (C_2)          | Benefit (the more the better) |
| Skill in similar project (C_3)                | Benefit (the more the better) |
| Technical feasibility (C_4)                   | Benefit (the more the better) |
| Overall cost of project (C_5)                 | Cost (the less the better) |
| Financial load on government (C_6)            | Cost (the less the better) |
| Environment impacts (C_7)                     | Cost (the less the better) |
| Quality of services (C_8)                     | Benefit (the more the better) |
| Tariff for users as per new guidelines (C_9)  | Cost (the less the better) |
| Possibility of expansion in future (C_{10})   | Benefit (the more the better) |

**Table 4: Linguistic assessments for the 10 criteria by decision makers**

| Criteria                                      | Decision Makers |
|-----------------------------------------------|-----------------|
| Time required for delivering project (C_1)    | DM_1 DM_2 DM_3  |
| Compliance with MSW 2016 rules (C_2)          | H VH VH         |
| Skill in similar project (C_3)                | M M M          |
| Technical feasibility (C_4)                   | MH H H         |
| Overall fee of project (C_5)                  | H VH VH        |
| Financial load on government (C_6)            | MH H MH        |
| Environment impacts (C_7)                     | MH H MH        |
| Quality of services (C_8)                     | M MH M         |
| Tariff for users as per new guidelines (C_9)  | M MH M         |
| Possibility of expansion in future (C_{10})   | M M ML         |

Let us assume that an urban local government is interested in selecting prospective partners for their upcoming transfer station facility at strategic locations of city. This selection is for new contract model under umbrella of waste infrastructure modernization as per new waste handling rules 2016. As per waste management rules 2016, the urban local bodies can take advice from external actor like academician, urban planners, designers, and experts for planning implementation of projects[26]. Therefore, committee of three experts (urban planner, academician and environmental expert) is...
formed for the selection of four alternatives (A$_1$, A$_2$, A$_3$, and A$_4$). To evaluate the performances of private firm for PPP arrangement, ten criteria \{C$_1$, C$_2$, C$_3$, C$_4$, C$_5$, C$_6$, C$_7$, C$_8$, C$_9$, and C$_{10}$\} are taken. These criteria are selected based on guidelines of waste rules 2016 and expert advices and consultations with policy makers and municipal authorities. The criteria are divided into two categories as benefit and cost criteria. The selection is based on the criteria shown in Table 3. The step by step calculation for application example is shown below:

**Table 5: Aggregated fuzzy weight**

| Criteria | Aggregated fuzzy weight |
|----------|-------------------------|
| $\tilde{w}_1$ | 0.7 0.9 1 |
| $\tilde{w}_2$ | 0.83 0.97 1 |
| $\tilde{w}_3$ | 0.3 0.5 0.7 |
| $\tilde{w}_4$ | 0.63 0.83 0.97 |
| $\tilde{w}_5$ | 0.83 0.97 1 |
| $\tilde{w}_6$ | 0.57 0.77 0.93 |
| $\tilde{w}_7$ | 0.57 0.77 0.93 |
| $\tilde{w}_8$ | 0.37 0.57 0.77 |
| $\tilde{w}_9$ | 0.37 0.57 0.77 |
| $\tilde{w}_{10}$ | 0.23 0.43 0.63 |

**Table 6: Linguistic assessments for the 4 alternatives by decision makers**

| Criteria | Alternative | Decision makers | Criteria | Alternatives | Decision makers |
|----------|-------------|-----------------|----------|--------------|-----------------|
| $C_1$ | A$1$ | DM | F | C$6$ | A$1$ | VG | G | G |
| | A$2$ | DM | G | VG | G | A$2$ | G | F | G |
| | A$3$ | DM | G | F | F | A$3$ | P | F | P |
| | A$4$ | DM | F | P | P | A$4$ | F | G | F |
| $C_2$ | A$1$ | DM | VG | G | G | C$7$ | A$1$ | F | G | F |
| | A$2$ | DM | G | F | G | A$2$ | F | F | F |
| | A$3$ | DM | G | F | F | A$3$ | G | F | F |
| | A$4$ | DM | F | F | F | A$4$ | P | F | G |
| $C_3$ | A$1$ | DM | G | G | G | C$8$ | A$1$ | G | VG | G |
| | A$2$ | DM | F | F | F | A$2$ | F | F | G |
| | A$3$ | DM | P | P | F | A$3$ | F | F | G |
| | A$4$ | DM | G | G | F | A$4$ | F | F | F |
| $C_4$ | A$1$ | DM | G | G | VG | C$9$ | A$1$ | F | G | G |
| | A$2$ | DM | F | VG | G | A$2$ | F | P | F |
| | A$3$ | DM | F | G | F | A$3$ | F | G | F |
| | A$4$ | DM | VG | G | VG | A$4$ | F | P | F |
| $C_5$ | A$1$ | DM | F | G | G | C$10$ | A$1$ | G | F | F |
| | A$2$ | DM | F | G | VG | A$2$ | F | F | F |
| | A$3$ | DM | F | F | G | A$3$ | F | F | P |
| | A$4$ | DM | F | F | G | A$4$ | F | F | F |
The committee was asked to rate linguistic assessments for the ten criteria. The scale used for the rating the criteria is given in Table 1. The linguistic assessments for the ten criteria are shown in Table 4. Then the aggregated fuzzy weight by integrating the opinions of experts can be calculated by using equation 1 and as shown below:
\[
\bar{w}_i = \frac{1}{3}[(0.7,0.9,1.0),(0.7,0.9,1.0),(0.7,0.9,1.0)] = (0.7,0.9,1.0)
\]
Similarly, the calculation for other criteria is performed and obtained values are shown in Table 5. The linguistic assessments for four alternatives provided by decision makers by using rating scale in Table 2 is shown in Table 6. The aggregated rating is calculated by using equation 2 and shown in Table 7. The values of aggregated fuzzy weight from Table 5 and normalized rating from Table 4 are used for calculating the weighted normalized decision matrix. For example, for the alternative \(A_1\) and Criteria \(C_1\) (Time required for delivering project), the calculation is shown below:
\[
\bar{v}_{ij} = \bar{r}_{ij} \cdot \bar{w}_i = (0.143,0.2,0.333)(1.0,0.7,0.9,1.0) = (0.1,0.18,0.333)
\]

| Decision makers | Aggregated Rating | Decision makers | Aggregated rating |
|-----------------|-------------------|-----------------|-------------------|
| DM1 | DM2 | DM3 | DM4 | DM5 | DM6 | DM7 |
| \(C_1\) | \(A_1\) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | \(C_6\) | (7,9,9) | (5,7,9) | (5,7,9) | (7,7,67,9) |
| \(A_2\) | (5,7,9) | (7,9,9) | (5,7,9) | (5,7,67,9) | (5,7,9) | (5,7,9) | (3,6,33,9) |
| \(A_3\) | (5,7,9) | (3,5,7) | (3,5,7) | (3,5,67,9) | (1,3,5) | (3,5,7) | (1,3,5) | (1,3,67,7) |
| \(A_4\) | (3,5,7) | (1,3,5) | (1,3,5) | (1,3,67,7) | (3,5,7) | (5,7,9) | (3,5,7) | (3,5,67,9) |
| \(C_2\) | \(A_1\) | (7,9,9) | (5,7,9) | (5,7,9) | (5,7,67,9) | \(C_7\) | (3,5,7) | (5,7,9) | (3,5,7) | (3,5,67,9) |
| \(A_2\) | (5,7,9) | (3,5,7) | (5,7,9) | (5,6,33,9) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) |
| \(A_3\) | (5,7,9) | (3,5,7) | (3,5,7) | (3,5,67,9) | (5,7,9) | (3,5,7) | (3,5,7) | (3,5,67,9) |
| \(A_4\) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (1,3,5) | (3,5,7) | (5,7,9) | (1,5,9) |
| \(C_3\) | \(A_1\) | (5,7,9) | (5,7,9) | (5,7,9) | (5,7,9) | \(C_8\) | (5,7,9) | (7,9,9) | (5,7,9) | (5,7,67,9) |
| \(A_2\) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,67,9) |
| \(A_3\) | (1,3,5) | (1,3,5) | (1,3,5) | (1,3,67,7) | (3,5,7) | (3,5,7) | (5,7,9) | (3,5,7) | (3,5,67,9) |
| \(A_4\) | (5,7,9) | (5,7,9) | (3,5,7) | (3,6,33,9) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,67,9) |
| \(C_4\) | \(A_1\) | (5,7,9) | (5,7,9) | (5,7,9) | (5,7,67,9) | \(C_9\) | (3,5,7) | (5,7,9) | (5,7,9) | (3,6,33,9) |
| \(A_2\) | (3,5,7) | (7,9,9) | (5,7,9) | (3,7,9) | (3,7,9) | (3,7,9) | (3,7,9) | (1,3,5) | (1,3,5) | (1,3,67,7) |
| \(A_3\) | (3,5,7) | (5,7,9) | (3,5,7) | (3,5,67,9) | (3,5,7) | (5,7,9) | (3,5,7) | (3,5,67,9) |
| \(A_4\) | (7,9,9) | (5,7,9) | (7,9,9) | (5,8,33,9) | (1,3,5) | (3,5,7) | (3,5,7) | (1,4,33,7) |
| \(C_5\) | \(A_1\) | (3,5,7) | (5,7,9) | (5,7,9) | (3,6,33,9) | \(C_{10}\) | (5,7,9) | (3,5,7) | (3,5,7) | (3,5,67,9) |
| \(A_2\) | (3,5,7) | (5,7,9) | (7,9,9) | (3,7,9) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,67,9) |
| \(A_3\) | (3,5,7) | (3,5,7) | (5,7,9) | (3,5,67,9) | (3,5,7) | (3,5,7) | (1,3,5) | (1,4,33,7) |
| \(A_4\) | (3,5,7) | (3,5,7) | (5,7,9) | (3,5,67,9) | (1,3,5) | (3,5,7) | (3,5,7) | (1,4,33,7) |

Then, for the four alternatives the fuzzy weighted decision matrix is computed by using equation (5). The values of aggregated fuzzy weight from Table 5 and normalized rating from Table 4 are used for calculating the weighted normalized decision matrix. For example, for the alternative \(A_1\) and Criteria \(C_1\) (Time required for delivering project), the calculation is shown below:
\[
\bar{v}_{ij} = \bar{r}_{ij} \cdot \bar{w}_i = (0.143,0.2,0.333)(1.0,0.7,0.9,1.0) = (0.1,0.18,0.333)
\]
Similarly, other values can be calculated. The calculated weighted normalized decision matrix is shown in Table 9.

**Table 8: Normalized decision matrix**

| Criteria | Normalized ratings | A₁ | A₂ | A₃ | A₄ |
|----------|-------------------|----|----|----|----|
| C₁       | (0.143,0.2,0.333) | (0.111,0.131,0.2) | (0.111,0.176,0.333) | (0.143,0.273,1) |
| C₂       | (0.556,0.852,1)   | (0.333,0.704,1)   | (0.333,0.629,1)   | (0.333,0.556,0.778) |
| C₃       | (0.556,0.778,1)   | (0.333,0.556,0.778) | (0.111,0.407,0.778) | (0.333,0.704,1) |
| C₄       | (0.556,0.852,1)   | (0.333,0.778,1)   | (0.333,0.629,1)   | (0.556,0.926,1) |
| C₅       | (0.333,0.473,1)   | (0.333,0.429,1)   | (0.333,0.529,1)   | (0.333,0.529,1) |
| C₆       | (0.111,0.130,0.2) | (0.111,0.158,0.333) | (0.143,0.273,1) | (0.111,0.176,0.333) |
| C₇       | (0.111,0.176,0.333) | (0.143,0.2,0.333) | (0.111,0.176,0.333) | (0.111,0.2,1) |
| C₈       | (0.556,0.852,1)   | (0.333,0.629,1)   | (0.333,0.629,1)   | (0.333,0.556,0.778) |
| C₉       | (0.111,0.158,0.333) | (0.143,0.273,1) | (0.111,0.176,0.333) | (0.143,0.231,1) |
| C₁₀      | (0.333,0.629,1)   | (0.333,0.556,0.778) | (0.111,0.481,0.778) | (0.111,0.482,0.778) |

**Table 9: Weighted Normalized decision matrix**

| Criteria | Weighted Normalized ratings | A₁ | A₂ | A₃ | A₄ |
|----------|-----------------------------|----|----|----|----|
| C₁       | (0.1,0.18,0.333)            | (0.078,0.117,0.2) | (0.078,0.159,0.333) | (0.1,0.245,1) |
| C₂       | (0.461,0.826,1)             | (0.277,0.683,1)  | (0.277,0.611,1)  | (0.277,0.539,0.778) |
| C₃       | (0.166,0.388,0.7)           | (0.1,0.278,0.544) | (0.033,0.204,0.544) | (0.1,0.352,0.7) |
| C₄       | (0.35,0.707,0.97)           | (0.21,0.646,0.97) | (0.21,0.523,0.97) | (0.35,0.769,0.97) |
| C₅       | (0.276,0.459,1)             | (0.276,0.415,1)  | (0.277,0.514,1)  | (0.277,0.513,1) |
| C₆       | (0.063,0.100,0.186)         | (0.063,0.122,0.31) | (0.081,0.21,0.93) | (0.063,0.135,0.31) |
| C₇       | (0.063,0.135,0.31)          | (0.081,0.154,0.31) | (0.063,0.136,0.31) | (0.063,0.154,0.93) |
| C₈       | (0.205,0.485,0.77)          | (0.123,0.358,0.77) | (0.123,0.356,0.77) | (0.123,0.317,0.599) |
| C₉       | (0.041,0.09,0.256)          | (0.053,0.155,0.77) | (0.041,0.101,0.257) | (0.053,0.132,0.77) |
| C₁₀      | (0.077,0.270,0.63)          | (0.077,0.239,0.49) | (0.026,0.207,0.49) | (0.026,0.207,0.49) |

**Table 10: FPNS and FPIS**

| | FPNS (A⁻) | FPIS (A⁺) |
|---|-----------|-----------|
| (0.078,0.078,0.078) | (1.1,1) |
| (0.277,0.277,0.277) | (1.1,1) |
| (0.033,0.033,0.033) | (0.7,0.7,0.7) |
| (0.21,0.21,0.21) | (0.97,0.97,0.97) |
| (0.277,0.277,0.277) | (1.1,1) |
| (0.063,0.063,0.063) | (0.93,0.93,0.93) |
| (0.063,0.063,0.063) | (0.93,0.93,0.93) |
| (0.123,0.123,0.123) | (0.77,0.77,0.77) |
| (0.041,0.041,0.041) | (0.77,0.77,0.77) |
| (0.026,0.026,0.026) | (0.63,0.63,0.63) |
Then, we compute the fuzzy negative ideal solutions \((A^-)\) and the fuzzy positive ideal solution \((A^+)\) using equation (6)–(7) for the four alternatives. For example, for criterion \(C_1\) (Time required for delivering project) the fuzzy negative ideal solutions \((A^-)\) is \((0.078, 0.078, 0.078)\) and the fuzzy positive ideal solution \((A^+)\) is \((1, 1, 1)\). The similar manner is the other values can be calculated and summary is shown in Table 10.

The distance of each alternative from the FPNS and FPIS can be calculated by using equation (8)-(9) respectively. The distance between two fuzzy number can be calculated by using Vertex method [13].

\[
d(\tilde{m}, \tilde{n}) = \left\{ \frac{(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2}{3} \right\}^{\frac{1}{2}}
\]

Where \((\tilde{m} \text{ and } \tilde{n})\) are two triangular fuzzy number. For example, by using the vertex method for \(A_1\) and \(C_1\) criterion calculation shown below:

\[
dv(A_1, A^+) = \left\{ \frac{(0.1 - 1)^2 + (0.18 - 1)^2 + (0.333 - 1)^2}{3} \right\}^{\frac{1}{2}} = 0.801
\]

\[
dv(A_1, A^-) = \left\{ \frac{(0.1 - 0.078)^2 + (0.18 - 0.078)^2 + (0.333 - 0.078)^2}{3} \right\}^{\frac{1}{2}} = 0.159
\]

Similarly, other values can be calculated. The summary of values obtained is shown in the Table 11

### Table 11: Distance of each alternative from the FPNS and FPIS

| Criteria | \(d_1(A_1, A^+)\) | \(d_2(A_2, A^+)\) | \(d_3(A_3, A^+)\) | \(d_4(A_4, A^+)\) | \(dv(A_1, A^+)\) | \(dv(A_2, A^+)\) | \(dv(A_3, A^-)\) | \(dv(A_4, A^-)\) |
|----------|-----------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|----------------|
| \(C_1\)  | 0.801           | 0.869           | 0.817           | 0.678           | 0.159          | 0.074          | 0.155          | 0.541          |
| \(C_2\)  | 0.327           | 0.456           | 0.474           | 0.512           | 0.535          | 0.479          | 0.46           | 0.327          |
| \(C_3\)  | 0.356           | 0.433           | 0.488           | 0.401           | 0.443          | 0.329          | 0.311          | 0.428          |
| \(C_4\)  | 0.389           | 0.477           | 0.509           | 0.376           | 0.531          | 0.506          | 0.474          | 0.551          |
| \(C_5\)  | 0.521           | 0.537           | 0.503           | 0.503           | 0.431          | 0.425          | 0.439          | 0.439          |
| \(C_6\)  | 0.815           | 0.772           | 0.643           | 0.767           | 0.074          | 0.146          | 0.508          | 0.148          |
| \(C_7\)  | 0.767           | 0.754           | 0.767           | 0.672           | 0.148          | 0.152          | 0.148          | 0.503          |
| \(C_8\)  | 0.365           | 0.442           | 0.442           | 0.467           | 0.431          | 0.397          | 0.397          | 0.296          |
| \(C_9\)  | 0.647           | 0.545           | 0.644           | 0.554           | 0.128          | 0.426          | 0.129          | 0.424          |
| \(C_{10}\)| 0.381           | 0.399           | 0.434           | 0.433           | 0.378          | 0.297          | 0.288          | 0.288          |

Then, we compute Closeness coefficients (CCI) of the Four alternatives by using equation (10). For example, \(A_1\)

\[
CCI = \frac{3.257}{3.257 + 5.37} = 0.378
\]

The summary of calculated values is shown below in Table 12

### Table 12: Closeness coefficients

|       | \(A_1\) | \(A_2\) | \(A_3\) | \(A_4\) |
|-------|---------|---------|---------|---------|
| \(d^*\) | 5.37    | 5.686   | 5.721   | 5.363   |
| \(d\)  | 3.257   | 3.232   | 3.31    | 3.946   |
| \(CCI\)| 0.378   | 0.362   | 0.367   | 0.424   |

Then based on calculated of Closeness coefficients (CCI) and comparison between them, the ranking of alternatives as \(A_3, A_4, A_2, A_1\). The example presented typically evaluate four alternatives based on 10 criteria. The study presented a case example of private firm selection for PPP arrangement.
limitation of study is as the alternatives and criteria increases the computation will become more complex and more integration of different MCDM method and computation techniques is required. Also, the judgement is typically based on expert decision and may vary based knowledge and number of experts evaluating criteria and alternative. The other limitation is dependence on decision maker judgement hence involved human judgement error. Overall, the study presented a case of selection problem for waste management planning, which will aid city officials in real world scenario based on city specific constraints.

5. Conclusion
The policy evolution and recent initiatives have increased the potential role of private partners in the MSW sector of India and given new market dynamics to this sector. The success of this partnership lay in careful attention to the constraints and parameters required for pre-feasibility studies. The role of decision is also important as per new guidelines of waste management rules. So, careful and effectiveness of PPP arrangement demands pre-feasibility analysis of the contract arrangement of the MSW sector. The changing market structure, regulatory structures, governance, institutional setting are increasing uncertainty in the selection of private actors into the system. The selection of appropriate private firms is often a complex issue and their selection is based on many evaluating criteria; therefore, it is the MCDM problem. The study tries to address and solve this issue with the illustrated example which can easily applied with inclusion of practical and real set of data in waste management planning problem of private firm selection. Therefore, manuscript attempts to solve the two main issues: regarding effective selection of private firm for new PPP contract arrangement and by applying the decision-making method based on fuzzy theory, which can be effective in real situation of planning.

A fuzzy-TOPSIS method based multi-criteria decision-making approach has been used for evaluating the private firm for the Design-Build-Finance-Operate-Transfer (DBFOT) contract model of MSWM operations. The alternatives where evaluated based on 10 criteria and opinions of three experts from a similar field. The approach is very much suitable for the selection of private partners for contract arrangement but demands more city-specific data for situated solution of the problem. The inclusion of more specific city data will ease the analysis and produce more realistic results. The analysis is necessary as successful integration will provide better services and achieves sustainable waste management for the city. Also, the integration of more MCDM methods is possible and necessary for effective implementation hence demands more research studies, hence will add more practical value to the methodology. The future work will be application of methodology with newer method integrations with inclusion of city-specific criteria.

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