International Journal of Mathematical, Engineering and Management Sciences
Vol. 10, No. 2, 350-367, 2025
https://doi.org/10.33889/IJMEMS.2025.10.2.018

Ram Arti Publishers

Novel Intuitionistic Fuzzy Fault Tree Analysis for Effective Infectious Medical Waste Management

Rocky Khajuria
Department of Mathematics,
School of Physical Sciences, Doon University, Dehradun, 248001, Uttarakhand, India.
E-mail: rocky.khajuria@gmail.com

Komal
Department of Mathematics,
School of Physical Sciences, Doon University, Dehradun, 248001, Uttarakhand, India.
Corresponding author: karyadma.iitr@gmail.com

Morteza Yazdani
SCODeM Research Group,
Universidad Internacional de Valencia-VIU, 46002, Valencia, Spain.
E-mail: morteza.yazdani@universidadviu.com

(Received on August 5, 2024; Revised on October 1, 2024 & December 21, 2024; Accepted on December 26, 2024)

Abstract
With an increasing population, the number of healthcare issues is also increasing due to various critical diseases. To treat these diseases, different types of medical facilities are required, which finally produce a large quantity of medical waste. Such medical waste may be harmful or even dangerous to people as well as the environment if inadequately treated. To prevent the spread of such diseases in a healthy civil society, an effective medical waste management system is required to be developed. Generally, to develop an effective medical waste management system, identification of the most critical incidents is needed, which requires a large quantity of data that may not be available. In this case, the problem is associated with ambiguity and uncertainty due to a variety of practical and financial reasons. So, the main objective of the paper is to analyze any infectious medical waste management system under uncertainty and identification of the critical incidents of its failure. The proposed study is actually based on this motivation. The paper proposes an intuitionistic fuzzy fault tree analysis (FFTA) method that quantifies data uncertainty through trapezoidal intuitionistic fuzzy numbers (TrIFN) while novel arithmetic operations are applied for computing the top incident failure possibility. To develop these novel operations, the weakest *t*-norm is applied to detract the accumulating circumstances of fuzziness, while Algebraic *t*-norm and *t*-conorm are used to estimate membership and non-membership degrees, respectively, of top event failure possibility in terms of trapezoidal intuitionistic fuzzy numbers (TrIFN). A Hamming distance-based ranking method has been developed and then applied for the identification of critical incidents. These are the primary contributions of the proposed study in the paper. The proposed intuitionistic fuzzy fault tree analysis (FFTA) method has been applied to investigate the failure phenomenon of an infectious medical waste management system under uncertainty. The effectiveness of the proposed method is shown by comparing the results with four existing fault tree methods. The findings may be helpful to develop an efficient medical waste management system.

Keywords- Algebraic *t*-norm and *t*-conorm, Fault tree analysis, Infectious medical waste, Weakest *t*-norm, Trapezoidal intuitionistic fuzzy number (TrIFN).

1. Introduction

The population of the world is increasing day by day and hence our natural resources are overstressed. Due to this, the climate is changing drastically. In these situations, people are facing health issues (Singh et al., 2020). To protect humans from critical diseases such as cancer, COVID-19, AIDS, swine flu, etc., there is an increase in demand for healthcare facilities, which, as a result, use different types of healthcare devices. To prevent the spread of such diseases, there is a trend to use single-use healthcare devices rather

than multi-use healthcare devices. This generates a large amount of medical waste, which is generally infectious and harmful and can even be dangerous to people and the environment if not properly disposed of (Klemes et al., 2020; Manupati et al., 2021; Narayanamoorthy et al., 2020; Patel et al., 2023). However, for the past few decades, governments across the world have been trying to develop efficient waste management systems to manage nuclear waste, thermal waste, medical waste, solid waste, etc. (Moreira and Gunther, 2013; Mishra et al., 2020; Windfeld and Brooks, 2015; Gao et al., 2024; Sandoval-Reyes et al., 2024). Recently, some researchers investigated different types of waste management systems with the help of multi-criteria decisions making approaches (Celik et al., 2023; Komal, 2023; Liu et al., 2022). So, the development of an effective medical waste management system for a healthy civil society by controlling infection and protecting the environment is an important issue. Generally, to develop an effective medical waste management system, identification of the most critical incidents is required. To identify the most critical incidents, a large quantity of data is required to be collected from different sources, which may contain uncertainty due to various practical and economic reasons (Krishankumar et al., 2022; Krishankumar et al., 2024; Liu et al., 2013, 2014). Thus, considering such types of constraints, the development of an effective medical waste management system in an uncertain environment is a challenging job (Singh et al., 2022; Tushar et al., 2023). So, the objective of the present study is to identify the obstacles and their solution methods for developing an effective medical waste management system in an uncertain environment. To achieve the objective, the following challenges are observed:

a) The first challenge is the mathematical modeling of the problem.
b) The second challenge is to appropriately quantify uncertainty in data and information.
c) The third challenge is to fuse this quantified data and information by applying an appropriate method and operations.
d) The fourth challenge is to identify the critical incidents that will be helpful to design an effective medical waste management system.

To address the first challenge, there are methods like incident tree analysis (ITA), root cause analysis (RCA), fault tree analysis (FTA) and failure mode and effect analysis (FMEA), etc. (Ebeling, 2001). The FTA is one of the most commonly used methods in various fields of healthcare and waste management from both qualitative and quantitative perspectives, such as in healthcare risk management, preventing wrong-site surgery, failure of critical medical devices, medical waste management, infection control, etc. (Abecassis et al., 2015; Chang et al., 2006; Hyman and Johnson, 2008; Komal, 2015; Mokajic-Nikolic et al., 2016; Park and Lee, 2009; Raheja and Escano, 2009). In a traditional FTA, a logical diagram is constructed in which the top incident is mentioned at the top level while all the possible reasons for it are denoted by intermediate incidents below it, which goes lower and lower till all the relevant basic incidents are traced out. All the intermediate and basic incidents are joined by logical AND/OR gates, which represent incidents in parallel/series configuration, respectively, and follow a bottom-up approach (Park and Lee, 2009). FTA utilizes both qualitative and quantitative methods to evaluate the top incident failure probability by exploring the exact values of all the bottom incident failure probabilities. So, due to these advantages, FTA has been selected as a tool to model the failure of an infectious medical waste management process.

To cope with the second challenge, fuzzy set theory, introduced by Zadeh (1965) may be used because from past few years researchers have applied it to handle data uncertainty-related issues in various engineering and healthcare-related fields (Komal, 2015; Mahmood et al., 2013; Song et al., 2009; Yucel et al., 2011). A typical fuzzy set contains elements with membership degrees in the closed interval [0; 1]. Unfortunately, a fuzzy set is unable to consider the non-membership degree of any element belonging to the set. So, by including a non-membership degree along with the membership degree of an element in

the set, Atanassov (1986) gave the definition of an intuitionistic fuzzy set (IFS), where the sum of membership and non-membership degrees does not exceed one. IFS effectively handles vagueness and hesitancy factors originating from uncertain information. Since its inception, the IFS has attracted a large number of researchers to work on a variety of complex problems such as logic programming and reasoning, multi-criterion decision making, medical diagnosis and pattern recognition, and so on (De et al., 2001; Jiang et al., 2009, 2018; Vlachos and Sergiadis, 2007). In medical diagnosis and waste management, generally, researchers use triangle intuitionistic fuzzy number (TIFN) due to its simplicity in calculations (De et al., 2001; Mishra et al., 2020). However, in the literature, various extensions are available which may be more appropriate to represent uncertain information, including trapezoidal intuitionistic fuzzy number (TrIFN), pentagonal fuzzy set, Pythagorean fuzzy set (PFS), interval-valued intuitionistic fuzzy set (IV-IFS) etc. (Abdullah et al., 2019; Asif et al., 2025; Gazi et al., 2025; Liu et al., 2015; Yager and Abbasov, 2013). In this paper, the TrIFN has been used to quantify data uncertainty because it provides a range at any confidence level and is best studied by experts for representing their views and suggestions in mathematical form.

The aim now is to address the third challenge by adopting appropriate fuzzy arithmetic operations, which optimizes the range of prediction with more confidence. To do this, traditional FTA is required to be integrated with intuitionistic fuzzy set theory with suitable operational laws which depend upon the pair of*t*-norm and *t*-conorm (Mahmood et al., 2013). In literature, a variety of predefined *t*-norms and *t*-conorms exist, such as Algebraic, Einstein, Hamacher, Dombi, Drastic and Frank *t*-norms and *t*-conorms etc. (Klir and Yuan, 1996). Among these, Drastic *t*-norm, i.e. weakest *t*-norm (T_ω) is very popular in FTA and useful to detract the accumulating phenomenon of fuzziness under different fuzzy environments (Komal, 2015, 2017; Kumar and Yadav, 2012; Kumar, 2014). Specifically for healthcare systems, Komal (2015) used weakest *t*-norm coupled arithmetic operations derived for trapezoidal fuzzy numbers to examine patient safety risk assessment under uncertainty. Komal (2017) investigated the fuzzy failure possibility of the handwashing process using distinct fuzzy sets along with T_ω-norm coupled arithmetic operations to control hygiene under uncertainty. Xia et al. (2012) raised some issues about the Archimedean *t*-conorm and *t*-norm. Later on, Liu et al. (2015) applied Algebraic *t*-norm (T_A) and *t*-conorm (S_A) coupled arithmetic operations to evaluate the membership and non-membership degrees of the fuzzy failure possibility of high-speed railway accidents through the novel FFTA method. To address the last issue, researchers generally rank all the bottom incidents based on their influential degrees, which are calculated with the help of the *V* -index, which was introduced by Tanaka et al. (1983) for fuzzy sets. However, due to its applicability, researchers developed its extended version for the intuitionistic fuzzy set and applied it in FFTA (Kumar and Yadav, 2012; Shu et al., 2006). In this extended version of the *V* -index, a measure deficiency is that it does not involve membership and non-membership degrees of top and bottom incidents' failure possibilities in evaluating bottom incidents' influential degrees. To overcome this deficiency of the *V* -index, the Hamming distance based ranking method can be applied because it will involve fuzzy values and membership and non-membership degrees of top and bottom incidents to compute the influential degree of each bottom incident (Wan, 2013).

Based on the above observations, the present study introduces a novel intuitionistic FFTA to analyze the fault assessment of an infectious medical waste management system under uncertainty. In this intuitionistic FFTA method:

a) TrIFN is used to quantify data uncertainty.
b) Weakest *t*-norm, algebraic *t*-norm and *t*-conorm coupled novel arithmetic operations are applied to detract the accumulating circumstances of fuzziness and to estimate the values of membership and non-membership degrees, respectively, of top incident failure possibility in the form of TrIFN.

c) A Hamming distance-based ranking method has been developed and then applied for the identification of critical incidents.

This is the main contribution of the paper. The rest of the paper is organized as follows. Section 2 provides some basic definitions. In Section 3, the novel intuitionistic FFTA has been developed. In Section 4, the proposed intuitionistic FFTA and four others existing FFTA methods have been applied to analyze the failure possibility of an infectious medical waste management system under uncertainty. The results are compared and plotted graphically. The section also provides the ranking results of the critical bottom incidents based on Hamming distance. The conclusions are given in Section 5.

2. Preliminary Concepts

The section gives an overview of some basic definitions including intuitionistic fuzzy set (IFS), trapezoidal intuitionistic fuzzy number (TrIFN), *t*-norm and *t*-conorm, Algebraic *t*-norm and Algebraic *t*-conorm, weakest *t*-norm along with some existing and newly defined arithmetic operations for TrIFN, and Hamming distance between two TrIFNs.

2.1 IFS

Let X be the universal set then the IFS $\tilde{A}$ in X is defined as (Atanassov, 1986):

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x), \vartheta_{\tilde{A}}(x)) : x \in X\} \quad (1)$$

where, $\mu_{\tilde{A}}(x)$, $\vartheta_{\tilde{A}}(x) x \in [0,1]$ are called the membership and non-membership degrees of $x \in \tilde{A}$ respectively with condition $0 \leq \mu_{\tilde{A}}(x) + \vartheta_{\tilde{A}}(x) \leq 1, \forall x \in X$ The degree of hesitation of $x \in \tilde{A}$ is defined as $\pi_{\tilde{A}}(x) = 1 - \mu_{\tilde{A}}(x) - \vartheta_{\tilde{A}}(x)$.

2.2 TrIFN

An IFS $\tilde{A}$ in X is said to be a TrIFN if its $\mu_{\tilde{A}}(x)$ and $\vartheta_{\tilde{A}}(x)$ degrees are defined as follows (Wan and Dong, 2015):

$$\mu_{\tilde{A}}(x) = \begin{cases} \left(\frac{x-a}{b-a}\right)\mu_{\tilde{A}}, & if\, a \leq x \leq b, \\ \mu_{\tilde{A}}, & if\, b \leq x \leq c, \\ \left(\frac{d-x}{d-c}\right)\mu_{\tilde{A}}, & if\, c \leq x \leq d \\ 0, & if\, x < a, x > d \end{cases} \quad (2)$$

$$\vartheta_{\tilde{A}}(x) = \begin{cases} \left(\frac{x-a}{b-a}\right)\vartheta_{\tilde{A}}, & if\, a \leq x \leq b, \\ \vartheta_{\tilde{A}}, & if\, b \leq x \leq c, \\ \left(\frac{d-x}{d-c}\right)\vartheta_{\tilde{A}}, & if\, c \leq x \leq d \\ 1, & if\, x < a, x > d \end{cases} \quad (3)$$

where, a, b, c and d are all real numbers, $\mu_{\tilde{A}}(x)$ and $\vartheta_{\tilde{A}}(x)$ are maximum and minimum degrees of membership and non-membership respectively with conditions: $0 \leq \mu_{\tilde{A}}, \vartheta_{\tilde{A}} \leq 1$ and $0 \leq \mu_{\tilde{A}} + \vartheta_{\tilde{A}} \leq 1$. A TrIFN $\tilde{A}$ can be denoted by $\tilde{A} = ([a, b, c, d]; \mu_{\tilde{A}}, \vartheta_{\tilde{A}})$ and represented pictorially in **Figure 1**. If $a > 0$, then $\tilde{A} > 0$ and called as a positive TrIFN.

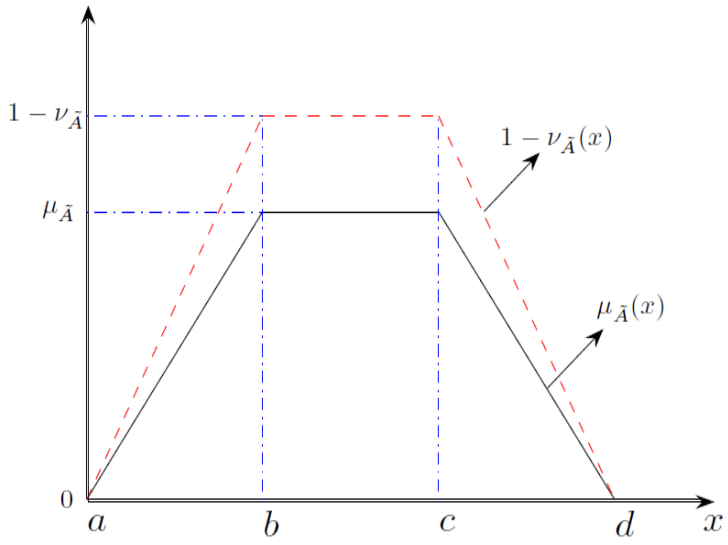

Figure 1. ATrIFN $\tilde{A}$ = ([*a*, *b*, *c*, *d*]; $\mu_{\tilde{A}}$, $\vartheta_{\tilde{A}}$).

2.3 The *t*-norm (T_A) and *t*-conorm (S_A)

The two binary functions *T*, *S*: [0, 1] x [0; 1] →[0, 1] are called *t*-norm and *t*-conorm respectively, if they satisfy the four conditions namely commutativity, associativity, monotonicity and boundary conditions (Xia et al., 2012). The pairwise *t*-norm and *t*-conorm satisfies the De Morgan duality: $S(x,y) = 1 - T(1-x,\ 1-y), \forall\ (x,y) \in [0,1]^2$. In literature, some predefined *t*-norms and *t*-conorms pairwise exist including Algebraic, Einstein, Ham achar, Drastic, Dombi, Frank etc. (Klir and Yuan, 1996). The present study uses Algebraic *t*-norm (T_A), Algebraic *t*-conorm (S_A), and the Drastic *t*-norm i.e. the weakest *t*-norm (T_ω) in developing novel arithmetic operations for TrIFNs which are defined as follows:

a) The Algebraic *t*-norm (T_A):

$$T_A(x,y) = xy \tag{4}$$

b) The Algebraic *t*-conorm (S_A):

$$S_A(x,y) = x + y - xy \tag{5}$$

c) The weakest *t*-norm (T_ω):

$$T_\omega(x,y) = \begin{cases} x,\ if y = 1, \\ y,\ if x = 1, \\ 0, otherwise \end{cases} \tag{6}$$

The Algebraic *t*-norm is continuous, strictly monotone, and have the Archimedean property (Xu, 2007). Similarly, T_ω-norm have shape-preserving nature and detracts fuzzy accumulating characteristic when fuzzy arithmetic operations are applied (Hong and Do, 1997; Lin et al., 2011).

2.4 Existing Fuzzy Arithmetic Operations Defined on TrIFNs

Let $\tilde{A}_1 = ([a_1, b_1, c_1, d_1];\ \mu_{\tilde{A}_1},\ \vartheta_{\tilde{A}_1})$ and $\tilde{A}_2 = ([a_2, b_2, c_2, d_2];\ \mu_{\tilde{A}_2},\ \vartheta_{\tilde{A}_2})$ be two TrIFNs then the four basic fuzzy arithmetic operations based on *Min* -*Max* operators are summarized in **Table 1** (Wan, 2013). These operations do not detract the accumulating phenomenon of fuzziness, so Kumar and Yadav (2012) defined T_ω-norm and *Min* - *Max* operators based four fuzzy arithmetic operations for triangular

intuitionistic fuzzy number (TIFN). Herein, their four fuzzy arithmetic operations have been extended for TrIFNs and are provided in **Table 2**. Both of these types of fuzzy arithmetic operations do not integrate the membership and non-membership degrees of bottom incidents to evaluate the membership and non-membership degrees of top incident fuzzy failure possibility in the form of TrIFN because they rely on *Min-Max* operators. To address this limitation by utilizing the benefits of Algebraic *t*-norm and *t*-conorm, Liu et al. (2015) defined four fuzzy arithmetic operations for TrIFNs and are given in **Table 3**. The drawback in these fuzzy arithmetic operations is that they are unable to detract from the accumulating phenomenon of fuzziness.

Table 1. Four basic fuzzy arithmetic operations defined on two TrIFNs $\tilde{A}_1$ and $\tilde{A}_2$ using *Min -Max* operators (Wan, 2013).

Operation	**Fuzzy expression**
Addition	$\tilde{A}_1 \oplus^m \tilde{A}_2 = ([a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2]; \min\{\mu_{\tilde{A}_1}, \mu_{\tilde{A}_2}\}, \max\{\vartheta_{\tilde{A}_1}, \vartheta_{\tilde{A}_2}\})$
Multiplication	$\tilde{A}_1 \otimes^m \tilde{A}_2 = ([a_1 a_2, b_1 b_2, c_1 c_2, d_1 d_2]; \min\{\mu_{\tilde{A}_1}, \mu_{\tilde{A}_2}\}, \max\{\vartheta_{\tilde{A}_1}, \vartheta_{\tilde{A}_2}\})$
Subtraction	$\tilde{A}_1 \ominus^m \tilde{A}_2 = ([a_1 - d_2, b_1 - c_2, c_1 - b_2, d_1 - a_2]; \min\{\mu_{\tilde{A}_1}, \mu_{\tilde{A}_2}\}, \max\{\vartheta_{\tilde{A}_1}, \vartheta_{\tilde{A}_2}\})$
Compliment	$1 \ominus^m \tilde{A}_1 = ([1 - d_1, 1 - c_1, 1 - b_1, 1 - a_1]; \vartheta_{\tilde{A}_1}, \mu_{\tilde{A}_1})$

Table 2. Four basic fuzzy arithmetic operations defined on two TrIFNs $\tilde{A}_1$and $\tilde{A}_2$ using T_ω-norm and *Min-Max* operators (Kumar and Yadav, 2012).

Operation	**Fuzzy expression**
Addition	$\tilde{A}_1 \oplus^m_{T_\omega} \tilde{A}_2 = ([b_1 + b_2 - \max(b_1 - a_1, b_2 - a_2), b_1 + b_2, c_1 + c_2, c_1 + c_1 + \max(d_1 - c_1, d_2 - c_2)]; \min\{\mu_{\tilde{A}_1}, \mu_{\tilde{A}_2}\}, \max\{\vartheta_{\tilde{A}_1}, \vartheta_{\tilde{A}_2}\})$
Multiplication	$\tilde{A}_1 \otimes^m_{T_\omega} \tilde{A}_2 = ([b_1 b_2 - \max((b_1 - a_1)c_2, (b_2 - a_2)c_1), b_1 b_2, c_1 c_2, c_1 c_1 + \max((d_1 - c_1)c_2, (d_2 - c_2)c_1)]; \min\{\mu_{\tilde{A}_1}, \mu_{\tilde{A}_2}\}, \max\{\vartheta_{\tilde{A}_1}, \vartheta_{\tilde{A}_2}\})$
Subtraction	$\tilde{A}_1 \ominus^m_{T_\omega} \tilde{A}_2 = ([b_1 - c_2 - \max(b_1 - a_1, d_2 - c_2), b_1 - c_2, c_1 - b_2, c_1 - b_2 + \max(d_1 - c_1, b_2 - a_2)]; \min\{\mu_{\tilde{A}_1}, \mu_{\tilde{A}_2}\}, \max\{\vartheta_{\tilde{A}_1}, \vartheta_{\tilde{A}_2}\})$
Compliment	$\tilde{A}_1 \ominus^m_{T_\omega} \tilde{A}_2 = ([1 - d_1, 1 - c_1, 1 - b_1, 1 - a_1]; \vartheta_{\tilde{A}_1}, \mu_{\tilde{A}_1})$

Table 3. Four basic fuzzy arithmetic operations defined on two TrIFNs $\tilde{A}_1$ and $\tilde{A}_2$ using Algebraic *t*-norm and *t*-conorm (Liu et al., 2015).

Operation	**Fuzzy expression**
Addition	$\tilde{A}_1 \oplus^a \tilde{A}_2 = ([a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2]; \mu_{\tilde{A}_1} + \mu_{\tilde{A}_2} - \mu_{\tilde{A}_1}\mu_{\tilde{A}_2}, \vartheta_{\tilde{A}_1}\vartheta_{\tilde{A}_2})$
Multiplication	$\tilde{A}_1 \otimes^a \tilde{A}_2 = ([a_1 a_2, b_1 b_2, c_1 c_2, d_1 d_2]; \mu_{\tilde{A}_1}\mu_{\tilde{A}_2}, \vartheta_{\tilde{A}_1} + \vartheta_{\tilde{A}_2} - \vartheta_{\tilde{A}_1}\vartheta_{\tilde{A}_2})$
Subtraction	$\tilde{A}_1 \ominus^a \tilde{A}_2 = ([a_1 - d_2, b_1 - c_2, c_1 - b_2, d_1 - a_2]; \mu_{\tilde{A}_1}\vartheta_{\tilde{A}_2}, \vartheta_{\tilde{A}_1} + \mu_{\tilde{A}_2} - \vartheta_{\tilde{A}_1}\mu_{\tilde{A}_2})$
Compliment	$1 \ominus^a \tilde{A}_1 = ([1 - d_1, 1 - c_1, 1 - b_1, 1 - a_1]; \vartheta_{\tilde{A}_1}, \mu_{\tilde{A}_1})$

2.5 Novel Fuzzy Arithmetic Operations Defined on TrIFNs

To detract the accumulating phenomenon of fuzziness using T_ω-norm and integrating the membership and non-membership degrees of all the bottom incidents in evaluating the membership and non-membership degrees of top incident's fuzzy failure possibility by utilizing the benefits of Algebraic *t*-norm and Algebraic *t*-conorm, this section introduces four novel fuzzy arithmetic operations for two TrIFNs $\tilde{A} = ([a_1, b_1, c_1, d_1];\ \mu_{\tilde{A}_1}, \vartheta_{\tilde{A}_1})$ and $\tilde{A}_2 = ([a_2, b_2, c_2, d_2];\ \mu_{\tilde{A}_2}, \vartheta_{\tilde{A}_2})$ which are provided in **Table 4**.

Table 4. Four basic fuzzy arithmetic operations defined on two TrIFNs $\tilde{A}_1$ and $\tilde{A}_2$ using T_ω-norm and algebraic *t*-norm and *t*-conorm.

Operation	Fuzzy expression
Addition	$\tilde{A}_1 \oplus^{a}_{T_\omega} \tilde{A}_2 = ([b_1 + b_2 - \max(b_1 - a_1, b_2 - a_2), b_1 + b_2, c_1 + c_2, c_1 + c_1 + \max(d_1 - c_1, d_2 - c_2)]; \mu_{\tilde{A}_1} + \mu_{\tilde{A}_2} - \mu_{\tilde{A}_1}\mu_{\tilde{A}_2}, \vartheta_{\tilde{A}_1}\vartheta_{\tilde{A}_2})$
Multiplication	$\tilde{A}_1 \otimes^{a}_{T_\omega} \tilde{A}_2 = ([b_1 b_2 - \max((b_1 - a_1)c_2, (b_2 - a_2)c_1), b_1 b_2, c_1 c_2, c_1 c_1 + \max((d_1 - c_1)c_2, (d_2 - c_2)c_1)]; \mu_{\tilde{A}_1}\mu_{\tilde{A}_2}, \vartheta_{\tilde{A}_1} + \vartheta_{\tilde{A}_2} - \vartheta_{\tilde{A}_1}\vartheta_{\tilde{A}_2})$
Subtraction	$\tilde{A}_1 \ominus^{a}_{T_\omega} \tilde{A}_2 = ([b_1 - c_2 - \max(b_1 - a_1, d_2 - c_2), b_1 - c_2, c_1 - b_2, c_1 - b_2 + \max(d_1 - c_1, b_2 - a_2)]; \mu_{\tilde{A}_1}\vartheta_{\tilde{A}_2}, \vartheta_{\tilde{A}_1} + \mu_{\tilde{A}_2} - \vartheta_{\tilde{A}_1}\mu_{\tilde{A}_2})$
Compliment	$\tilde{A}_1 \ominus^{a}_{T_\omega} \tilde{A}_2 = ([1 - d_1, 1 - c_1, 1 - b_1, 1 - a_1]; \vartheta_{\tilde{A}_1}, \mu_{\tilde{A}_1})$

2.6 Hamming Distance

The Hamming distance $d_h(\tilde{A}_1\tilde{A}_2)$ between two TrIFNs $\tilde{A} = ([a_1, b_1, c_1, d_1]; \mu_{\tilde{A}_1}, \vartheta_{\tilde{A}_1})$ and $\tilde{A}_2 = ([a_2, b_2, c_2, d_2]; \mu_{\tilde{A}_2}, \vartheta_{\tilde{A}_2})$ is defined as follows (Wan, 2013):

$$d_h(\tilde{A}_1\tilde{A}_2) = \frac{1}{4}(|a_1 - a_2| + |b_1 - b_2| + |c_1 - c_2| + |d_1 - d_2|) + \max\{|\mu_{\tilde{A}_1} - \mu_{\tilde{A}_2}|, |\vartheta_{\tilde{A}_1}\vartheta_{\tilde{A}_2}|\}.$$

3. Proposed Intuitionistic FFTA Method

The proposed intuitionistic FFTA is shown through a flowchart in **Figure 2** and the steps are explained as follows:

Step 1. *Development of the fault-tree diagram:*
Based on the aggregated information and experts' advice, the fault-tree diagram is developed using logical OR/AND gates to denote series/parallel incidents, say $n$in numbers and denoted by P_i, $i = 1,2,.,n$, as per the interaction among them. The whole process of incidents can be trace-out by moving from top incident to bottom incidents.

Step 2. *Collection of possible bottom incidents' failure data:*
The failure data for all the possible bottom incident's P_i are collected from various sources and then integrated with experts. Based on the expert's opinion, failure possibility data, denoted by q_i, $i = 1,2,.,n$ for bottom incidents, is quantified to address the issue of uncertainty and now represented by TrIFNs $\tilde{q}_i$, $i = 1,2,.,n$.

Step 3. *Evaluation of top incident fuzzy failure possibility:*
In this step, first the expression for top incident fuzzy failure possibility ($\tilde{q}_T$) in terms of bottom incidents ($\tilde{q}_i$) is obtained with the help of fault-tree, minimal cut-sets and the expressions provided in the **Table 5** for logical gates OR/AND (Row 5). Let $\tilde{q}_i = ([a_{q_i}, b_{q_i}, c_{q_i}, d_{q_i}]; \mu_{\tilde{q}_i}, \vartheta_{\tilde{q}_i})$ be the fuzzy failure possibility of i^{th} bottom incident represented by the TrIFN. Let $\tilde{q}_T = ([a_{q_T}, b_{q_T}, c_{q_T}, d_{q_T}]; \mu_{\tilde{q}_T}, \vartheta_{\tilde{q}_T})$ be the top incident fuzzy failure possibility which is the result of n bottom incidents connected in OR/AND configuration and their fuzzy failure possibilities are represented by $\tilde{q}_i$, $i = 1,2,..,n$, then $\tilde{q}_T$ can be expressed by the functional Equation (7).

$$\tilde{q}_T = q_T(\tilde{q}_1, \tilde{q}_2, \ldots, \tilde{q}_i, \ldots \tilde{q}_n) \equiv ([a_{q_T}, b_{q_T}, c_{q_T}, d_{q_T}]; \mu_{\tilde{q}_T}, \vartheta_{\tilde{q}_T}) \quad (7)$$

Now, to computed the top incident fuzzy failure possibility (q_T), four novel fuzzy arithmetic operations as given in **Table 4** are applied.

Step 4. *Evaluation of top incident fuzzy reliability ($\tilde{R}_T$):*

Top incident fuzzy reliability $\tilde{R}_T$ is computed using the following Equation (8).

$$\tilde{R}_T = \tilde{1} \ominus_{T_\omega}^{a} \tilde{q}_T \tag{8}$$

Step 5. *Rank all the critical bottom incidents:*
Recompute the top incident fuzzy failure possibility as done in Step-3 after eliminating i^{th} bottom incident by considering its fuzzy failure possibility as $\tilde{q}_T = \tilde{0}$ = ([0,0,0,0]; 0,1). The recomputed value of the top incident fuzzy failure possibility is denoted by q_{T_i} and the associated functional equation is given as followings (Equation (9)).

$$\tilde{q}_T = q_T(\tilde{q}_1, \tilde{q}_2, \ldots, \tilde{0}, \ldots \tilde{q}_n) \equiv ([a_{q_T}, b_{q_T}, c_{q_T}, d_{q_T}]; \mu_{\widetilde{q_T}}, \vartheta_{\widetilde{q_T}}) \tag{9}$$

Now, compute the Hamming distance $d_h(\tilde{q}_T, \tilde{q}_{T_i})$ between q_T and q_{T_i} using Equation (10).

$$d_h(\tilde{q}_T, \tilde{q}_{T_i}) = \frac{1}{4}\left(\left|a_{q_T} - a_{q_{T_i}}\right| + \left|b_{q_T} - b_{q_{T_i}}\right| + \left|c_q - c_{q_{T_i}}\right| + \left|d_{q_T} - d_{q_{T_i}}\right|\right) + \max\left\{\left|\mu_{\tilde{q}_T} - \mu_{\tilde{q}_{T_i}}\right|, \left|\vartheta_{\tilde{q}_T} \vartheta_{\tilde{q}_{T_i}}\right|\right\} \tag{10}$$

Here, $d_h(\tilde{q}_T, \tilde{q}_{T_i})$ provides the influence on top incident fuzzy failure possibility after the elimination of i^{th} bottom incident. If $d_h(\tilde{q}_T, \tilde{q}_{T_i}) \geq d_h(\tilde{q}_T, \tilde{q}_{T_j})$, then the elimination of i^{th} bottom incident is more effective than the elimination of j^{th} bottom incident. Now, calculate $d_h(\tilde{q}_T, \tilde{q}_{T_i})$ for all the bottom incidents by taking $i = 1,2,..,n$ and then rank all the critical bottom incidents by arranging the values of $d_h(\tilde{q}_T, \tilde{q}_{T_i})$ in decreasing manner.

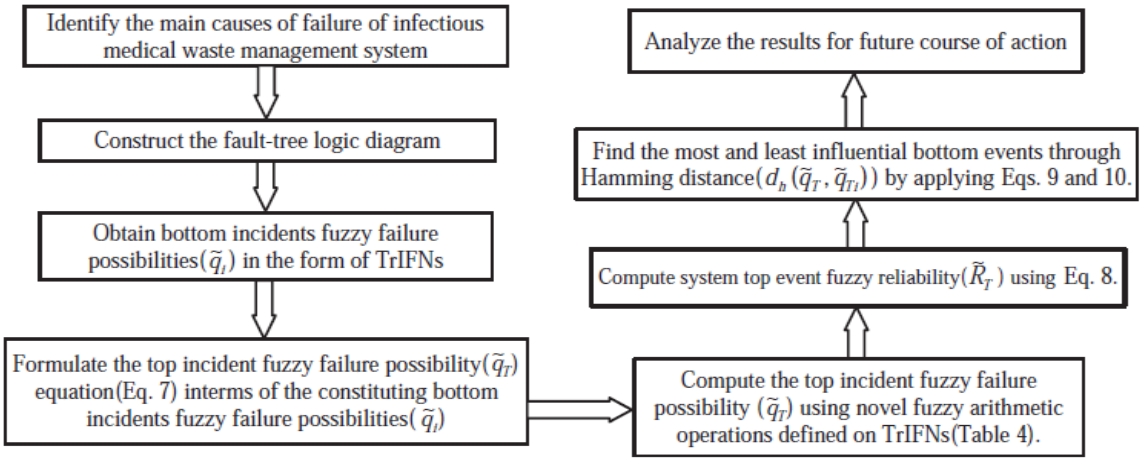

Figure 2. Flowchart of the proposed intuitionistic FFTA method.

Step 6. *Analysis of results and extraction of suggestions:*
Based on the sequence of bottom incidents as per the values of $d_h(\tilde{q}_T, \tilde{q}_{T_i})$ in decreasing order, the most and least influential bottom incidents can be found out. The result can be integrated with experts and then some influential suggestions can be extracted for future course of action.

4. Illustrative Applications

This section illustrates the proposed intuitionistic FFTA by analyzing the infectious medical waste management system of the Clinical Centre of Serbia taken from Mokajic-Nikolic et al. (2016) under

uncertainly. The computed results will also be compared with results obtained from Mokajic-Nikolic et al. (2016) traditional FTA method and three other FFTA methods including Kumar and Yadav (2012), Liu et al. (2015), and Miao and Wang (2009). The functional equations for logical gates (OR/AND) with n bottom incidents used in these methods are given in **Table 5**, where q_i and $\widetilde{q_i}$ are representing the crisp and fuzzy failure possibility of i^{th} bottom incident respectively. The proposed method is explained in detail hereafter.

Table 5. The functional equations for logic gates used in traditional FTA and intuitionistic FFTA methods.

Row No.	Fault tree method	Gate	Mathematical equations	Data type(q_i)	Arithmetic operations
1.	Mokajic-Nikolic et al. (2016)	OR AND	$P_{OR} = 1 - [(1-q_1) \times (1-q_1) \times \ldots (1-q_n)$ $P_{AND} = q_1 \times q_2 \times \ldots \times q_n$	Crisp	Ordinary arithmetic operations
2.	Miao and Wang (2009)	OR AND	$P_{OR} =$ $1 \ominus^m [(1 \ominus^m \widetilde{q_1}) \otimes^m \ominus^m \widetilde{q_2}) \otimes^m \ldots \otimes^m (1 \ominus^m \widetilde{q_1})]$ $\widetilde{P_{AND}} = \widetilde{q_1} \otimes^m \widetilde{q_2} \otimes^m \ldots \otimes^m \widetilde{q_n}$	TrIFN numbers (in present study)	*Min –Max* operators fuzzy based arithmetic operations (**Table 1**)
3.	Kumar and Yadav (2012)	OR AND	$P_{OR} =$ $1 \ominus_{T_\omega}^m [(1 \ominus_{T_\omega}^m \widetilde{q_1}) \otimes^m \ominus_{T_\omega}^m \widetilde{q_2}) \otimes^m \ldots \otimes^m (1 \ominus_{T_\omega}^m \widetilde{q_n})]$ $\widetilde{P_{AND}} = \widetilde{q_1} \otimes_{T_\omega}^m \widetilde{q_2} \otimes_{T_\omega}^m \ldots \otimes_{T_\omega}^m \widetilde{q_n}$	TrIFN numbers (in present study)	T_ω norm and *Min –Max* operators based fuzzy arithmetic operations (**Table 2**)
4.	Liu et al. (2015)	OR AND	$P_{OR} = 1 \ominus^a [(1 \ominus^a \widetilde{q_1}) \otimes^a \ominus^a \widetilde{q_2}) \otimes^a \ldots \otimes^a (1 \ominus^a \widetilde{q_1})\ ]$ $\widetilde{P_{AND}} = \widetilde{q_1} \otimes^a \widetilde{q_2} \otimes^a \ldots \otimes^a \widetilde{q_n}$	TrIFN numbers	Algebraic *t*-norm and *t*-conorm based fuzzy arithmetic operations (**Table 3**)
5.	Proposed FFTA method	OR AND	$P_{OR} =$ $1 \ominus_{T_\omega}^a [(1 \ominus_{T_\omega}^a \widetilde{q_1}) \otimes^a \ominus_{T_\omega}^a \widetilde{q_2}) \otimes^a \ldots \otimes^a (1 \ominus_{T_\omega}^a \widetilde{q_n})\ ]$ $\widetilde{P_{AND}} = \widetilde{q_1} \otimes_{T_\omega}^a \widetilde{q_2} \otimes_{T_\omega}^a \ldots \otimes_{T_\omega}^a \widetilde{q_n}$	TrIFN numbers	T_ω and algebraic *t*-norm and *t*-conorm based fuzzy arithmetic operations (**Table 4**)

Table 6. Basic incidents' crisp and fuzzy failure possibility values in the failure of infectious medical waste management system (Mokajic-Nikolic et al., 2016).

Bottom incident	Cause description	Failure possibility q_i	Crisp value of q_i	TrIFN value of $q_i$denoted by $\widetilde{q_i} = ([a_i, b_i, c_i, d_i]; \mu_i, \vartheta_i)$
*P*1	Patient infected	q_1	0.0100	([0.0080,0.0090,0.0110,0.0120]; 0.60, 0.30)
*P*2	Inadequate education	q_2	0.0690	([0.0552,0.0621,0.0759,0.0828]; 0.60, 0.30)
*P*3	Intentional failure to respect the procedures	q_3	0.0710	([0.0568,0.0639,0.0781,0.0852]; 0.60, 0.30)
*P*4	Inattention during work, fatigue	q_4	0.0399	([0.0319,0.0359,0.0439,0.0479]; 0.60, 0.30)
*P*5	Injury at work	q_5	0.0180	([0.0144,0.0162,0.0198,0.0216]; 0.60, 0.30)
*P*6	Not using the protective equipment	q_6	0.0700	([0.0560,0.0630,0.0770,0.0840]; 0.60, 0.30)
*P*7	Inadequate packaging (waste containers)	q_7	0.0501	([0.0401,0.0451,0.0551,0.0601]; 0.60, 0.30)
*P*8	Inadequate transport conditions	q_8	0.0499	([0.0399,0.0449,0.0549,0.0599]; 0.60, 0.30)
*P*9	Spilling or leaking of the waste from container	q_9	0.0500	([0.0400,0.0450,0.0550,0.0600]; 0.60, 0.30)
*P*10	Contact with infectious waste	q_{10}	0.0599	([0.0479,0.0539,0.0659,0.0719]; 0.60, 0.30)
*P*11	Inadequate packing and handling the waste	q_{11}	0.0610	([0.0488,0.0549,0.0671,0.0732]; 0.60, 0.30)

4.1 Fault Tree Development and Top Incident Failure Possibility Equation (Mokajic-Nikolic et al., 2016)

To apply the proposed intuitionistic FFTA method, a problem of infectious medical waste management system has been selected for discussion. The problem is taken from Mokajic-Nikolic et al. (2016) in which they studied the failure of an infectious medical waste management system in Clinical Centre of Serbia. They classified the entire infectious medical waste management process into four sub-processes such as diagnostic, treatment, transport (internal and external) and waste treatment. These sub-processes were further decomposed into undesired incidents and reach to the bottom incidents by following top to

bottom approach. The fault tree diagram of the infectious medical waste management system is shown in **Figure 3** (Mokajic-Nikolic et al., 2016). The complete details of the fault tree and its bottom incidents can be found in Mokajic-Nikolic et al. (2016) work. However, the necessary details of top and all the intermediate incidents are provided in **Figure 3** while the cause description of bottom incidents is given in **Table 6**. The nine minimal-cut sets are obtained with the help of fault tree which are as follows: {P1, P2, P5}, {P1, P3, P5}, {P1, P5, P4}, {P2, P5}, {P6, P5}, {P7, P5}, {P8, P5}, {P6, P9, P10} and {P11, P6}. To formulate an equivalent mathematical equation of the fault tree, the symbols ∩ and ∪ are used to connect the incidents in "AND" (parallel) and "OR" (series) configurations respectively. The equivalent mathematical equation of the fault tree diagram shown in **Figure 3** is as follows:

$$T = (P1 \cap P2 \cap P5) \cup (P1 \cap P3 \cap P5) \cup (P1 \cap P5 \cap P4) \cup (P2 \cap P5) \cup (P6 \cap P5) \cup (P7 \cap P5) \cup (P8 \cap P5) \cup (P6 \cap PP10) \cup (P11 \cap P6) \quad (11)$$

Let $q_i$be the failure possibility of the i^{th} bottom incident P_i. Using **Table 5** (first row) and Equation (11), the mathematical equation of the top incident \ Infection spreading caused by malfunctioning of the infectious medical waste management" failure possibility (q_T) can be written as follows:

$$q_T = 1 - [(1 - q_1q_2q_5)(1 - q_1q_3q_5)(1 - q_1q_5q_4)(1 - q_2q_5)(1 - q_6q_5)(1 - q_7q_5)(1 - q_8q_5)\ (1 - q_6q_9q_{10})(1 - q_{11}q_6) \quad (12)$$

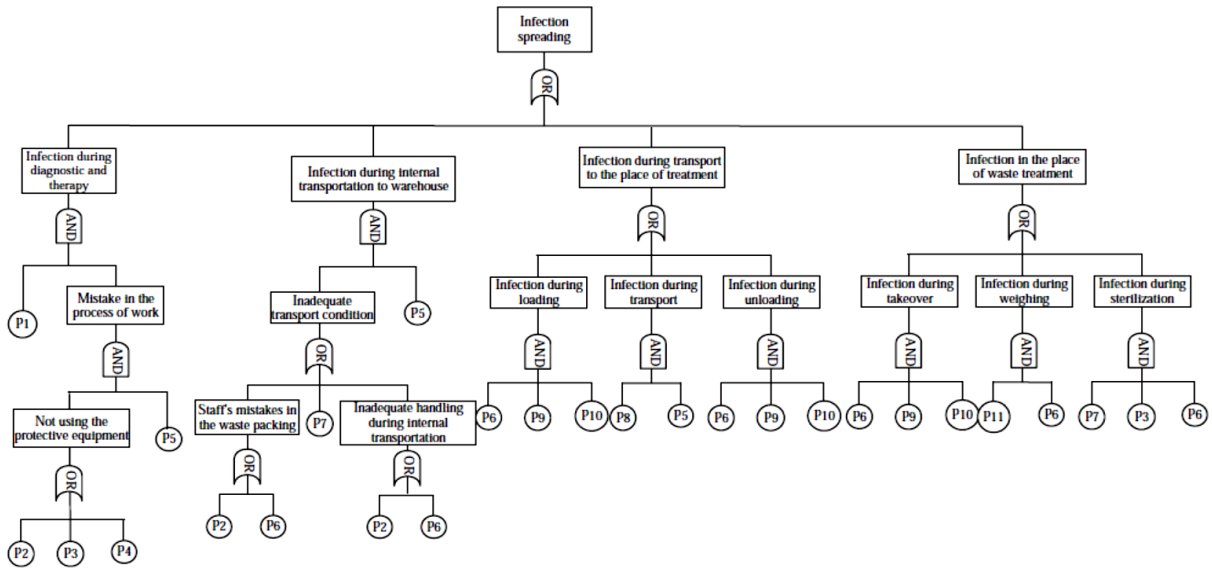

Figure 3. Fault tree for infection spreading (Mokajic-Nikolic et al., 2016).

4.2 Data Extraction and its Fuzzification

The failure possibility value (q_i) of each bottom incident in crisp form is taken from Mokajic-Nikolic et al. (2016) and listed in **Table 6** (Column-4). Extracted data may have uncertainty due to diverse practical and financial reasons, so before initiating FTA, uncertainty present in data should be quantified carefully. Since, data is related to medical waste, so its data uncertainty can be quantified using intuitionistic fuzzy sets (De et al., 2001). Specifically, in the present study, TrIFN has been used for fuzzification of extracted

uncertain data. To select a suitable shape of TrIFN to fuzzily a bottom incident failure possibility, opinions from different experts having enough experience with the medical waste treatment process have been considered. The suggested fuzzified data ($\widetilde{q_i}$) for all the bottom incidents in the form of TrIFN are provided in **Table 6** (Column-5).

4.3 Results and Discussion

The proposed intuitionistic FFTA method has been applied to analyze the failure in infectious medical waste management system along with Mokajic-Nikolic et al. (2016) traditional FTA method and three others intuitionistic FFTA methods such as Kumar and Yadav (2012), Liu et al. (2015), and Miao and Wang (2009). Computed results are compared and plotted graphically. The detailed computation is given hereafter.

4.3.1 Traditional FTA Method (Mokajic-Nikolic et al., 2016)

Mokajic-Nikolic et al. (2016) applied traditional FTA method in which fault tree, crisp data without quantifying uncertainty and probability theory are used to estimate top incident failure probability. Now by Mokajic-Nikolic et al. (2016) approach, top incident Infection spreading caused by malfunctioning of the infectious medical waste management" failure probability can be computed using Equation (12), ordinary arithmetic operations and data as provided in **Table 6** (Column 4). The top incident failure probability is computed as follows:

$q_T = 1 - [(1 - q_1q_2q_5)(1 - q_1q_3q_5)(1 - q_1q_5q_4)(1 - q_2q_5) \ldots (1 - q_6q_5)(1 - q_7q_5)(1 - q_8q_5)(1 - q_6q_9q_{10})(1 - q_{11}q_6)$

= 1 – [(1 – (0.01) (0.069) (0.018)) × (1 – (0.01) (0.071) (0.018)) × (1 – (0.01) (0.018) (0.0399))×(1 – (0.069) (0.018)) ×(1 – (0.018) (0.07)) × (1 – (0.0501) (0.018)) × (1 – (0.0499) (0.018)) × (1 – (0.07) (0.05) (0.0599)) × (1 – (0.061) (0.07))] = 0.008787 (13)

The failure possibility of top incident Infection spreading caused by malfunctioning of the "infectious medical waste management" is approximately 0.008787 (Mokajic-Nikolic et al., 2016). Also, the reliability of "Infection is not spreading caused by malfunctioning of the infectious medical waste management" is 0.991213.

4.3.2 Intuitionistic FFTA Method (Miao and Wang, 2009)

Miao and Wang (2009) in their intuitionistic FFTA method used fault tree, TIFN to quantify data uncertainty and *Min -Max* operator's-based arithmetic operations defined for TIFN to evaluate fuzzy failure possibility of a computer security system. Wan (2013) and later on Wan and Dong (2015) extended these operations for TrIFN and applied to analyze multi-criterion decision making problems. The present study uses *Min - Max* operator's based fuzzy arithmetic operations defined on TrIFN and given in **Table 1** (Wan, 2013; Wan and Dong, 2015). Now using failure possibility Equation (11), mathematical expressions as given in **Table 5** (second row), fuzzy arithmetic operations given in **Table 1** and fuzzified failure possibility data given in **Table 6** (Column 5), computations have been done which are as follows:

$\widetilde{q_T} = \tilde{1} \ominus^m [(\tilde{1} \ominus^m (\widetilde{q_1} \otimes^m \widetilde{q_2} \otimes^m \widetilde{q_5})) \otimes^m (\tilde{1} \ominus^m (\widetilde{q_1} \otimes^m \widetilde{q_3} \otimes^m \widetilde{q_5})) \otimes^m \ldots$

$(\tilde{1} \ominus^m (\widetilde{q_1} \otimes^m \widetilde{q_5} \otimes^m \widetilde{q_4})) \otimes^m (\tilde{1} \ominus^m (\widetilde{q_2} \otimes^m \widetilde{q_5}))(\tilde{1} \ominus^m (\widetilde{q_6} \otimes^m \widetilde{q_5})) \otimes^m \ldots$

$(\tilde{1} \ominus^m (\widetilde{q_7} \otimes^m \widetilde{q_5})) \otimes^m (\tilde{1} \ominus^m (\widetilde{q_8} \otimes^m \widetilde{q_5})) \otimes^m \ldots$

$(\tilde{1} \ominus^m (\widetilde{q_6} \otimes^m \widetilde{q_9} \otimes^m \widetilde{q_{10}})) \otimes^m (\tilde{1} \ominus^m (\widetilde{q_{11}} \otimes^m \widetilde{q_6}))]$

= ([0.005522, 0.007079, 0.010677, 0.012751], 0.600000, 0.300000) (14)

The fuzzy failure possibility value of top incident "Infection spreading caused by malfunctioning of the infectious medical waste management" is evaluated as ([0.005552,0.007079, 0.010677, 0.012751];0.60, 0.30) while the fuzzy reliability of "Infection is not spreading caused by malfunctioning of the infectious medical waste management" is computed as ([0.987249, 0.989323, 0.992921, 0.994448]; 0.30, 0.60).

4.3.3 Intuitionistic FFTA Method (Kumar and Yadav, 2012)

Kumar and Yadav (2012) in their intuitionistic FFTA method used TIFN to quantify uncertainty while T_ω-norm and *Min-Max* operators based fuzzy arithmetic operations defined on TIFNs have been implemented to evaluate top incident fuzzy failure possibility. In the present study, their approach has been extended to TrIFNs. To implement the extended version of Kumar and Yadav (2012) intuitionistic FFTA method for TrIFNs, present study uses Equation (11), fuzzified mathematical expressions as provided in **Table 5** (third row), fuzzy arithmetic operations given in **Table 2** and fuzzified data as listed in **Table 6** (Column 5), computations have been done which are as follows.

$\widetilde{q_T} = \tilde{1} \ominus^m_{T_\omega} [(\tilde{1} \ominus^m_{T_\omega} (\widetilde{q_1} \otimes^m_{T_\omega} \widetilde{q_2} \otimes^m_{T_\omega} \widetilde{q_5})) \otimes^m_{T_\omega} (\tilde{1} \ominus^m_{T_\omega} (\widetilde{q_1} \otimes^m_{T_\omega} \widetilde{q_3} \otimes^m_{T_\omega} \widetilde{q_5})) \otimes^m_{T_\omega} \ldots$

$(\tilde{1} \ominus^m_{T_\omega} (\widetilde{q_1} \otimes^m_{T_\omega} \widetilde{q_5} \otimes^m_{T_\omega} \widetilde{q_4})) \otimes^m_{T_\omega} (\tilde{1} \ominus^m_{T_\omega} (\widetilde{q_2} \otimes^m_{T_\omega} \widetilde{q_5})) (\tilde{1} \ominus^m_{T_\omega} (\widetilde{q_6} \otimes^m_{T_\omega} \widetilde{q_5})) \otimes^m_{T_\omega} \ldots$

$(\tilde{1} \ominus^m_{T_\omega} (\widetilde{q_7} \otimes^m_{T_\omega} \widetilde{q_5})) \otimes^m_{T_\omega} (\tilde{1} \ominus^m_{T_\omega} (\widetilde{q_8} \otimes^m_{T_\omega} \widetilde{q_5})) \otimes^m_{T_\omega} \ldots$

$(\tilde{1} \ominus^m_{T_\omega} (\widetilde{q_6} \otimes^m_{T_\omega} \widetilde{q_9} \otimes^m_{T_\omega} \widetilde{q_{10}})) \otimes^m_{T_\omega} (\tilde{1} \ominus^m_{T_\omega} (\widetilde{q_{11}} \otimes^m_{T_\omega} \widetilde{q_6}))]$

$=([0.006610, 0.007079, 0.010677, 0.011146], 0.600000, 0.300000)$ (15)

The fuzzy failure possibility value of top incident "Infection spreading caused by malfunctioning of the infectious medical waste management" is ([0.005552, 0.007079, 0.010677, 0.012751]; 0.384914, 0.248079), while the fuzzy reliability of "Infection is not spreading caused by malfunctioning of the infectious medical waste management" is ([0.988854, 0.989323, 0.992921, 0.993390]; 0.30, 0.60).

4.3.4 Intuitionistic FFTA Method (Liu et al., 2015)

Liu et al. (2015) in their intuitionistic FFTA method used Algebraic *t*-norm and *t*-conorm coupled arithmetic operations defined on TrIFNs as given in **Table 3** for analyzing high-speed railway accidents. To apply Liu et al. (2015) intuitionistic FFTA method, failure possibility Equation (11), expressions provided in **Table 5** (fourth row), arithmetic operations mentioned in **Table 3** and fuzzified data in the form of TrIFN given in **Table 6** (Column 5) are used. The computation process is as follows:

$\widetilde{q_T} = \tilde{1} \ominus^a [(\tilde{1} \ominus^a (\widetilde{q_1} \otimes^a \widetilde{q_2} \otimes^a \widetilde{q_5})) \otimes^a (\tilde{1} \ominus^a (\widetilde{q_1} \otimes^a \widetilde{q_3} \otimes^a \widetilde{q_5})) \otimes^a \ldots$

$(\tilde{1} \ominus^a (\widetilde{q_1} \otimes^a \widetilde{q_5} \otimes^a \widetilde{q_4})) \otimes^a (\tilde{1} \ominus^a (\widetilde{q_2} \otimes^a \widetilde{q_5})) (\tilde{1} \ominus^a (\widetilde{q_6} \otimes^a \widetilde{q_5})) \otimes^a \ldots$

$(\tilde{1} \ominus^a (\widetilde{q_7} \otimes^a \widetilde{q_5})) \otimes^a (\tilde{1} \ominus^a (\widetilde{q_8} \otimes^a \widetilde{q_5})) \otimes^a \ldots$

$(\tilde{1} \ominus^a (\widetilde{q_6} \otimes^a \widetilde{q_9} \otimes^a \widetilde{q_{10}})) \otimes^a (\tilde{1} \ominus^a (\widetilde{q_{11}} \otimes^a \widetilde{q_6}))]$

$= ([0.005522, 0.007079, 0.010677, 0.012751], 0.384914, 0.248079)$ (16)

The fuzzy failure possibility value of top incident "Infection spreading caused by malfunctioning of the infectious medical waste management" is ([0.005552, 0.007079, 0.010677, 0.012751]; 0.384914, 0.248079), while the fuzzy reliability of "Infection is not spreading caused by malfunctioning of the infectious medical waste management" is ([0:987249; 0:989323; 0:992921; 0:994448]; 0:248079; 0:384914).

4.3.5 Proposed Intuitionistic FFTA Method

The proposed intuitionistic FFTA method, as discussed in Section 3, used T_ω-norm for detracting the accumulating phenomenon of fuzziness, and Algebraic *t*-norm and *t*-conorm for evaluating the values of membership and non-membership degrees of top incident fuzzy failure possibility in the form of TrIFN. To apply the proposed intuitionistic FFTA method, failure possibility Equation (11), mathematical expressions provided in **Table 5** (fifth row), novel arithmetic operations listed in **Table 4** and TrIFN data given in **Table 6** (Column 5) are used. The computation process is as follows.

$\widetilde{q_T} = \tilde{1} \ominus^a_{T_\omega}$ $[(\tilde{1} \ominus^a_{T_\omega} (\widetilde{q_1} \otimes^a_{T_\omega} \widetilde{q_2} \otimes^a_{T_\omega} \widetilde{q_5})) \otimes^a_{T_\omega} (\tilde{1} \ominus^a_{T_\omega} (\widetilde{q_1} \otimes^a_{T_\omega} \widetilde{q_3} \otimes^a_{T_\omega} \widetilde{q_5})) \otimes^a_{T_\omega} \ldots$

$(\tilde{1} \ominus^a_{T_\omega} (\widetilde{q_1} \otimes^a_{T_\omega} \widetilde{q_5} \otimes^a_{T_\omega} \widetilde{q_4})) \otimes^a_{T_\omega} (\tilde{1} \ominus^a_{T_\omega} (\widetilde{q_2} \otimes^a_{T_\omega} \widetilde{q_5})) (\tilde{1} \ominus^a_{T_\omega} (\widetilde{q_6} \otimes^a_{T_\omega} \widetilde{q_5})) \otimes^a_{T_\omega} \ldots$

$(\tilde{1} \ominus^a_{T_\omega} (\widetilde{q_7} \otimes^a_{T_\omega} \widetilde{q_5})) \otimes^a_{T_\omega} (\tilde{1} \ominus^a_{T_\omega} (\widetilde{q_8} \otimes^a_{T_\omega} \widetilde{q_5})) \otimes^a_{T_\omega} \ldots$

$(\tilde{1} \ominus^a_{T_\omega} (\widetilde{q_6} \otimes^a_{T_\omega} \widetilde{q_9} \otimes^a_{T_\omega} \widetilde{q_{10}})) \otimes^a_{T_\omega} (\tilde{1} \ominus^a_{T_\omega} (\widetilde{q_{11}} \otimes^a_{T_\omega} \widetilde{q_6}))]$

= ([0.006610, 0.007079, 0.010677, 0.011146], 0.384914, 0.248079) (17)

The fuzzy failure possibility value of top incident "Infection spreading caused by malfunctioning of the infectious medical waste management" is ([0.006610, 0.007079, 0.010677, 0.011146], 0.384914, 0.248079), while the fuzzy reliability of "Infection is not spreading caused by malfunctioning of the infectious medical waste management" is ([0.988854, 0.989323, 0.992921, 0.993390], 0.248079, 0.384914).

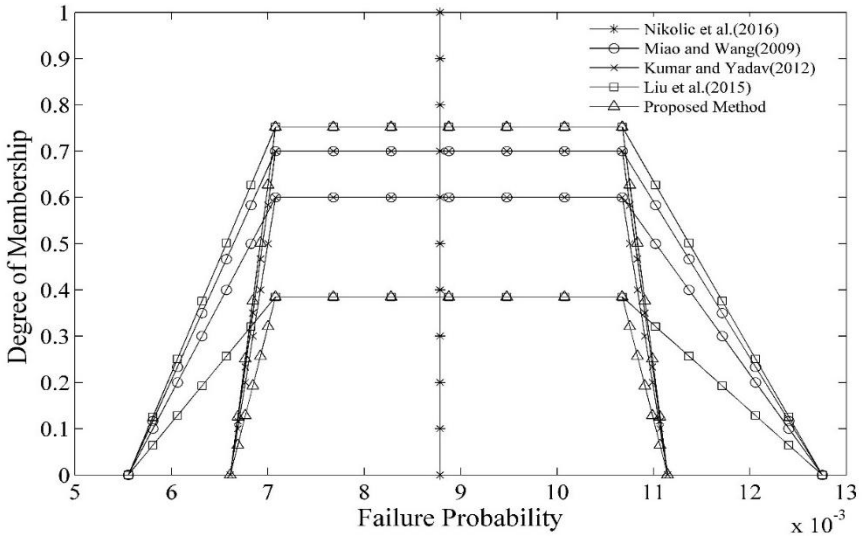

Figure 4. Fuzzy failure possibility of top incident "Infection spreading caused by malfunctioning of the infectious medical waste management".

The computed results are plotted in **Figure 4**. The figure clearly shows that the proposed intuitionistic FFTA method not only reduces the range of prediction of top incident fuzzy failure possibility at any cut level but also provides the optimized degrees of membership and non-membership of the top incident by involving each bottom incident membership and non-membership degrees. This is due to the use of T_ω-norm which detracts from the accumulating phenomenon of fuzziness, and the pair of Algebraic *t*-norm and *t*-conorm which provides the optimum values of membership and non-membership degrees of top incident failure possibility.

4.4 Ranking of Critical Incidents

To design an effective waste management system, identification of critical incidents will be very much useful. For this purpose, hamming distance-based ranking method has been developed in Step 5 of Section 3 (Wan, 2013). To apply this method, top incident fuzzy failure possibility is recomputed using above discussed proposed intuitionistic FFTA method by eliminating i bottom incident with $\tilde{q}_i = \tilde{0} = ([0,0,0,0]; 0,1), \forall i = 1,2, \dots 11$ however the values of fuzzy failure possibilities for rest of the incidents are same as listed in **Table 6** (Column 5). The recomputed computed value of top incident fuzzy failure possibility is denoted by $\tilde{q}_{T_i}$. This process is repeated for each bottom incident i by recomputing the top incident fuzzy failure possibility value $\tilde{q}_{T_i}$ after taking $\tilde{q}_i = \tilde{0} = ([0,0,0,0]; 0,1), \forall i = 1,2, \dots 11$. Now, the Hamming distance $d_h(\tilde{q}_T, \tilde{q}_{T_i})$ for all the bottom incidents have been computed and results are tabulated in **Table 7**. Now, arrange the computed values of $d_h(\tilde{q}_T, \tilde{q}_{T_i})$ in decreasing order and then rank them accordingly. From **Table 7**, it is observed that the most critical bottom incidents are injury at work (i = 5), not using protective equipment (i = 6) and inadequate packing and handling the waste (i = 11). These findings resemble with the conclusions of Mokajic-Nikolic et al. (2016). Hence, the presented FFTA method, provides consistent results by exploring IFS, the T_ω and algebraic norms based operational rules, and Hamming distance based ranking method, and confirms that the objectives are completely achieved. Thus, based on these findings, the firms dealing with waste management can take appropriate decisions and precautionary measures to minimize the occurrence of undesired incidents with more confidence under uncertain environment by using suggested FFTA method.

Table 7. Ranking result obtained from the proposed method.

Eliminated incident (i)	$\tilde{q}_{T_i} = (\left[a_{q_{T_i}} b_{q_{T_i}} c_{q_{T_i}} d_{q_{T_i}}\right]; \mu_{\tilde{q}_{T_i}} \vartheta_{\tilde{q}_{T_i}})$	$d_h(\tilde{q}_T, \tilde{q}_{T_i})$	Rank
$P1$ (i=1)	([0.006587, 0.007056, 0.010634, 0.11103]; 0.402076, 0.266227)	0.018181	4
$P2$ (i=2)	([0.005609, 0.006078, 0.009163, 0.009633]; 0.394132, 0.257936)	0.011114	5
$P3$ (i=3)	([0.006601, 0.007070, 0.010660, 0.011129]; 0.389063, 0.252536)	0.004470	9
$P4$ (i=4)	([0.006605, 0.007074, 0.010667, 0.011137]; 0.399063, 0.252536)	0.004465	10
$P5$ (i=5)	([0.003140, 0.003610, 0.005445, 0.005915]; 0.414501, 0.386775)	0.143046	1
$P6$ (i=6)	([0.002346, 0.002483, 0.003722, 0.003858]; 0.402631, 0.268857)	0.026553	2
$P7$ (i=7)	([0.005890, 0.006359, 0.009590, 0.010060]; 0.388416, 0.251849)	0.004673	7
$P8$ (i=8)	([0.005893, 0.006362, 0.009594, 0.010064]; 0.388416, 0.251849)	0.004670	8
$P9$ (i=9)	([0.006460, 0.006930, 0.010399, 0.010868]; 0.391825, 0.257336)	0.009471	6
$P10$ (i=10)	([0.006460, 0.006930, 0.010399, 0.010868]; 0.391825, 0.257336)	0.009471	6
$P11$ (i=11)	([0.003511, 0.003649, 0.005522, 0.005661]; 0.393462, 0.243130)	0.012840	3

5. Conclusion

With an increasing population size, the quantity of medical waste is increasing day-by-day, which may be harmful or even dangerous for people as well as the environment if inadequately treated. So, as an objective, an effective medical waste management system is essentially required to control infection and protect the environment for a healthy civil society. The fundamental challenge in developing an effective medical waste management system is the scarcity of reliable data on accidents and failures throughout the infectious medical waste management process. In light of these drawbacks, the paper proposed a new intuitionistic FFTA method in which TrIFN is utilized to quantify data uncertainty while T_ω-norm, Algebraic t-norm, and t-conorm coupled arithmetic operations are applied to evaluate the fuzzy failure possibility of an infectious medical waste management system. The weakest t-norm (T_ω) detracts the accumulating circumstances of fuzziness, while Algebraic t-norm (TA) and t-conorm (SA) provide the optimum values of membership and non-membership degrees of top incident's failure possibility with the help of each bottom incident's membership and non-membership degrees. A Hamming distance-based ranking method has been developed and then applied to identify the critical incidents. The proposed

intuitionistic FFTA method has been executed to analyze the failure of an infectious medical waste management system under uncertainty. The effectiveness of the proposed intuitionistic FFTA method is discussed along with four existing fault tree methods. Results infer that injury at work, not using protective equipment, and inadequate packing and handling of waste are the most critical incidents in the entire medical waste management system. Based on these findings, some precautionary measures may be considered, which include: (i) running awareness, motivational, and training programmed for staff involved in medical waste management; (ii) monitoring and registering the occurrence of most critical incidents like injury at work, not using protective equipment, and inadequate packing and handling of the waste in a very detailed manner for any future course of action. The results and findings suggest that the proposed intuitionistic FFTA method is an effective method to analyze faults in any medical waste management system. The proposed intuitionistic FFTA method can also be applied to evaluate the fuzzy failure possibility of other healthcare and engineering systems. The main limitation of the study is that it uses IFS, Hamming distance and algebraic arithmetic operations. In future, some novel intuitionistic FFTA methods can be developed by resolving these limitations in which different types of IFS can be used to quantify uncertainty, Archimedean operation rules can be used to fuse the information, while more general distance function can be explored to rank the critical basic events.

Conflict of Interest
The authors have no conflict of interest.

AI Disclosure
The author(s) declare that no assistance is taken from generative AI to write this article.

Acknowledgments
The authors are thankful to the editor, associate editor, and anonymous referees for providing their valuable comments and suggestions to improve the quality of the paper.

References

Abdullah, L., Zulkifli, N., Liao, H., Herrera-Viedma, E., & Al-Barakati, A. (2019). An interval-valued intuitionistic fuzzy DEMATEL method combined with Choquet integral for sustainable solid waste management. *Engineering Applications of Artificial Intelligence, 82*, 207-215. https://doi.org/10.1016/j.engappai.2019.04.005.

Abecassis, Z.A., McElroy, L.M., Patel, R.M., Khorzad, R., Carrol, C., & Mehrotra, S. (2015). Applying fault tree analysis to the prevention of wrong-site surgery. *Journal of Surgical Research, 193*(1), 88-94. https://doi.org/10.1016/j.jss.2014.08.062.

Asif, M., Ishtiaq, U., & Argyros, I.K. (2025). Hamacher aggregation operators for Pythagorean fuzzy set and its application in multi-attribute decision-making problem. *Spectrum of Operational Research, 2*(1), 27-40. https://doi.org/10.31181/sor2120258.

Atanassov, K.T. (1986). Intuitionistic fuzzy sets. *Fuzzy Sets and Systems, 20*(1), 87-96. https://doi.org/10.1016/S0165-0114(86)80034-3.

Celik, S., Peker, I., Gok-Kisa, A.C., & Büyüközkan, G. (2023). Multi-criteria evaluation of medical waste management process under intuitionistic fuzzy environment: a case study on hospitals in Turkey. *Socio-Economic Planning Sciences, 86*, 101499. https://doi.org/10.1016/j.seps.2022.101499.

Chang, J.R., Chang, K.H., Liao, S.H., & Cheng, C.H. (2006). The reliability of general vague fault-tree analysis on weapon systems fault diagnosis. *Soft Computing, 10*, 531-542. https://doi.org/10.1007/s00500-005-0483-y.

De, S.K., Biswas, R., & Roy, A.R. (2001). An application of intuitionistic fuzzy sets in medical diagnosis. *Fuzzy Sets and Systems, 117*(2), 209-213. https://doi.org/10.1016/s0165-0114(98)00235-8.

Ebeling, C.E. (2001). *An introduction to reliability and maintainability engineering*. Tata McGraw-Hill Company Limited, New York. ISBN: 9780070421387. https://books.google.co.in/books?id=iFumyeVLIEAC.

Gao, F., Han, M, Wang, S., & Gao, J. (2024). A novel Fermata fuzzy BWM-VIKOR based multi-criteria decision-making approach for selecting health care waste treatment technology. *Engineering Applications of Artificial Intelligence, 127*(B), 107451. https://doi.org/10.1016/j.engappai.2023.107451.

Gazi, K.H., Raisa, N., Biswas, A., Azizzadeh, F., & Mondal, S.P. (2025). Finding most important criteria in women's empowerment for sports sector by pentagonal fuzzy DEMATEL methodology. *Spectrum of Decision Making and Applications, 2*(1), 28-52. https://doi.org/10.31181/sdmap21202510.

Hong, D.H., & Do, H.Y. (1997). Fuzzy system reliability analysis by the use of T_ω (the weakest t-norm) on fuzzy number arithmetic operations. *Fuzzy Sets and Systems, 90*(3), 307-316. https://doi.org/10.1016/s0165-0114(96)00125-x.

Hyman, W.A., & Johnson, E. (2008). Fault tree analysis of clinical alarms. *Journal of Clinical Engineering, 33*(2), 85-94. https://doi.org/10.1097/01.jce.0000305872.86942.66.

Jiang, W., Wei, B., Liu, X., & Zheng, H. (2018). Intuitionistic fuzzy power aggregation operator based on entropy and its application in decision making. *International Journal of Intelligent Systems, 33*(1), 49-67. https://doi.org/10.1002/int.21939.

Jiang, Y., Tang, Y., Wang, J., & Tang, S. (2009). Reasoning within intuitionistic fuzzy rough description logics. *Information Sciences, 179*(114), 2362-2378. https://doi.org/10.1016/j.ins.2009.03.001.

Klemes, J.J., Fan, Y.V., Tan, R.R., & Jiang, P. (2020). Minimizing the present and future plastic waste, energy and environmental footprints related to COVID-19. *Renewable and Sustainable Energy Reviews, 127*, 109883. https://doi.org/10.1016/j.rser.2020.109883.

Klir, G.J., & Yuan, B. (1996). *Fuzzy sets and fuzzy logic: theory and applications*. Prentice Hall, New Jersey.

Komal (2015). Fuzzy fault tree analysis for patient safety risk modeling in healthcare under uncertainty. *Applied Soft Computing, 37*(C), 942-951. https://doi.org/10.1016/j.asoc.2015.08.005.

Komal (2017). A novel FFTA for handwashing process to maintain hygiene with events following different membership function. *Arabian Journal of Science and Engineering, 42*(7), 3007-3019. https://doi.org/10.1007/s13369-017-2479-1.

Komal (2023). Archimedean *t*-norm and *t*-conorm based intuitionistic fuzzy WASPAS method to evaluate health-care waste disposal alternatives with unknown weight information. *Applied Soft Computing, 146*, 110751. https://doi.org/10.1016/j.asoc.2023.110751.

Krishankumar, R., Dhruva, S., Ravichandran, K.S., & Kar, S. (2024). Selection of a viable blockchain service provider for data management within the internet of medical things: an MCDM approach to Indian healthcare. *Information Sciences, 657*, 119890. https://doi.org/10.1016/j.ins.2023.119890.

Krishankumar, R., Mishra, A.R., Rani, P., Zavadskas, E.K., Ravichandran, K.S., & Kar, S. (2022). A new decision model with integrated approach for healthcare waste treatment technology selection with generalized ortho pair fuzzy information. *Information Sciences, 610*, 1010-1028. https://doi.org/10.1016/j.ins.2022.08.022.

Kumar, M. (2014). Applying weakest *t*-norm based approximate fuzzy arithmetic operations on different types of intuitionistic fuzzy numbers to evaluate reliability of PCBA fault. *Applied Soft Computing, 23*, 387-406. https://doi.org/10.1016/j.asoc.2014.06.036.

Kumar, M., & Yadav, S.P. (2012). The weakest *t*-norm based intuitionistic fuzzy fault-tree analysis to evaluate system reliability. *ISA Transactions, 51*(4), 531-538. https://doi.org/10.1016/j.isatra.2012.01.004.

Lin, K.P., Wen, W., Chou, C.C., Jen, C.H., & Hung, K.C. (2011). Applying fuzzy GERT with approximate fuzzy arithmetic based on the weakest *t*-norm operations to evaluate repairable reliability. *Applied Mathematical Modelling, 35*(11), 5314-5325. https://doi.org/10.1016/j.apm.2011.04.022.

Liu, H.C., Wu, J., & Li, P. (2013). Assessment of health-care waste disposal methods using a VIKOR-based fuzzy multi-criteria decision-making method. *Waste Management, 33*(12), 2744-2751. https://doi.org/10.1016/j.wasman.2013.08.006.

Liu, H.C., You, J.X., Lu, C., & Shan, M.M. (2014). Application of interval 2-tuple linguistic MULTIMOORA method for healthcare waste treatment technology evaluation and selection. *Waste Management, 34*(11), 2355-2364. https://doi.org/10.1016/j.wasman.2014.07.016.

Liu, P., Yang, L., Gao, Z., Li, S., & Gao, Y. (2015). Fault tree analysis combined with quantitative analysis for high-speed railway accidents. *Safety Science, 79*, 344-357. https://doi.org/10.1016/j.ssci.2015.06.017.

Liu, S., Zhang, J., Niu, B., Liu, L., & He, X. (2022). A novel hybrid multi-criteria group decision-making approach with intuitionistic fuzzy sets to design reverse supply chains for COVID-19 medical waste recycling channels. *Computers & Industrial Engineering, 169*, 108228. https://doi.org/10.1016/j.cie.2022.108228.

Mahmood, Y.A., Ahmadi, A., Verma, A.K., Srividya, A., & Kumar, U. (2013). Fuzzy fault tree analysis: a review of concept and application. *International Journal of System Assurance Engineering and Management, 4*(1), 19-32. https://doi.org/10.1007/s13198-013-0145-x.

Manupati, V.K., Ramkumar, M., Baba, V., & Agarwal, A. (2021). Selection of the best healthcare waste disposal techniques during and post COVID-19 pandemic era. *Journal of Cleaner Production, 281*, 125175. https://doi.org/10.1016/j.jclepro.2020.125175.

Miao, Z., & Wang, Z. (2009). Fault-tree analysis on computer security system using intuitionistic fuzzy sets. In *2009 4th International Conference on Computer Science & Education* (pp. 459-463). IEEE. Nanning, China. https://doi.org/10.1109/iccse.2009.5228390.

Mishra, A.R., Mardani, A., Rani, P., & Zavadskas, E.K. (2020). A novel EDAS approach on intuitionistic fuzzy set for assessment of health-care waste disposal technology using new parametric divergence measures. *Journal of Cleaner Production, 272*, 122807. https://doi.org/10.1016/j.jclepro.2020.122807.

Mokajic-Nikolic, D., Petrovic, N., Belic, A., Rokvic, M., Radakovic, J.A., & Tubic, V. (2016). The fault tree analysis of infectious medical waste management. *Journal of Cleaner Production, 113*, 365-373. https://doi.org/10.1016/j.jclepro.2015.11.022.

Moreira, A.M.M., & Gunther, W.M.R. (2013). Assessment of medical waste management at a primary health-care center in Sao Paulo, Brazil. *Waste Management, 33*(1), 162-167. https://doi.org/10.1016/j.wasman.2012.09.018.

Narayanamoorthy, S., Annapoorani, V., Kang, D., Baleanu, D., Jeon, J., Kureethara, J.V., & Ramya, L. (2020). A novel assessment of bio-medical waste disposal methods using integrating weighting approach and hesitant fuzzy MOOSRA. *Journal of Cleaner Production, 275*, 122587. https://doi.org/10.1016/j.jclepro.2020.122587.

Park, A., & Lee, S.J. (2009). Fault tree analysis on handwashing for hygiene management. *Food Control, 20*(3), 223-229. https://doi.org/10.1016/j.foodcont.2008.05.001.

Patel, A., Jana, S., & Mahanta, J. (2023). Intuitionistic fuzzy EM-SWARA-TOPSIS approach based on new distance measure to assess the medical waste treatment techniques. *Applied Soft Computing, 144*, 110521. https://doi.org/10.1016/j.asoc.2023.110521.

Raheja, D., & Escano, M.C. (2009). Reducing patient healthcare safety risks through fault tree analysis. *Journal of System Safety, 45*(5), 13-15.

Sandoval-Reyes, M., He, R., Semeion, R., & Ferrao, P. (2024). Mathematical optimization of waste management systems: methodological review and perspectives for application. *Waste Management, 174*, 630-645. https://doi.org/10.1016/j.wasman.2023.10.006.

Shu, M.H., Cheng, C.H., & Chang, J.R. (2006). Using intuitionistic fuzzy sets for fault-tree analysis on printed circuit board assembly. *Microelectronics Reliability, 46*(12), 2139-2148. https://doi.org/10.1016/j.microrel.2006.01.007.

Singh, N., Ogunseitan, O.A., & Tang, Y. (2022). Medical waste: current challenges and future opportunities for sustainable management. *Critical Reviews in Environmental Science and Technology, 52*(11), 2000-2022. https://doi.org/10.1080/10643389.2021.1885325.

Singh, N., Tang, Y., Zhang, Z., & Zheng, C. (2020). COVID-19 waste management: effective and successful measures in Wuhan, China. *Resources, Conservation & Recycling, 163*, 105071. https://doi.org/10.1016/j.resconrec.2020.105071.

Song, H., Zhang, H.Y., & Chan, C.W. (2009). Fuzzy fault tree analysis based on T-S model with application to INS/GPS navigation system. *Soft Computing, 13*, 31-40. https://doi.org/10.1007/s00500-008-0290-3.

Tanaka, H., Fan, L.T., Lai, F.S., & Toguchi, K. (1983). Fault-tree analysis by Fuzzy probability. *Transactions on Reliability, R-32*(5), 453-457. https://doi.org/10.1109/tr.1983.5221727.

Tushar, S.R., Alam, M.F.B., Mainul Bari, A.B.M., & Karmaker, C.L. (2023). Assessing the challenges to medical waste management during the COVID-19 pandemic: implications for the environmental sustainability in the emerging economies. *Socio-Economic Planning Sciences, 87*, 101513. https://doi.org/10.1016/j.seps.2023.101513.

Vlachos, I.K., & Sergiadis, G.D. (2007). Intuitionistic fuzzy information - applications to pattern recognition. *Pattern Recognition Letters, 28*(2), 197-206. https://doi.org/10.1016/j.patrec.2006.07.004.

Wan, S.P. (2013). Power average operators of trapezoidal intuitionistic fuzzy numbers and application to multi-attribute group decision making. *Applied Mathematical Modelling, 37*(6), 4112-4126. https://doi.org/10.1016/j.apm.2012.09.017.

Wan, S.P., & Dong, J.Y. (2015). Power geometric operators of trapezoidal intuitionistic fuzzy numbers and application to multi-attribute group decision making. *Applied Soft Computing, 29*, 153-168. https://doi.org/10.1016/j.asoc.2014.12.031.

Windfeld, E.S., & Brooks, M.S.L. (2015). Medical waste management - a review. *Journal of Environmental Management, 163*, 98-108. https://doi.org/10.1016/j.jenvman.2015.08.013.

Xia, M., Xu, Z., & Zhu, B. (2012). Some issues on intuitionistic fuzzy aggregation operators based on Archimedean t-conorm and *t*-norm. *Knowledge-Based Systems, 31*, 78-88. https://doi.org/10.1016/j.knosys.2012.02.004.

Xu, Z. (2007). Intuitionistic fuzzy aggregation operators. *IEEE Transactions on Fuzzy Systems, 15*(6), 1179-1187. https://doi.org/10.1109/tfuzz.2006.890678.

Yager, R.R., & Abbasov, A.M. (2013). Pythagorean membership grades, complex numbers and decision making. *International Journal of Intelligent Systems, 28*(5), 436-452. https://doi.org/10.1002/int.21584.

Yucel, G., Cebi, S., Hoege, B., & Ozok, A.F. (2011). A fuzzy risk assessment model for hospital information system implementation. *Expert System and Applications, 39*(1), 1211-1218. https://doi.org/10.1016/j.eswa.2011.07.129.

Zadeh, L.A. (1965). Fuzzy sets. *Information and Control, 8*(3), 338-353. https://doi.org/10.1016/s0019-9958(65)90241-x.