

Chapter 2

An Intuitionistic Fuzzy MCDM Approach for Effective Hazardous Waste Management

Gülçin Büyüközkan and Fethullah Gocer

Abstract Improperly handled hazardous waste can pose significant threat to human health and the environment. Safety of waste transportation is an important aspect of hazardous waste management. This makes the evaluation and selection of the most suitable hazardous waste transportation firm (HWTF) a crucial problem for hazardous waste generators. A number of factors affect the selection of the proper HWTF, which need to be addressed with usually vague and imprecise data provided by a team of experts from different backgrounds. This chapter proposes a systematic and integrated multi criteria decision making (MCDM) approach to support the HWTF selection process. This approach is based on the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method in an intuitionistic fuzzy (IF) environment. A Group Decision Making (GDM) approach is utilized by the means of IF to minimize the bias stemming from experts' fuzzy evaluations and to better manage the associated uncertainties and partiality. A real case application from Turkey is presented to illustrate the use of the proposed methodology.

2.1 Introduction

In modern societies, almost all materials, devices and objects sooner or later turn into waste (Gumus 2009). Waste can be classified as hazardous or non-hazardous, depending on whether they exhibit particular characteristics. Hazardous waste has been defined for the first time in the USA in early 1980s (Marinković et al. 2008) as unwanted flammable, oxidizing, poisonous, radioactive, toxic or explosive materials which pose a threat to humans or environment when handled improperly. Sources of hazardous waste are various; it may be produced in hospitals, by metal finishing or timber treatment processes, petrol storage, paint manufacture etc.

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Economic growth and industrial prosperity globally undergone in recent decades has accelerated the generation of hazardous waste (Duan et al. 2008), putting hazardous waste concerns into agenda of many developed or developing countries, which has led to the exploration of alternative ways for proper hazardous waste management and handling.

Considering associated dangers, it presents to humans and environment, prevention of contamination by hazardous waste is vital, underlining the importance of its safe transportation. However, hazardous waste generators believe that safe transportation regulations are particularly enforced by policy makers because other parties handle those processes (Gumus 2009; Orford 2007). For these reasons, generators explore safe and cost-effective solutions in hazardous waste management (HWM), presenting a problem with several different objectives. For a commercial firm, for instance, the most feasible HWM solution might be the option with the minimum cost, whereas a public authority might look for the solution with lowest spillage or leakage risk. Therefore, a hazardous waste transportation firm (HWTF) must have a certain level of quality, safety, service and responsibility at the same time, in an environment where it is expected to comply with legislation and act correctly (Ho 2011).

In this chapter, a Group Decision Making (GDM) approach is implemented for the selection of the most suitable HWTF. At first, the literature about HWM and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods under Intuitionistic Fuzzy (IF) environment will be reviewed. Following that, the proposed methodology structure will be explained and a real case from Turkey will be presented. Then, procedural IF TOPSIS steps and related calculations will be provided to introduce the technique. A numerical application of the case study will be illustrated at the final stage in order to display how the proposed method functions.

2.2 Literature Review

2.2.1 Hazardous Waste Management

Hazardous waste with explosive, ignitable/flammable, oxidizing, poisonous, corrosive, radioactive or toxic characteristics can be generated during petrol storage, metal finishing, paint manufacturing, dry cleaning and hospitals, beside others.

If handled poorly, hazardous waste will cause significant damage to both humans and environment, putting specific emphasis on choosing the right transportation and disposal firm for hazardous waste. Hsu et al. (2008) selected the most suitable medical hazardous waste disposal firm with the help of AHP and a modified Delphi technique. They suggested that their method reduced overhead costs and thus enhanced the management of hazardous waste. Ho (2011) suggested a fuzzy AHP method for this kind of evaluation with which medical and health care

institutions could objectively and systematically choose appropriate infectious medical waste disposal firms. Using a MCDA approach, Feo and Gisi (2014) developed a hazardous waste minimization procedure with geographical information. In their study, AHP is used to define the priorities of evaluation criteria for its ease and usefulness. A HWM case study in the USA is done using DEA-TOPSIS techniques by Ali et al. (2015). In another study, Mohsin et al. (2015) made an assessment of HWM proposal using AHP. Abessi and Saeedi (2014) presented an approach for siting hazardous waste landfill in large areas using site screening method and AHP. Alidi (1996) suggested a multi objective optimization model for the proper management of hazardous waste. They combined AHP with a goal programming approach to prioritize conflicting goals.

To the extent of our knowledge, the most recent studies about HWTF are presented by Gumus, Kabir and Sumi. Kabir (2015) extended VIKOR method under fuzzy environment for the selection of HWTF. Kabir and Sumi (2015) also proposed a method for selecting HWTF by using AHP and PROMETHEE. Gumus (2009) evaluated a two-step methodology for HWTF by using fuzzy AHP and TOPSIS.

In this study, an IF TOPSIS method is used in order to decide on the most appropriate HWTF. It must be underlined that this technique is applied for the problem evaluation and the results of IF TOPSIS show the ranking order of the HWTFs. To the best of our knowledge, this kind of a study has not appeared in related literature in earlier publications, differentiating itself by integrating TOPSIS and IF with a GDM approach for a real case HWTF selection problem.

2.2.2 *IF TOPSIS Literature*

In this section, literature related to the TOPSIS technique under IF set is reviewed.

This literature survey in the HWT context revealed that key aspects have been, for the most part, overlooked by researchers, indicating a research gap for selecting suitable HWTF. Fuzzy TOPSIS is commonly used in HWM to obtain the effective ranking of HWTF. GDM is often preferred to avoid the bias and minimize the partiality in this kind of decision process. From literature, however, it is observed that in some situations classical fuzzy sets can be inadequate and even defective in handling the ambiguity of the concepts that are associated with human beings' subjective judgments. IF sets, on the other hand, are useful tools to investigate the fuzziness in decision makers' (DMs') judgments in the complexity of socio-economic environment and the lack of knowledge or data about the problem. A fusion of GDM with DMs' assessments is considered as one uniform group decision by means of IF set.

Table 2.1 displays a summary of the TOPSIS literature under IF or Interval Valued IF (IVIF) environment with an emphasis on the focus and the employed technique.

Table 2.1 IF TOPSIS literature

Author	Aim of the study	Applied technique	GDM	Illustrative or case study
Boran et al. (2009)	Supplier selection	IF TOPSIS	X	Illustrative
Boran (2011)	Supplier selection	IF TOPSIS	X	Illustrative
Park et al. (2011)	Equipment selection	IVIF TOPSIS	X	Illustrative
Wang et al. (2011)	Supplier selection	IVIF TOPSIS	–	Illustrative
Boran et al. (2012)	Technology evaluation	IF TOPSIS	–	Illustrative
İntepe et al. (2013)	Forecasting method	IVIF TOPSIS	X	Illustrative
Yue and Jia (2013)	Partner selection	IF TOPSIS	X	Illustrative
Aloini et al. (2014)	Machine selection	IF TOPSIS	X	Case study
Kucukvar et al. (2014)	Sustainability performance	IF TOPSIS	X	Illustrative
Li et al. (2014)	Module partitioning evaluation	IVIF TOPSIS	X	Case study
Long and Geng (2015)	Module selection	IVIF TOPSIS	–	Case study
Wu (2015)	Supplier selection	IF TOPSIS	X	Illustrative
Wan et al. (2015)	Technology selection	IF TOPSIS	X	Case study
Wang et al. (2015)	E-tendering	IF TOPSIS	–	Illustrative
Yang et al. (2015)	Method proposal for deriving weights	IF TOPSIS	X	Illustrative
Zhang and Xu (2015)	Soft computing technique	IVIF TOPSIS	X	Illustrative
Joshi and Kumar (2016)	Personnel selection	IVIF TOPSIS	X	Illustrative
Wan et al. (2016)	Logistics outsourcing	IF TOPSIS	X	Illustrative

2.3 IF TOPSIS Methodology

This section presents the IF TOPSIS multi criteria GDM method. Let us denote, $D = \{D_1, D_2, \dots, D_k\}$ be a set of DMs, assume that the importance of DM D_k is λ_k , where $\sum_{k=1}^K \lambda_k = 1$, and $C = \{C_1, C_2, \dots, C_n\}$ be a set of criteria, $w = \{w_1, w_2, \dots, w_n\}$ the weight vector of criteria, where $w_j \geq 0$, $j = 1, 2, \dots, n$, $\sum_{j=1}^n w_j = 1$. The set of alternatives: $A = \{A_1, A_2, \dots, A_m\}$ in the form of TIFN.

2.3.1 Intuitionistic Fuzzy Sets

In this section, the basic concept of intuitionistic fuzzy sets will be briefly introduced. The Intuitionistic Fuzzy Set (IFS) is developed by Atanassov (1986) and

constitutes an extension of Zadeh's fuzzy set. It assigns a degree of membership to each element and defines a (crisp) set E , with $A \subset E$ be a fixed set. An IFS A in E is an object of the following form:

$$A = \{x, \mu_A(x), \nu_A(x) | x \in E\},$$

The functions $\mu_A: E \rightarrow [0, 1]$ and $\nu_A: E \rightarrow [0, 1]$ define the degree of membership and the degree of non-membership of the element $x \in E$ to the set A , respectively. For every $x \in E$:

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1.$$

$$\{(x, \mu_A(x), 1 - \mu_A(x) | x \in E)\}$$

If

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x),$$

then $\pi_A(x)$ is the degree of non-determinacy (uncertainty) of the membership of element $x \in E$ to set A . In the case of ordinary fuzzy sets, $\pi_A(x) = 0$ for every $x \in E$.

2.3.2 Proposed Computational Steps

In this section, computational steps for IF TOPSIS method is presented. This integrated method is quite suitable for solving MCDM problems. The alternatives are ranked using IF TOPSIS method, as adapted from the studies of Boran et al. (2011) and Boran (2011). The evaluation of the study, which is based on our method, is given in Fig. 2.1 as a schematic diagram.

The steps of the method for IF TOPSIS MCDM are as follows.

Step 1: Construct a hierarchy for the evaluation of the problem.

Define the goal, objective, attributes and alternatives for resolving the problem.

Step 2: Determine the weights of Experts.

Importance of experts is considered as linguistic variables. The defined TIFNs seven-point linguistic variable scale is introduced to estimate the weight of each DM in the GDM process. In order to express DMs' individual assessments more precisely, the linguistic variable scale, which is adapted from the five-point scale of Boran et al. (2009) is improved with a minor addition to intermediate values. The new seven-point scale used in DMs' assessment stages ranges from Very Unimportant to Very Important, as presented in Table 2.2.

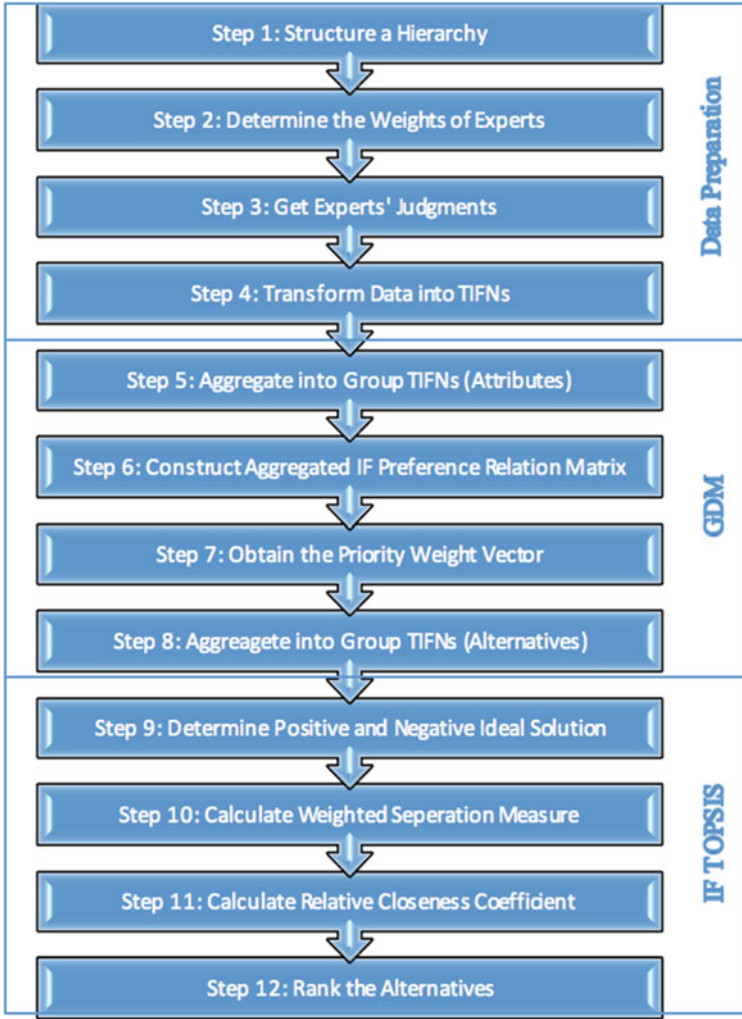


Fig. 2.1 The proposed IF TOPSIS MCDM methodology to determine the best alternative for a HWTF

Let $D_k = (\mu_k, \nu_k, \pi_k)$ be an IF number for rating of the k th DM. The weights of the k th DM are obtained using the following Eq. (2.1) which is adapted from the study of Boran et al. (2009).

$$\lambda_k = \frac{\left[\mu_k + \pi_k \left[\frac{\mu_k}{1 - \pi_k} \right] \right]}{\sum_{k=1}^K \left[\mu_k + \pi_k \left[\frac{\mu_k}{1 - \pi_k} \right] \right]}, \quad \text{where } \sum_{k=1}^K \lambda_k = 1 \quad (2.1)$$

Table 2.2 Linguistic variable for the importance of each DM

Linguistic variables	TIFNs		
	μ	ν	Π
Very important	0.90	0.05	0.05
Important	0.75	0.20	0.05
Somewhat important	0.60	0.30	0.10
Medium important	0.50	0.40	0.10
Somewhat unimportant	0.30	0.60	0.10
Unimportant	0.25	0.60	0.15
Very unimportant	0.10	0.80	0.10

Step 3: Based on prior knowledge and expertise on their specific topics, experts are required to provide their judgments.

In this step, assume that each expert provides his/her judgments on each factor in linguistic terms.

Step 4: Transform Data into TIFNs.

Construct the preference relation matrix for attributes and alternatives.

After forming the hierarchy, the preference relation matrix is structured. During the preference relation, a TIFNs preference scale is used for the evaluation. Since the linguistic terms are not mathematically operable, the next step is to make a standardization of experts' evaluations by converting them to TIFNs, once all linguistic assessments of factors from each expert are obtained. The scale used in TOPSIS stage for preparing the preference relation matrix ranges from 1 (Extremely Unimportant) to 9 (Extremely Important), as presented in Table 2.3. The linguistic scale is adapted from Abdullah and Najib (2014).

Step 5: Aggregate individual TIFNs into group TIFNs for the attributes.

In this step, each individual experts' opinion is aggregated into IF environment. It has been decided to use the intuitionistic fuzzy weighted averaging (IFWA) operator which is used to aggregate the matrix assessment of DMs into a group

Table 2.3 Linguistic variable for the importance of factors (Abdullah and Najib 2014)

Linguistic variable		μ	ν	π
Extremely unimportant	EU	0.02	0.18	0.80
Very strong unimportance	VSU	0.06	0.23	0.70
Strongly unimportant	SU	0.13	0.27	0.60
Moderately unimportant	MU	0.22	0.28	0.50
Equally important	EI	0.33	0.27	0.40
Moderately important	MI	0.47	0.23	0.30
Strongly important	SI	0.62	0.18	0.20
Very strong importance	VSI	0.80	0.10	0.10
Extremely important	EMI	1.00	0.00	0.00

opinion due to Xu (2011) since IFWA weights only the IF arguments but not the ordered position and practical in use.

Step 6: Construct the aggregated IF preference relation matrix

$$B = \begin{bmatrix} \hat{b}_{11} & \hat{b}_{12} & \dots & \hat{b}_{1n} \\ \hat{b}_{21} & \hat{b}_{22} & \dots & \hat{b}_{2n} \\ & & \ddots & \\ & & & \ddots \\ \hat{b}_{m1} & \hat{b}_{m2} & \dots & \hat{b}_{mn} \end{bmatrix}$$

where $\tilde{b}_{ij} = (\mu_{ij}, v_{ij}) (i = 1, 2, \dots, n; j = 1, 2, \dots, n)$ and satisfies the following Eqs. (2.2) and (2.3).

$$(\mu_{ij})^* = \max \left\{ \mu_{ij}, \max_p \left\{ \frac{\mu_{ip}\mu_{pj}}{\mu_{ip}\mu_{pj} + (1 - \mu_{ip})(1 - \mu_{pj})} \right\} \right\} \quad (2.2)$$

$$(v_{ij})^* = \max \left\{ v_{ij}, \max_p \left\{ \frac{v_{ip}v_{pj}}{v_{ip}v_{pj} + (1 - v_{ip})(1 - v_{pj})} \right\} \right\} \quad (2.3)$$

Step 7: Obtain the priority vector of criteria:

$$w = (w_1, w_2, \dots, w_n)^T$$

Weights of the criteria can be estimated with the help of the equation proposed by Genç et al. (2010).

$$w_j = [w_j^L, w_j^U] = \left(\frac{1}{\sum_{j=1}^n \left(\frac{(1 - \mu_{ij}^*)}{\mu_{ij}^*} \right)}, \frac{1}{\sum_{j=1}^n \left(\frac{(1 - v_{ij}^*)}{v_{ij}^*} \right)} \right) \quad (2.4)$$

Step 8: Aggregate individual TIFNs into group TIFNs for the alternatives.

In this step, each individual expert's opinion is aggregated into IF environment and the aggregated IF decision matrices for each expert is constructed:

Assume that R is the group decision making matrix where

$$R = \left(R_{ij}^k \right) = \begin{bmatrix} R_{11}^k & \cdots & R_{1n}^k \\ \vdots & \ddots & \vdots \\ R_{m1}^k & \cdots & R_{mn}^k \end{bmatrix}, \quad k \in K$$

where $R_{ij}^k = (\mu_{ij}^k, v_{ij}^k, \pi_{ij}^k)$. Use the following Eq. (2.5) for individual aggregation of each expert's opinions.

$$R_{ij} = IFWA_{\lambda} \left(R_{ij}^{(k)} \right) = \lambda_k r_{ij}^{(k)} \quad (2.5)$$

Step 9: Determine the positive ideal solution and the negative ideal solution.

A^* is the positive ideal solution, and A^- is the negative ideal solution,

$$A^* = (\tilde{r}_1^*, \tilde{r}_2^*, \dots, \tilde{r}_n^*), \tilde{r}_j^* = (\mu_j^*, v_j^*, \pi_j^*), \quad j = 1, 2, \dots, n \quad (2.6)$$

$$A^- = (\tilde{r}_1^-, \tilde{r}_2^-, \dots, \tilde{r}_n^-), \tilde{r}_j^- = (\mu_j^-, v_j^-, \pi_j^-), \quad j = 1, 2, \dots, n \quad (2.7)$$

where

$$\begin{aligned} \mu_j^* &= \left\{ \left(\max_i \{ \mu_{ij} \} | j \in J_1 \right) \right\}, \left\{ \left(\min_i \{ \mu_{ij} \} | j \in J_2 \right) \right\} \\ v_j^* &= \left\{ \left(\min_i \{ v_{ij} \} | j \in J_1 \right) \right\}, \left\{ \left(\max_i \{ v_{ij} \} | j \in J_2 \right) \right\} \\ \mu_j^- &= \left\{ \left(\min_i \{ \mu_{ij} \} | j \in J_1 \right) \right\}, \left\{ \left(\max_i \{ \mu_{ij} \} | j \in J_2 \right) \right\} \\ v_j^- &= \left\{ \left(\max_i \{ v_{ij} \} | j \in J_1 \right) \right\}, \left\{ \left(\min_i \{ v_{ij} \} | j \in J_2 \right) \right\} \end{aligned}$$

Step 10: Calculate the weighted separation measures.

The weighted Hamming distance is utilized to calculate the separation measures (Xu 2011).

$$(S_i^*)^L = \frac{1}{2} \sum_{j=1}^n w_j^L \left[\left| \mu_{ij} - \mu_j^* \right| + \left| v_{ij} - v_j^* \right| + \left| \pi_{ij} - \pi_j^* \right| \right] \quad (2.8)$$

$$(S_i^*)^U = \frac{1}{2} \sum_{j=1}^n w_j^U \left[\left| \mu_{ij} - \mu_j^* \right| + \left| v_{ij} - v_j^* \right| + \left| \pi_{ij} - \pi_j^* \right| \right] \quad (2.9)$$

$$(S_i^-)^L = \frac{1}{2} \sum_{j=1}^n w_j^L \left[\left| \mu_{ij} - \mu_j^- \right| + \left| v_{ij} - v_j^- \right| + \left| \pi_{ij} - \pi_j^- \right| \right] \quad (2.10)$$

$$(S_i^-)^U = \frac{1}{2} \sum_{j=1}^n w_j^U \left[\left| \mu_{ij} - \mu_j^- \right| + \left| v_{ij} - v_j^- \right| + \left| \pi_{ij} - \pi_j^- \right| \right] \quad (2.11)$$

Step 11: Calculate the relative closeness coefficients.

$$(C_i^*)^L = \left(\frac{(S_i^-)^L}{(S_i^*)^U + (S_i^-)^U} \right) \quad (2.12)$$

$$(C_i^*)^U = \left(\frac{(S_i^-)^U}{(S_i^*)^L + (S_i^-)^L} \right) \quad (2.13)$$

Step 12: Rank the alternatives in ascending order of the relative closeness coefficients.

The best alternative is selected in ascending order of the relative closeness coefficient. The possibility degree formula, which is proposed by Xu and Da (2002), is used to rank the alternatives as shown in Eqs. (2.14) and (2.15).

$$p(a \geq b) = \max \left\{ 1 - \max \left(\frac{b^U - a^L}{b^U - b^L + a^U - a^L}, 0 \right), 0 \right\} \quad (2.14)$$

$$p(b \geq a) = \max \left\{ 1 - \max \left(\frac{a^U - b^L}{b^U - b^L + a^U - a^L}, 0 \right), 0 \right\} \quad (2.15)$$

2.4 Case Study

2.4.1 Company Background

The proposed method has been implemented in a chemical company registered in Turkey. Due to privacy concerns, the identity of the firm is kept anonymous. In this chapter, the company is referred as ABC Company from now on.

The ABC Company is established in 1924 to deal with chemicals trading with recognized international suppliers, mainly polymer emulsions and specialty chemicals. The first polymer emulsions and textile auxiliaries investment of ABC had a plant capacity of 6000 tons. As of 2007, over the last 28 years this production

capacity grew more than 30-fold to 200,000 tons per year, thanks to 5 plant expansions with an ambition to grow and passion for its business.

Environment is a key concern for ABC, not only in production, but also in new product development, both at individual and corporate levels. ABC is well aware that reducing the use of Polyethylene (PE) adds up to sizable benefits for the environment. ABC's goal is to improve the production performance by analyzing each step in the production, logistics and transport and determine the way for decreasing energy consumption, raw material use, equipment wear and tear and byproducts and increasing the customer satisfaction, hygiene, environmental safety and the wellbeing of its workers and community. For this reason, ABC is willing to find a suitable HWTF for all its hazardous waste.

2.4.2 *Implementation of the Proposed Methodology*

ABC's main objective is to select the most suitable HWTF that can satisfy its needs. There are 5 HWTF alternatives with which ABC has worked in the past for hazardous waste material transportation. At this stage, experts' earlier works done with the company's existing firms is taken as reference. These 5 firms, referred as A_1 , A_2 , A_3 , A_4 and A_5 from now on, are assessed in the following case study.

The criteria determined for the purpose of evaluating and ranking alternative transportation firms are taken from similar studies in literature (Gumus 2009; Kabir and Sumi 2015; Kabir 2015) and experts' opinions. Three experts are designated for evaluation; the logistics and distribution manager, the sales coordination manager and the health-safety and environment specialist. ABC's logistic director has been employed since 1990 to manage stock levels, delivery times and negotiations with customers and suppliers, etc. He is one of the most experienced and longest serving staff of the company. ABC's sales coordination manager is working for the company since 1999. He has worked in different departments in the company in the past and currently works as a manager for coordinating the sales team, assessing the progress of the department and developing sales strategies. Health-safety and environmental specialist works for the company in order to ensure that environmental regulations and workplace safety standards are fully met to protect the wellbeing of the public and the environment. She is employed in ABC since 2005.

The details of the HWTF selection process for ABC Company is illustrated below.

Step 1. The hierarchical structure is constructed.

The goal of finding the best suitable HWTF and 5 transportation firm alternatives for resolving the problem is defined. The evaluation criteria that are grouped under 10 categories for evaluating transportation firms are given as follows:

- C_1 Economic Capability (EC)
- C_2 Cost of Service (CS)

- C₃ Financial Stability (FS)
- C₄ Service Capability (SC)
- C₅ Service Time (ST)
- C₆ Experience and Qualification (E&Q)
- C₇ Technical Capability (TC)
- C₈ Environmental and Safety (ES)
- C₉ Hygiene and Safety (HS)
- C₁₀ Taking Care of Human Health (TCH)

Step 2. Weights of the DMs are determined.

Importance weights of the experts are calculated, as seen in Table 2.4.

Step 3. Experts' judgments are collected for each HWTF.

Table 2.5 shows the judgment matrix of the first DM as an example. Table 2.6 shows the judgment matrix for all alternatives for each DM.

Step 4. Linguistic data are transformed into TIFNs.

The sample of the transformed TIFNs is shown in Table 2.7 for the first alternative.

Step 5. Individual data are aggregated into group TIFNs.

Table 2.8 displays B matrix, the group TIFNs for attributes.

Table 2.4 Importance weights of the experts

	DM-1	DM-2	DM-3
Linguistic terms	Very important	Important	Medium important
Weight	0.4133	0.3444	0.2423

Table 2.5 Judgment matrix of criteria for DM1

	EC	CS	FS	SC	ST	E&Q	TC	ES	HS	TCH
EC	EU	EI	SU	SI	EI	EI	SU	SU	VSU	SU
CS	EI	EU	EI	MU	SI	MI	MU	MU	SU	VSU
FS	MI	EI	EU	EI	SU	EI	SU	VSU	MU	VSU
SC	VSU	MI	EI	EU	MU	VSU	MU	SU	SU	SU
ST	EI	SI	MI	SI	EU	MU	EI	VSU	VSU	VSU
E&Q	EI	MU	EI	VSI	SI	EU	MU	SU	MU	SU
TC	MI	SI	MI	SI	EI	SI	EU	VSU	SU	VSU
ES	MI	SI	VSI	MI	VSI	MI	VSI	EU	VSU	SU
HS	VSI	MI	SI	MI	VSI	SI	MI	VSI	EU	VSU
TCH	MI	VSI	VSI	MI	VSI	VSI	VSI	MI	VSI	EU

Table 2.7 TIFNs for the first alternative

		DM1			DM2			DM3		
		μ	ν	π	μ	ν	π	μ	ν	π
A1	EC	0.62	0.18	0.2	0.8	0.1	0.1	0.47	0.23	0.3
	CS	0.47	0.23	0.3	0.62	0.18	0.2	0.62	0.18	0.2
	FS	0.47	0.23	0.3	0.33	0.27	0.4	0.8	0.1	0.1
	SC	0.22	0.28	0.5	0.33	0.27	0.4	0.22	0.28	0.5
	ST	0.33	0.27	0.4	0.47	0.23	0.3	0.47	0.23	0.3
	E&Q	0.22	0.28	0.5	0.62	0.18	0.2	0.47	0.23	0.3
	TC	0.47	0.23	0.3	0.22	0.28	0.5	0.33	0.27	0.4
	ES	0.8	0.1	0.1	0.8	0.1	0.1	0.8	0.1	0.1
	HS	0.62	0.18	0.2	0.47	0.23	0.3	0.62	0.18	0.2
	TCH	0.62	0.18	0.2	0.62	0.18	0.2	0.8	0.1	0.1

Table 2.8 Aggregated TIFNs for attributes (B)

	EC		CS		FS		SC		ST	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
EC	0.02	0.18	0.48	0.23	0.23	0.27	0.5	0.22	0.36	0.26
CS	0.23	0.45	0.02	0.18	0.24	0.27	0.41	0.24	0.59	0.19
FS	0.27	0.2	0.27	0.22	0.02	0.18	0.36	0.26	0.15	0.26
SC	0.26	0.24	0.24	0.35	0.26	0.34	0.02	0.18	0.24	0.27
ST	0.26	0.34	0.19	0.58	0.27	0.13	0.27	0.22	0.02	0.18
E&Q	0.26	0.31	0.22	0.5	0.27	0.3	0.25	0.08	0.27	0.22
TC	0.27	0.2	0.28	0.22	0.26	0.1	0.27	0.28	0.27	0.3
ES	0.26	0.11	0.28	0.19	0.26	0.1	0.26	0.15	0.2	0.11
HS	0.24	0.08	0.25	0.09	0.28	0.19	0.25	0.09	0.25	0.1
TCH	0.25	0.09	0.26	0.12	0.26	0.1	0.26	0.11	0.2	0.11
	E&Q		TC		ES		HS		TCH	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
EC	0.33	0.26	0.23	0.27	0.11	0.26	0.08	0.24	0.09	0.25
CS	0.51	0.22	0.22	0.28	0.2	0.28	0.09	0.25	0.14	0.26
FS	0.3	0.27	0.11	0.26	0.1	0.25	0.2	0.28	0.1	0.25
SC	0.09	0.25	0.29	0.27	0.19	0.26	0.09	0.25	0.11	0.26
ST	0.24	0.27	0.3	0.27	0.08	0.23	0.12	0.25	0.08	0.23
E&Q	0.02	0.18	0.25	0.28	0.15	0.27	0.17	0.27	0.15	0.27
TC	0.28	0.24	0.02	0.18	0.12	0.25	0.09	0.23	0.11	0.25
ES	0.27	0.15	0.25	0.1	0.02	0.18	0.05	0.22	0.11	0.26
HS	0.27	0.16	0.24	0.07	0.19	0.08	0.02	0.18	0.06	0.24
TCH	0.26	0.11	0.25	0.09	0.26	0.11	0.18	0.07	0.02	0.18

Step 6. Aggregated IF preference relation matrix is constructed.

After taking the judgments of experts about all criteria, the aggregated preference relation matrix is formed and then using the Eqs. (2.2) and (2.3), the consistent IF preference relation matrix is constructed, as shown in Table 2.9.

Step 7. Obtain the priority vector.

The priority vector of criteria is estimated using Eq. (2.4). Table 2.10 displays the calculated data.

Step 8. Alternatives are aggregated into group TIFNs.

Table 2.11 displays the aggregated IF decision matrix for each alternative.

Step 9. Positive and negative ideal solutions are calculated.

The positive and negative ideal solutions are calculated by considering ranking values and Eqs. (2.6) and (2.7) (Table 2.12). Economic capability, cost of service and financial stability criteria are considered as cost criteria and the rest are considered as benefit criteria.

Table 2.9 IF preference relation matrix for attributes (consistent B*)

	EC		CS		FS		SC		ST	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
EC	0.260	0.191	0.479	0.324	0.258	0.272	0.499	0.220	0.568	0.258
CS	0.333	0.447	0.254	0.246	0.340	0.272	0.413	0.238	0.588	0.219
FS	0.272	0.204	0.272	0.331	0.164	0.180	0.359	0.258	0.348	0.264
SC	0.261	0.300	0.245	0.347	0.259	0.338	0.260	0.180	0.316	0.274
ST	0.259	0.527	0.243	0.580	0.265	0.341	0.274	0.302	0.254	0.246
E&Q	0.264	0.449	0.248	0.503	0.272	0.299	0.263	0.240	0.285	0.223
TC	0.272	0.204	0.280	0.371	0.258	0.165	0.274	0.279	0.357	0.299
ES	0.262	0.162	0.278	0.194	0.256	0.098	0.262	0.151	0.354	0.106
HS	0.244	0.081	0.250	0.163	0.278	0.194	0.250	0.087	0.322	0.099
TCH	0.250	0.097	0.259	0.140	0.256	0.098	0.262	0.110	0.333	0.106
	E&Q		TC		ES		HS		TCH	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
EC	0.490	0.263	0.286	0.272	0.190	0.261	0.092	0.243	0.127	0.249
CS	0.511	0.224	0.385	0.280	0.199	0.278	0.175	0.249	0.159	0.258
FS	0.305	0.272	0.183	0.257	0.117	0.255	0.199	0.278	0.104	0.255
SC	0.253	0.247	0.287	0.274	0.191	0.261	0.092	0.249	0.115	0.261
ST	0.240	0.276	0.305	0.349	0.082	0.346	0.122	0.314	0.077	0.324
E&Q	0.226	0.219	0.248	0.282	0.153	0.280	0.168	0.274	0.153	0.272
TC	0.289	0.243	0.141	0.180	0.122	0.250	0.094	0.235	0.105	0.245
ES	0.287	0.148	0.251	0.099	0.087	0.180	0.079	0.220	0.115	0.261
HS	0.274	0.162	0.240	0.077	0.188	0.083	0.087	0.180	0.065	0.235
TCH	0.268	0.111	0.246	0.087	0.262	0.110	0.180	0.065	0.059	0.180

Table 2.10 Priority weight vector

	Lower	Upper
EC	0.030	0.033
CS	0.039	0.035
FS	0.024	0.033
SC	0.024	0.036
ST	0.020	0.051
E&Q	0.028	0.040
TC	0.021	0.031
ES	0.021	0.017
HS	0.020	0.013
TCH	0.023	0.012

Table 2.11 IF decision matrix

	EC		CS		FS		SC		ST	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
A ₁	0.670	0.156	0.564	0.199	0.546	0.199	0.260	0.277	0.416	0.246
A ₂	0.546	0.199	0.441	0.232	0.605	0.179	0.317	0.262	0.335	0.258
A ₃	0.369	0.255	0.449	0.235	0.317	0.262	0.330	0.270	0.441	0.231
A ₄	0.546	0.199	0.322	0.232	0.605	0.179	0.317	0.262	0.335	0.258
A ₅	0.470	0.230	0.449	0.235	0.330	0.270	0.190	0.277	0.441	0.231
	E&Q		TC		ES		HS		TCH	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
A ₁	0.446	0.229	0.359	0.256	0.800	0.100	0.574	0.196	0.675	0.156
A ₂	0.163	0.257	0.406	0.218	0.392	0.253	0.479	0.226	0.470	0.230
A ₃	0.369	0.255	0.147	0.261	0.461	0.232	0.511	0.216	0.470	0.230
A ₄	0.441	0.232	0.479	0.226	0.392	0.253	0.202	0.257	0.470	0.230
A ₅	0.330	0.270	0.511	0.216	0.461	0.232	0.317	0.262	0.369	0.255

Table 2.12 The negative and positive ideal solutions

	A*			A ⁻		
EC	0.369	0.255	0.376	0.670	0.156	0.174
CS	0.322	0.235	0.443	0.564	0.199	0.237
FS	0.317	0.270	0.413	0.605	0.179	0.216
SC	0.330	0.262	0.408	0.190	0.277	0.533
ST	0.441	0.231	0.327	0.335	0.258	0.407
E&Q	0.446	0.229	0.325	0.163	0.270	0.567
TC	0.511	0.216	0.273	0.147	0.261	0.591
ES	0.800	0.100	0.100	0.392	0.253	0.355
HS	0.574	0.196	0.230	0.202	0.262	0.536
TCH	0.675	0.156	0.169	0.369	0.255	0.376

Step 10. Weighted separation measures are calculated.

Negative and positive separation measures, based on the weighted lower and upper hamming distance for each alternative, have been calculated using the Eqs. (2.8), (2.9), (2.10), and (2.11) (Table 2.13).

Step 11. Relative closeness coefficient is calculated.

The distances of each alternative to the ideal solutions and the closeness coefficient are calculated as given in Table 2.14.

Step 12. Alternatives are ranked.

Five candidate HWTF have been ranked in descending order of the relative closeness coefficients. The candidates are ranked by using the possibility degree formula, thus the matrix in Table 2.15 is created. The ranking of the alternatives is $A_2 > A_1 > A_3 > A_4 > A_5$. Finally, A_2 is selected as the best alternative for ABC Company.

Table 2.13 Separation measures

	S_i^*		S_i^-	
	Upper	Lower	Upper	Lower
A1	0.035	0.030	0.042	0.040
A2	0.051	0.045	0.026	0.026
A3	0.028	0.028	0.049	0.042
A4	0.037	0.037	0.040	0.034
A5	0.031	0.034	0.046	0.036

Table 2.14 Closeness coefficient

Lower	Upper
0.528	0.596
0.333	0.374
0.545	0.693
0.438	0.566
0.466	0.655

Table 2.15 Possibility degree matrix

A_1	0.500	1.000	0.765	0.197	0.494	2.956	2
A_2	0.000	0.500	1.000	1.000	1.000	3.500	1
A_3	0.235	0.000	0.500	0.923	0.674	2.333	3
A_4	0.803	0.000	0.077	0.500	0.683	2.063	4
A_5	0.506	0.000	0.326	0.317	0.500	1.649	5

2.5 Conclusion

MCDM methods are used for comparing, ranking and selecting multiple alternatives with multiple criteria. When there are several alternatives available, MCDM can be used, since a decision needs to be taken that is favorable over others. The HWTF selection problem is often influenced by vagueness and uncertainty in practice since DMs' judgments cannot be explained precisely in numerical values. Therefore, DMs' preferences and evaluations are very often expressed in linguistic terms. Some of researchers extend the typical MCDM methods to the fuzzy environment. A fuzzy MCDM is used in case of uncertainty and vagueness in DMs' perceptions. A variety of different MCDM/fuzzy MCDM approaches have been proposed by researchers (such as AHP, ANP, TOPSIS, ELECTRE, etc.). From literature, it is observed that in some situations Fuzzy Sets can be insufficient for dealing with subjectivity and ambiguity which is an unavoidable aspect of human statements. IF sets, however, are useful tools to investigate the fuzziness in DMs' judgments in the lack of knowledge or data about the problem. This study proposes integrated IF TOPSIS as a MCDM technique with a group decision making approach for a real case HWTF selection problem in order to decide on the most appropriate HWTF. Our approach is used to obtain the effective ranking of HWTF alternatives. IF TOPSIS approach is a flexible and robust way for DMs to better understand a decision problem in case of uncertainty and vagueness in DMs perceptions.

There are several future research directions to follow this study. Only ten criteria are used for this analysis. More HWTF evaluation criteria can be used to improve the effectiveness of the decision making process. Also, the present approach only considers IF sets. Another promising future work would be to consider the regular fuzzy logic and to compare the results by a sensitivity analysis. Another area to be studied could be the use of other MCDM methods in integration with fuzzy or IF, AHP, TOPSIS or VIKOR, etc. in order to resolve these problems effectively and satisfactorily.

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References

- Abdullah, L., & Najib, L. (2014, December). Sustainable energy planning decision using the intuitionistic fuzzy analytic hierarchy process: Choosing energy technology in Malaysia. *International Journal of Sustainable Energy*, 1–18.
- Abessi, O., & Saeedi, M. (2014). Hazardous waste landfill siting using GIS technique and analytical hierarchy process. *Environment Asia*, 7(2), 104–111.

- Ali, M., Yadav, A., & Anis, M. (2015a). Assessment of hazardous waste management proposal: Using the analytic hierarchy process. *International Journal of Economics, Commerce and Management*, 3(7), 315–327.
- Ali, M., Yadav, A., Anis, M., & Sharma, P. (2015b). Multiple criteria decision analysis using Dea-TOPSIS method for hazardous waste management: A case study of the USA. *International Journal of Managing Information Technology*, 7(3), 1–17.
- Alidi, A. S. (1996). A multiobjective optimization model for the waste management of the petrochemical industry. *Applied Mathematical Modelling*, 20(12), 925–933.
- Aloini, D., Dulmin, R., & Mininno, V. (2014). A peer IF-TOPSIS based decision support system for packaging machine selection. *Expert Systems with Applications*, 41(5), 2157–2165.
- Atanassov, K. T. (1986). Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 20(1), 87–96.
- Boran, F. E. (2011). An integrated intuitionistic fuzzy multi criteria decision making method for facility location selection. *Mathematical and Computational Applications*, 16(2), 456–466.
- Boran, F. E., Boran, K., & Menlik, T. (2012). The evaluation of renewable energy technologies for electricity generation in Turkey using intuitionistic fuzzy TOPSIS. *Energy Sources, Part B: Economics, Planning and Policy*, 7(1), 81–90.
- Boran, F. E., Genc, S., & Akay, D. (2011). Personnel selection based on intuitionistic fuzzy sets. *Human Factors and Ergonomics in Manufacturing*, 21(5), 493–503.
- Boran, F. E., Genç, S., Kurt, M., & Akay, D. (2009). A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method. *Expert Systems with Applications*, 36(8), 11363–11368.
- De Feo, G., & De Gisi, S. (2014). Using MCDA and GIS for hazardous waste landfill siting considering land scarcity for waste disposal. *Waste Management*, 34(11), 2225–2238.
- Duan, H., Huang, Q., Wang, Q., Zhou, B., & Li, J. (2008). Hazardous waste generation and management in China: A review. *Journal of Hazardous Materials*, 158, 221–227.
- Genç, S., Boran, F. E., Akay, D., & Xu, Z. (2010). Interval multiplicative transitivity for consistency, missing values and priority weights of interval fuzzy preference relations. *Information Sciences*, 180(24), 4877–4891.
- Gumus, A. T. (2009). Evaluation of hazardous waste transportation firms by using a two step fuzzy-AHP and TOPSIS methodology. *Expert Systems with Applications*, 36(2 PART 2), 4067–4074.
- Ho, C. C. (2011). Optimal evaluation of infectious medical waste disposal companies using the fuzzy analytic hierarchy process. *Waste management (New York, N.Y.)*, 31(7), 1553–1559.
- Hsu, P.-F., Wu, C.-R., & Li, Y.-T. (2008). Selection of infectious medical waste disposal firms by using the analytic hierarchy process and sensitivity analysis. *Waste management (New York, N.Y.)*, 28(8), 1386–1394.
- İntepe, G., Bozdog, E., & Koc, T. (2013). The selection of technology forecasting method using a multi-criteria interval-valued intuitionistic fuzzy group decision making approach. *Computers & Industrial Engineering*, 65(2), 277–285.
- Joshi, D., & Kumar, S. (2016). Interval-valued intuitionistic hesitant fuzzy choquet integral based TOPSIS method for multi-criteria group decision making. *European Journal of Operational Research*, 248(1), 183–191.
- Kabir, G. (2015). Selection of hazardous industrial waste transportation firm using extended VIKOR method under fuzzy environment Golam Kabir. *International Journal of Data Analysis Techniques and Strategies*, 7(1), 40–58.
- Kabir, G., & Sumi, R. S. (2015). Hazardous waste transportation firm selection using fuzzy analytic hierarchy and PROMETHEE methods. *International Journal of Shipping and Transport Logistics*, 7(2), 115–136.
- Kucukvar, M., Gumus, S., Egilmez, G., & Tatari, O. (2014). Ranking the sustainability performance of pavements: An intuitionistic fuzzy decision making method. *Automation in Construction*, 40, 33–43.
- Li, Y., Chu, X., Chu, D., Geng, X., & Wu, X. (2014). An integrated approach to evaluate module partition schemes of complex products and systems based on interval-valued intuitionistic fuzzy sets. *International Journal of Computer Integrated Manufacturing*, 27(7), 675–689.

- Long, S., & Geng, S. (2015). Decision framework of photovoltaic module selection under interval-valued intuitionistic fuzzy environment. *Energy Conversion and Management*, 106, 1242–1250.
- Marinković, N., Vitale, K., Holcer, N. J., Dzakula, A., & Pavić, T. (2008). Management of hazardous medical waste in Croatia. *Waste Management*, 28(6), 1049–1056.
- Orford, P. (2007). Hazardous waste—A UK compliance overview. *Reinforced Plastics*, 51(3), 55–58.
- Park, J. H., Park, I. Y., Kwun, Y. C., & Tan, X. (2011). Extension of the TOPSIS method for decision making problems under interval-valued intuitionistic fuzzy environment. *Applied Mathematical Modelling*, 35(5), 2544–2556.
- Wan, S.-P., Wang, F., & Dong, J.-Y. (2016). A novel group decision making method with intuitionistic fuzzy preference relations for RFID technology selection. *Applied Soft Computing*, 38(168), 405–422.
- Wan, S.-P., Wang, F., Lin, L.-L., & Dong, J.-Y. (2015). Knowledge-based systems an intuitionistic fuzzy linear programming method for logistics outsourcing provider selection. *Knowledge-Based Systems*, 82, 1–15.
- Wang, Z., Li, K. W., & Xu, J. (2011). A mathematical programming approach to multi-attribute decision making with interval-valued intuitionistic fuzzy assessment information. *Expert Systems with Applications*, 38(10), 12462–12469.
- Wang, Y., Xi, C., Zhang, S., Zhang, W., & Yu, D. (2015). Combined approach for government E-tendering using GA and TOPSIS with intuitionistic fuzzy information. *PLoS ONE*, 10(7), e0130767.
- Wu, J. (2015). A SD-IITFOWA operator and TOPSIS based approach for MAGDM problems with intuitionistic trapezoidal fuzzy numbers. *Technological & Economic Development of Economy*, 21(1), 28–47.
- Xu, Z. (2011). *Intuitionistic preference modeling and interactive decision making*. Berlin: Springer.
- Xu, Z. S., & Da, Q. L. (2002). The uncertain OWA operator. *International Journal of Intelligent Systems*, 17(6), 569–575.
- Yang, W., Chen, Z., & Zhang, F. (2015). New group decision making method in intuitionistic fuzzy setting based on TOPSIS. *Technological and Economic Development of Economy*, 4913 (November), 1–21.
- Yue, Z., & Jia, Y. (2013). An application of soft computing technique in group decision making under interval-valued intuitionistic fuzzy environment. *Applied Soft Computing*, 13(5), 2490–2503.
- Zhang, X., & Xu, Z. (2015). Soft computing based on maximizing consensus and fuzzy TOPSIS approach to interval-valued intuitionistic fuzzy group decision making. *Applied Soft Computing*, 26, 42–56.

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