Journal of Future Sustainability 4 (2024) 85–100

Contents lists available at GrowingScience

Journal of Future Sustainability

homepage: www.GrowingScience.com/jfs

A fuzzy Pythagorean TODIM method for sustainable ABC analysis in inventory management

V.K. Chawla[a*], Itika[a], Preeti Singh[a] and Stuti Singh[a]

[a]*Department of Mechanical and Automation Engineering, Indira Gandhi Delhi Technical University for Women, New Delhi, India*

C H R O N I C L E

Article history:
Received: March 4, 2023
Received in revised format: March 28, 2023
Accepted: May 19, 2023
Available online: May 19, 2023

Keywords:
ABC Analysis
Sustainability
Inventory Management
Fuzzy Pythagorean TODIM

A B S T R A C T

This paper aims to improve the ABC analysis method used for inventory management by applying the Pythagorean Fuzzy TODIM approach. ABC analysis is one the well-known and widely used inventory classification techniques which divides inventory items into three categories according to their importance and value. However, the traditional ABC analysis does not consider the imprecision and vagueness of real-world inventory data, which can lead to inaccurate results and poor inventory management decisions. The proposed approach enhances the traditional ABC analysis by incorporating fuzzy numbers to be considered in real-world inventory data. The improved ABC analysis helps companies to optimize inventory levels, reduce costs, improve customer service, and increase overall operational efficiency. To check for the reliability and effectiveness of the developed model under different scenarios sensitivity analysis is conducted. Additionally, the comparative analysis among other existing models further demonstrates the model's accuracy. The model prepared shows that the Pythagorean Fuzzy TODIM approach is superior to the conventional ABC analysis in terms of reliability and dealing with the uncertain inventory data. Overall, this paper provides a novel and effective approach to inventory management and offers valuable insights for practitioners and researchers in the field.

1. Introduction

The material handling and storage system is one of the extremely important parts of the flow of goods as they act as a link between consumption points and production therefore inventory management systems become highly significant for any organization which deals with production (raw material and final goods). The inventory management system is one of the crucial issues in logistics companies, i.e., the warehousing systems (Van den Berg & Zijm, 1999), therefore for increased business efficiency and reduced logistics, the goal of the research is to evolve an intelligent inventory management system. It is also one of the biggest contributors to the financial performance of a firm, so cost reduction should be considered in all inventory logistics activities (Sadjadi, 2023). A better logistic implementation will have a great impact on business growth, better efficiency, productivity, and overall better quality (Chanda et al., 2018; Chawla et al., 2018, 2019a, 2019b, 2019c, 2020). There is an urgent need for attention towards sustainable production operations to strike an optimum balance between industrial growth and environmental protection (Sadjadi, 2021, Parashar & Chawla 2021, 2023; Saxena & Chawla 2021, 2022). Sustainable material development (alloys, composites, green materials, biomaterials, etc.) is an evolving field and can play a significant role in directing futuristic development and growth plans in all fields toward a sustainable future (Parashar & Chawla 2021, 2023; Dwivedi et al., 2021; Pol et al., 2022; Rahman et al., 2022).

1.1 Inventory Management

Inventory management refers to the system for placing orders, storing them safely in the warehouse or stores or hubs, and using and selling a company's inventory as shown in Fig. 1. Some of the objectives of inventory management are -

* Corresponding author.
E-mail address: vivekchawla@igdtuw.ac.in (V.K. Chawla)

ISSN 2816-8151 (Online) - ISSN 2816-8143 (Print)

doi: 10.5267/j.jfs.2024.5.003

Optimization of storage cost, maintaining sufficient stock, preventing dead stock, reducing purchase cost of goods, uninterrupted supply of material, etc. There are different types of techniques used in inventory management e.g., JIT, EOQ, ABC, etc.

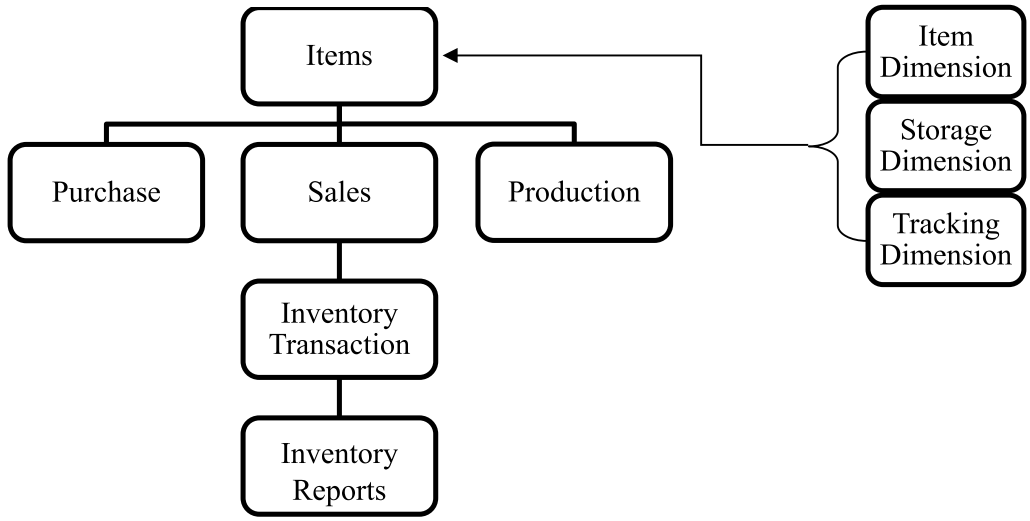

Fig. 1. Working of an Inventory Management System

1.2 ABC Analysis

ABC Analysis is an inventory management method that involves identifying the items that make up a substantial portion of the total inventory value and classifying them as critical, important, or moderately important. Classification of the items in the inventory depends upon the annual demand and unit cost. The derived equation for A, B, and C analysis is shown below as Eq. (1). After applying the traditional ABC analysis on the dataset, the results for the categorization of items in A, B, & C are shown in Table 1.

$$Cr = f(x_i), where\ x_i = \sum_{i=1}^{n} \frac{AUV}{total\ AUV} \times 100,$$

$$where, x_i = \begin{cases} 75,\ n = 20\%\ of\ T \\ 20, n = 30\%\ of\ T \\ 5, n = 50\%\ of\ T \end{cases} ,T = total\ number\ of\ items\ and\ Cr = \begin{cases} A,\ \ x_i = 75 \\ B,\ \ x_i = 20 \\ C,\ \ x_i = 5 \end{cases} \quad (1)$$

Table 1

Categorization of items of inventory according to the traditional ABC analysis

Item no.	Annual Usage Price ($) (j = 3)	CP (%)	Sum of CP	Item no.	Annual Usage Price ($) (j = 3)	CP (%)	Sum of CP	Item no.	Annual Usage Price ($) (j = 3)	CP (%)	Sum of CP
It. No.1	5840.64	0.113		It. No.11	1075.2	0.021		It. No.25	370.5	0.007	
It. No.2	5670	0.11		It. No.12	1043.5	0.02		It. No.26	338.4	0.007	
It. No.3	5037.12	0.097		It. No.13	1038	0.02		It. No.27	336.12	0.007	
It. No.4	4769.56	0.092	73.6	It. No.14	883.2	0.017		It. No.28	313.6	0.006	
It. No.5	3478.8	0.067		It. No.15	854.4	0.017	19	It. No.29	268.68	0.005	
It. No.6	2936.67	0.057		It. No.16	810	0.016		It. No.30	224	0.004	
It. No.7	2820	0.055	A	It. No.17	703.68	0.014		It. No.31	216	0.004	
It. No.8	2640	0.051		It. No.18	594	0.011		It. No.32	212.08	0.004	
It. No.9	2423.52	0.047		It. No.19	570	0.011	B	It. No.33	197.92	0.004	
It. No.10	2407.5	0.047		It. No.20	467.6	0.009		It. No.34	190.89	0.004	
				It. No.21	463.6	0.009		It. No.35	181.8	0.004	7.6
				It. No.22	455	0.009		It. No.36	163.28	0.003	
				It. No.23	432.5	0.008		It. No.37	150	0.003	
				It. No.24	398.4	0.008		It. No.38	134.8	0.003	C
								It. No.39	119.2	0.002	
								It. No.40	103.36	0.002	
								It. No.41	79.2	0.002	
								It. No.42	75.4	0.001	
								It. No.43	59.78	0.001	
								It. No.44	48.3	0.001	
								It. No.45	34.4	0.001	
								It. No.46	28.8	0.001	
								It. No.47	25.38	0	

1.3 Multi-Criteria Decision Making

The Multi-Criteria Decision Analysis or Multi-Criteria Decision Making is a tool that helps to select the best-fit option among all the other options. The use of MCDM generally started from research in operations but later they were applied in many different fields such as education, agriculture (Hayashi, 2000), transportation (Dodgson et al., 2009), health systems (Diaby et al., 2013), energy system (Sánchez-Lozano et al., 2013), environment (Kahraman et al., 2017), computer modeling (Shyur & Shih, 2006) and many more. By using MCDM, better decisions can be made that are genuinely feasible and sensible among all the available options (Touni et al., 2019; Naeini et al., 2019; Ali et al., 2020; Chawla et al., 2021).

1.4 Fuzzy Sets

The theory of fuzzy sets (FS) was originally introduced by Zadeh (1965). It is widely applied in various fields due to its effectiveness in handling uncertainty. The limitation of FS is that it only considers the membership degree and ignores the non-membership degree. Atanassov (1994) proposed intuitionistic fuzzy sets (IFSs), which consider both the degrees of the elements but fail when the total sum turns out to be more than 1. The Pythagorean fuzzy sets (PFSs) are based on Pythagorean negation allowing for a larger space for imprecise memberships (Wu et al., 2019; Yadav & Chawla 2022a, 2022b; Gupta et al, 2022)

1.5 TODIM Method

TODIM (an acronym for "Tomada de Decisão Interativa e Multicritério" in Portuguese, which translates to Interactive and Multicriteria Decision Making) is a method used in MCDM to support decision-making when there are multiple criteria and alternatives to consider. The TODIM method is based on prospect theory. It involves evaluating alternatives through pairwise comparison and uses a value function, initially to determine the dominance of one alternative over the other for each criterion.

2. Literature Review

Implementing different multicriteria decision-making methods to improve inventory management techniques such as ABC (Hadi-Vencheh & Mohamadghasemi, 2011), etc. have been done by many researchers. Many researchers developed integrated MCDM models and an approach for inventory management that gave more consistent results. Partovi and Anandarajan (2002) observed that the accuracy in the classification of different objects enhances the operational benefits such as managing the end outputs, managing sensitive raw materials, controlling and maintaining the inventory, and reducing the expenses of inventory to the minimum possible level. Rauf et al. (2018) put forward an MCDM technique for Multi-Criteria Inventory Classification (MCIC), which involves utilizing the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) technique to manage multiple criteria. The weights are assigned through Best-Worst Method, and further analysis and ranking are done using an integrated approach having an Analytic Hierarchy Process (AHP) and TOPSIS method together. The study also recommends different strategies and methods regarding the efficient management of the firm's warehouses. Hadi-Vencheh & Mohamadghasemi (2011) presented a method that incorporates the fuzzy AHP method within ABC categorization; it also shows envelopment analysis of data to manage the items in inventory efficiently and to find the policies for ordering that are appropriate. Partovi and Burton (1993) have used the AHP method to categorize items in inventory based on both qualitative as well as quantitative criteria for ABC categorization. Similarly, Braglia et al. (2004) recommended an inventory categorization model using the AHP multi-criteria method about sensitivity and suggested several strategies for spare parts inventory management. Antosz and Ratnayake (2016) used a combination of strategies in storage and control, along with their own opinions, for determining the optimum number of different spare parts to be stored in the warehouse. Partovi and Burton (1993) conducted a study that presented the classification of items using the ABC (single criterion) method, in addition to multi-criteria classification using AHP. However, the integration of AHP and TOPSIS was not employed in their research on item categorization. Kaabi et al. (2018) proposed an integrated model relying on the weighted sum (an algorithm) and TOPSIS. Li et al. (2015) proposed an evaluation method utilizing intuitionistic fuzzy numbers that has advantages over other data types such as real numbers, fuzzy numbers, or language regarding the uncertainty and ambiguity in data. Finally, this model presents four distance formulas based on the distance for the intuitionistic fuzzy set-in order to conduct a comparative analysis and more comprehensively display the data relationship among the evaluation values. This approach avoids deviations caused by improper distance formula selection. Many researchers have proposed a new MCDM technique for classifying inventories. Ghorabaee et al. (2016) proposed a comparison between a newly proposed method and some already existing methods, suggesting that the approach is also suitable for solving other MCDM issues.

The literature examined so far has been limited to specific MCDM models to improve inventory analysis techniques. Further, the varied applications of the TODIM method have a lot of potential to be explored in different dimensions of decision-making. MCDM techniques mentioned in the literature have unique advantages and disadvantages for specific applications. If the TODIM method was applied to inventory management, the results would conform to that of the decision-maker (Kaur et al. 2022). The ABC analysis, which considers only one criterion, compromises economic development. Although the traditional ABC analysis is simple and commonly used to evaluate the status of equities, it has a significant drawback in adopting a single-criterion function (Rabbani et al, 2014). Many studies in literature have examined multiple criteria, recognizing the limitation of conventional ABC analysis. Table 2 shows the advantages and disadvantages of different MCDM methods observed from different kinds of literature.

Table 2
Advantages and disadvantages of different MCDM models

MCDM Method	Advantages	Disadvantages	Literature
SAW	It has simple calculations. The steps involved in calculations remain the same no matter how the no. of attributes changes. It can make decisions intuitively.	The value of all criteria should be maximum and positive. The obtained results may not conform to reality.	Zanakis et al.(1998), Wang et al. (2016)
AHP	Forms the problem into a hierarchy tree, A pairwise comparison is done	It can lead to inconsistencies if alternatives and criteria are independent. The number of calculations increases and becomes complex with the increase in no. of the criteria and alternatives. Scoring and ranking can be changed (rank reversal) if the addition or removal of alternatives is done.	Vidal et al. (2022), Mulliner et al. (2016), Zanakis et al.(1998)
TOPSIS	The computational process is simple and can be easily applied. The steps involved in calculations remain the same no matter how the no. of attributes changes.	If the deviation from the ideal solution is less then only the method is most suitable. Due to considering Euclidean distance the negative and positive values do not change the calculations much. It does not consider the interrelation of attributes, so consistency is hard to maintain.	Büyüközkan & Çifçi (2012), Mulliner et al,(2016), Opricovic et al. (2004), Ren et al. (2007), Zanakis et al.(1998), Zavadskas et al. (2016),
VIKOR	It is based on regret theory. It determines the preference ranking by using compromise programming by the regret results of a group or individual regrets.	Due to the usage of normalized matrices, the findings may be biased by the worst values, which might lead to an inaccurate preference ranking of alternatives.	Vidal et al. (2022), Huang et al. (2009), Opricovic et al. (2016),
EDAS	The involved calculations are simple. The time required for calculations is also less. The weightage of beneficial attributes or criteria and non-beneficial attributes or criteria involved in the problem are done separately.	The rank reversal phenomenon is observed	Ghorabaee et al. (2016)
PROMTHEE	It can be applied to both quantitative as well as qualitative information. It is generally used when the alternatives do not harmonize with each other or are not proportionate.	A clear method is not provided as to how to assign weights to the alternatives. The process of computation is long. The involved calculations are complicated.	Behzadian et al. (2010)
TODIM	It considers the subjectivity of the decision-makers behavior in decision-making. It provides dominance of each alternative over the other.	It does not include the complexity and uncertainty in the numbers so it can make it difficult to explain anyone's perception in crisp numbers	Fan et al. (2013), Gomes et al. (1991), Gomes et al. (2009), Huang et al. (2017), Wang & Liu (2017)

Inventory management is a crucial aspect of business operations, and effective inventory management is essential for maintaining profitability and ensuring customer satisfaction. The categorization of inventory items based on their value and importance is a popular inventory management technique known as the ABC analysis. However, the traditional ABC analysis method does not account for the imprecision and vagueness of real-world inventory data Celik et al. (2014), which can lead to inaccurate results and poor inventory management decisions, which can result in inefficient use of resources, overstocking, stock-outs, and other related problems. To address this issue, this study aims to improve the ABC analysis method using the Pythagorean fuzzy TODIM approach. The integrated TODIM and Pythagorean fuzzy approach incorporates fuzzy numbers to account for the imprecision and vagueness of real-world inventory data (Liang et al., 2019). By doing so, it is expected to provide a more accurate and reliable method for inventory management. The fuzzified data type is particularly useful in evaluating uncertain values related to selecting distributors for upstream enterprises. This advantage reduces computational complexity and increases result accuracy. Additionally, using the TODIM method as the model's core requires standardization, which is not necessary for intuitionistic fuzzy numbers due to their natural range between 0 and 1. The TODIM method is a popular choice for distributor selection due to its consideration of decision makers' psychological behavior and its practical value compared to methods of decision-making formed on the utility value that is expected. The primary goal of this paper is to provide decision-makers in the inventory management field with valuable insights to assist companies in enhancing their overall performance and profitability.

3. Methodology

In this study, a method is presented for enhancing inventory management's ABC analysis using a TODIM-based multi-criteria decision-making approach in a Pythagorean fuzzy environment. The approach deals with both qualitative and quantitative factors, which may be ambiguous and conflicting, due to the lack of clarity and consistency in the collected data. To address this issue, the Pythagorean fuzzy approach assigns membership and non-membership rolls to these factors, thereby eliminating any ambiguity. By utilizing this method to enhance the ABC analysis, organizations can make more informed inventory management decisions based on precise and dependable data.

The process chosen to solve the given problem statement involves various steps beginning with the generic categorization of items with ABC analysis and checking the stability and accuracy of the model developed. Figure 2 shown below represents the process flow applied in the study.

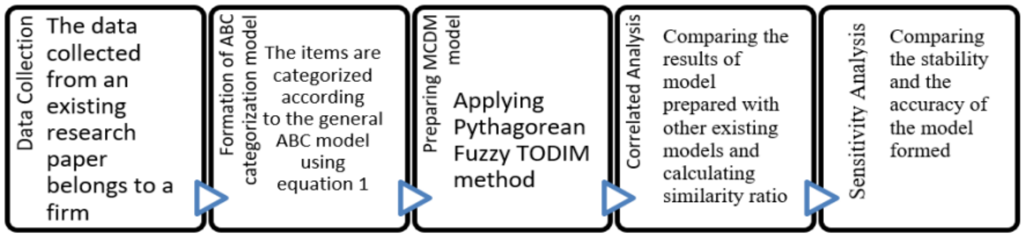

Fig. 2. Research flow for improving ABC analysis

3.1 Formation of Fuzzy Pythagorean TODIM model

The Pythagorean fuzzy TODIM is a type of multi-criteria decision-making (MCDM) method that extends the TODIM method by incorporating Pythagorean Fuzzy Sets (PFSs), introduced by Yager & Abbasov (2013), to account for imprecision and uncertainty that arise during decision-making processes. PFs represent a more flexible version of traditional fuzzy sets that allows an element to have varying degrees of membership to a set. In this kind of fuzzy set, the degree of membership is represented by a pair of real numbers, (a, b), where a and b are the membership and non-membership degrees, respectively, as shown in equation 2 (Kaur et al., 2022).

$$P = \begin{cases} < x, P(\left(\mu_P(x), v_p(x)\right) > \middle| \; x \in X \\ 0 \le \left(\mu_p(x)^2 + v_p(x)^2\right)^2 \le 1 \end{cases} \tag{2}$$

The procedure to create the Pythagorean Fuzzy TODIM model is represented in Fig. 3. In this problem statement, we have three criteria predominantly; Lead time (x_1, j=1), Avg. unit cost (x_2, j=2), and Avg. dollar cost (x_3, j=3), where x represents the criteria and j represents the priority. Least to Most priority: $x_1<x_2<x_3$. The following section explains the steps shown in Figure 2, that are utilized to solve the issue statement using the Pythagorean Fuzzification TODIM method.

Step 1: Design a Pythagorean decision fuzzy matrix $R_{ij}= r_{ij(m\times n)}$, here r_{ij} (Kaur et al., 2022) represents Pythagorean Fuzzy Number using equation 3. Using Pythagorean fuzzy set theory, the original data in Pythagorean Fuzzy TODIM are transformed throughout the normalization process into a fuzzy membership function. It also enables us to take into account the decision-makers tastes and opinions while capturing the uncertainty and imprecision involved in the decision-making process.

$$Rij = \begin{matrix} P(S1, x1) & P(S1, x2) & P(S1, x3) \\ P(S2, x1) & P(S2, x2) & P(S2, x3) \\ \vdots & \vdots & \vdots \\ P(S47, x1) & P(S47, x2) & P(S47, x3) \end{matrix} \tag{3}$$

where *P* represents the Pythagorean fuzzy number (PFN) calculated by eq. (2).

Avg. for Criteria 1:- 3.91, Criteria 2:- 54.44, Criteria 3:- 1099.68

Standard Deviations for Criteria 1:- 1.68, Criteria 2:- 38.57, Criteria 3:- 1570.17.

Membership function (S_i) = z-score (distance of the point from the mean value), the formula used in Excel: [=abs (round (STANDARDIZE (Value, Avg, standard deviation),2)].

Non-Membership function (x_i) = for beneficiary function, it is calculated as the value of S_i divided by the maximum value of all the S_i values for each criterion, while for non-beneficiary minimum value is considered, the formula used in Excel is: =round (Value/Minimum (S_i),2),)].

The calculated Pythagorean fuzzy numbers for the first few items are represented below:

Item 1:

S_1 =standard (2,3.91,1.68) =1.14;x_1= 1.14/1.84 = 0.62

S_2 =standard(49.92,54.44 ,38.57) =0.12;x_2= 0.12/4.03 = 0.03

S_3 =standard(5840.64, 1099.68,1570.17) = 3.02; x_3= 3.02/3.02 = 1

Item 2:

S_1 = standard(5,3.91,1.68) = 0.65;x_1= 0.65/1.84 = 0.35

S_2 =standard(210,54.44,38.57) = 4.03;x_2= 4.03/4.03= 1

S_3 =standard(5670,1099.68,1570.17) = 2.91; x_1= 2.91/3.02 = 0.96

Item 3:

S_1 =standard(4,3.91,1.68) = 0.05; x_1= 0.05/1.84 = 0.03

S_2 = standard(23.76,54.44,38.57) = 0.8; x_2 = 0.8/4.03 = 0.2

S_3= standard(5037.12,1099.68,1570.17) = 2.51; x_3 = 2.51/3.02 = 0.83

and so on. The values of the matrix formed for all 47 items are represented in Table 3.

Step 2: Transform the matrix to calculate the score and verify the accuracy of the function given in Eq. (4).

$$d(\beta_1, \beta_2) = \sqrt{\frac{1}{2}\{\left[\left(u_{\beta_1}\right)^2 - \left(u_{\beta_2}\right)^2\right]^2 + \left[\left(v_{\beta_1}\right)^2 - \left(v_{\beta_2}\right)^2\right]^2\}} \tag{4}$$

The calculated scores of each criterion for the first few items are shown below:

$d(I_1, C_1)$ = 0.92; $d(I_1, C_2)$ = 0.01; $d(I_1, C_3)$ = 8.12

$d(I_2, C_1)$ = 0.3; $d(I_2, C_2)$ = 15.24; $d(I_2, C_3)$ = 7.55

$d(I_3, C_1)$ = 0; $d(I_3, C_2)$ = 0.6; $d(I_3, C_3)$ = 5.61

further, the calculated score for each criterion of each item is shown in Table 3.

Step 3: Calculation for relative weights of each criterion

According to the data we collected, the value j represents the absolute priority given to each criterion, from which we calculate the relative weights by the formula represented in Eq. (5):

$$w_{jr} = \frac{w_j}{w_r} \tag{5}$$

where w_j represents weights and w_r represents the max(w_j), $j = \{1,2,3\}$

$w_1 = 0.167$, $w_2 = 0.333$, and $w_3 = 0.5$, are the weights associated with each criterion.

Relative weights:

$max\ |w_1,w_2,w_3| = w_3 = 0.5$

$w_{13} = w_1/w_3 = 0.334$, $w_{23} = w_2/w_3 = 0.66$, $w_{33} = w_3/w_3 = 1$

Step 4: Calculate the degree of dominance, by the formula given in Eq. (6):

$$A_{ij} = \frac{\sqrt{d_i \times w_{jr}}}{\Sigma w_{jr}}, \tag{6}$$

where i varies from *1* to *47* and *j* from *1* to *3*

Sum of relative weights of the three criteria = 0.334 + 0.66 + 1 = 1.994 ~ 2

The calculated degree of dominance for the first few items is shown below of each criterion is shown below:

$A_{11} = \frac{\sqrt{0.92 \times 0.334}}{2} = 0.554$, $A_{12} = \frac{\sqrt{0.01 \times 0.66}}{2} = 0.81$, $A_{13} = \frac{\sqrt{8.12 \times 1}}{2} = 2.85$

$A_{11} = \frac{\sqrt{0.3 \times 0.334}}{2} = 0.317$, $A_{12} = \frac{\sqrt{15.24 \times 0.66}}{2} = 3.171$, $A_{13} = \frac{\sqrt{7.55 \times 1}}{2} = 2.748$

$A_{11} = \frac{\sqrt{0 \times 0.334}}{2} = 0$, $A_{12} = \frac{\sqrt{0.6 \times 0.66}}{2} = 0.629$, $A_{13} = \frac{\sqrt{5.61 \times 1}}{2} = 2.369$

Further, the calculated degree of dominance for each criterion of each item is shown in Table 3.

Step 5: Derive the overall degree of dominance by summing each alternative's degree of dominance (refer to Eq. (7)).

$$Ai = \sum_{j=1}^{3} A_{ij}, \tag{7}$$

j varies from 1 to 37

The overall degree of dominance for the first few items is shown below, further for all items is shown in Table 3:

A_1= 0.554 +0.81 + 2.85 = 3.485

A_2= 0.317 + 3.171 + 2.748 = 6.236

A_3=0 + 0.629 + 2.369 = 2.998

Step 6: Derive the overall value for each item which is to be calculated as the sum of the square root of the value of A_{ij} for each row.

$$V = \frac{A_i - \min(A_i)}{\max(A_i) - min(A_i)}, \tag{8}$$

here i vary from 1 to 47

Using Eq. (8), the overall score is calculated, through which the overall value of annual usage cost (the value on which ABC analysis depends) is modified by multiplying the value obtained with the annual usage cost. The calculated values for the first few items are shown below, and further values are illustrated in Table 3.

Min (A_i) = 0.455 and Max (A_i) = 6.236; max(A_i) – min(A_i) = 5.781

V_1= (3.485 – 0.455) / 5.781 = 0.52

V_2= (6.236 – 0.455) / 5.781 = 1

V_3= (2.998 – 0.455) / 5.781 = 0.44

Step 7: According to the values categorize the items

The value obtained for each item is its final score, the more the score the more will be the priority for those items i.e., will be categorized into A group, followed by B group and C group. This score is multiplied by the annual usage value obtained for each item to get the overall inventory cost and the value determines the categorization of the items in the three groups.

The arrangement of the items is in descending order and then categorization into 3 groups i.e., A, B, and C is shown in Table 3 along with the comparison with other models.

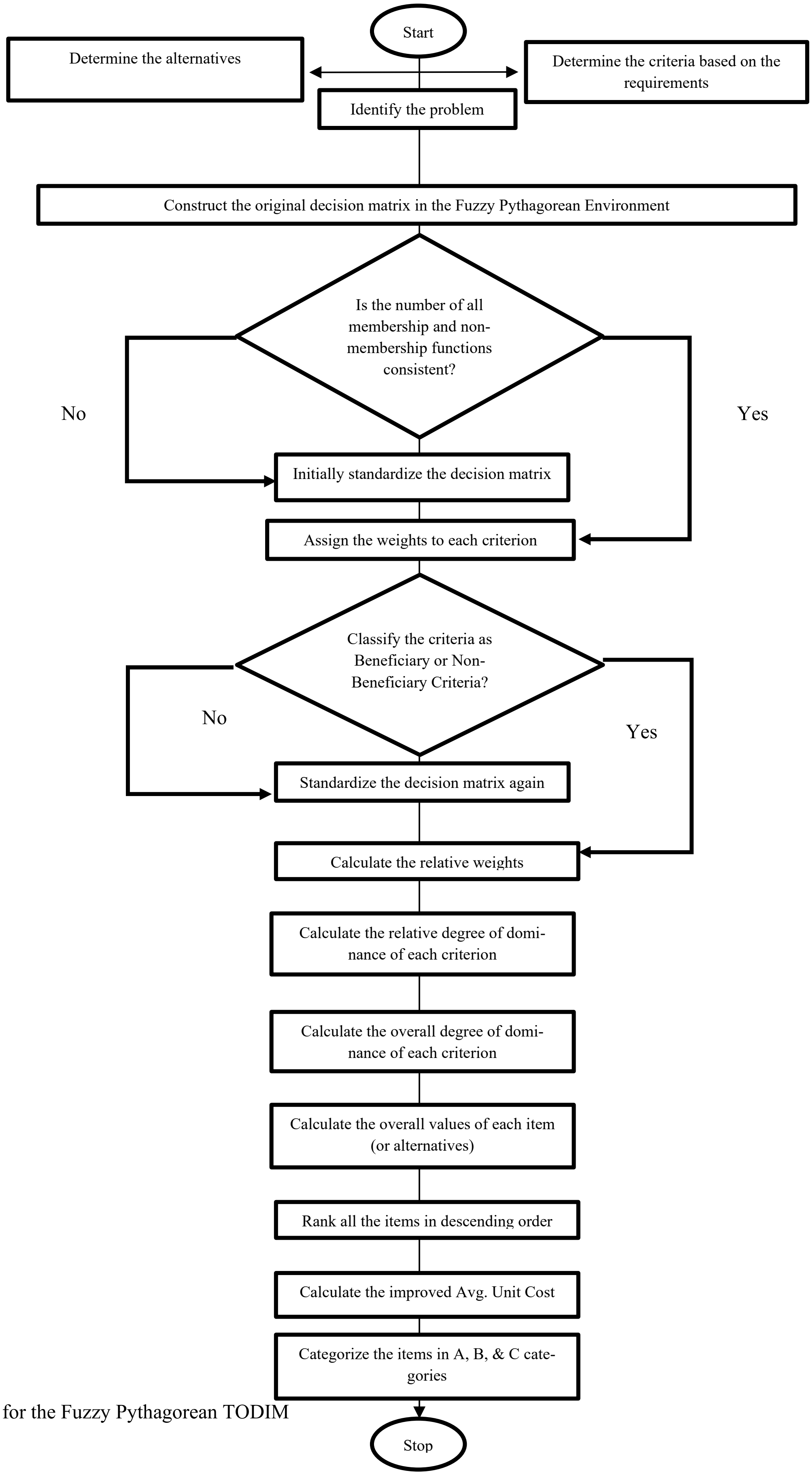

Fig. 3. Flow chart for the Fuzzy Pythagorean TODIM

Table 3
Pythagorean Fuzzy matrix

PFS	PFN P1		PFN P2		PFN P3		Score			Degree of the dominance of each criterion			The overall degree of dominance	Value
	S_1	x_1	S_2	x_2	S_3	x_3	$d_1(\beta_1, \beta_2)$	$d_2(\beta_1, \beta_2)$	$d_3(\beta_1, \beta_2)$	A_{ij}	A_{ij}	A_{ij}		
										w_1=0.334	w_2=0.66	w_3=1		
R1	1.14	0.62	0.12	0.03	3.02	1	0.92	0.01	8.12	0.554	0.081	2.85	3.485	0.52
R2	0.65	0.35	4.03	1	2.91	0.96	0.3	15.24	7.55	0.317	3.171	2.748	6.236	1
R3	0.05	0.03	0.8	0.2	2.51	0.83	0	0.6	5.61	0	0.629	2.369	2.998	0.44
R4	1.73	0.94	0.69	0.17	2.34	0.77	2.11	0.45	4.88	0.839	0.545	2.209	3.593	0.54
R5	0.54	0.29	0.09	0.02	1.52	0.5	0.21	0.01	2.06	0.265	0.081	1.435	1.781	0.23
R6	0.54	0.29	0.6	0.15	1.17	0.39	0.21	0.34	1.22	0.265	0.474	1.105	1.844	0.24
R7	0.54	0.29	0.68	0.17	1.1	0.36	0.21	0.43	1.08	0.265	0.533	1.039	1.837	0.24
R8	0.05	0.03	0.01	0	0.98	0.32	0	0	0.86	0	0	0.927	0.927	0.08
R9	1.24	0.67	0.49	0.12	0.84	0.28	1.09	0.23	0.63	0.603	0.39	0.794	1.787	0.23
R10	0.05	0.03	2.75	0.68	0.83	0.27	0	7.1	0.62	0	2.165	0.787	2.952	0.43
R11	1.14	0.62	1.28	0.32	0.02	0.01	0.92	1.54	0	0.554	1.008	0	1.562	0.19
R12	0.65	0.35	0.87	0.22	0.04	0.01	0.3	0.71	0	0.317	0.685	0	1.002	0.09
R13	1.84	1	0.83	0.21	0.04	0.01	2.39	0.64	0	0.893	0.65	0	1.543	0.19
R14	0.65	0.35	1.45	0.36	0.14	0.05	0.3	1.97	0.02	0.317	1.14	0.141	1.598	0.2
R15	0.54	0.29	0.43	0.11	0.16	0.05	0.21	0.17	0.02	0.265	0.335	0.141	0.741	0.05
R16	0.54	0.29	0.24	0.06	0.18	0.06	0.21	0.05	0.03	0.265	0.182	0.173	0.62	0.03
R17	0.05	0.03	1.03	0.26	0.25	0.08	0	0.99	0.06	0	0.808	0.245	1.053	0.1
R18	1.24	0.67	0.13	0.03	0.32	0.11	1.09	0.02	0.09	0.603	0.115	0.3	1.018	0.1
R19	0.65	0.35	0.18	0.04	0.34	0.11	0.3	0.03	0.1	0.317	0.141	0.316	0.774	0.06
R20	0.05	0.03	0.1	0.02	0.4	0.13	0	0.01	0.14	0	0.081	0.374	0.455	0
R21	0.05	0.03	0.78	0.19	0.41	0.14	0	0.57	0.15	0	0.613	0.387	1	0.09
R22	0.05	0.03	0.27	0.07	0.41	0.14	0	0.07	0.15	0	0.215	0.387	0.602	0.03
R23	0.05	0.03	0.83	0.21	0.42	0.14	0	0.64	0.16	0	0.65	0.4	1.05	0.1
R24	0.54	0.29	0.55	0.14	0.45	0.15	0.21	0.28	0.18	0.265	0.43	0.424	1.119	0.11
R25	1.73	0.94	0.45	0.11	0.46	0.15	2.11	0.19	0.19	0.839	0.354	0.436	1.629	0.2
R26	0.54	0.29	0.53	0.13	0.48	0.16	0.21	0.26	0.2	0.265	0.414	0.447	1.126	0.12
R27	1.73	0.94	0.77	0.19	0.49	0.16	2.11	0.56	0.21	0.839	0.608	0.458	1.905	0.25
R28	1.24	0.67	0.62	0.15	0.5	0.17	1.09	0.36	0.22	0.603	0.487	0.469	1.559	0.19
R29	1.84	1	2.07	0.51	0.53	0.18	2.39	4.02	0.25	0.893	1.629	0.5	3.022	0.44
R30	1.73	0.94	0.04	0.01	0.56	0.19	2.11	0	0.28	0.839	0	0.529	1.368	0.16
R31	0.65	0.35	0.46	0.11	0.56	0.19	0.3	0.2	0.28	0.317	0.363	0.529	1.209	0.13
R32	1.14	0.62	0.04	0.01	0.57	0.19	0.92	0	0.29	0.554	0	0.539	1.093	0.11
R33	0.65	0.35	0.13	0.03	0.57	0.19	0.3	0.02	0.29	0.317	0.115	0.539	0.971	0.09
R34	1.84	1	1.23	0.31	0.58	0.19	2.39	1.42	0.3	0.893	0.968	0.548	2.409	0.34
R35	0.54	0.29	0.16	0.04	0.58	0.19	0.21	0.02	0.3	0.265	0.115	0.548	0.928	0.08
R36	0.54	0.29	0.35	0.09	0.6	0.2	0.21	0.11	0.32	0.265	0.269	0.566	1.1	0.11
R37	0.65	0.35	0.63	0.16	0.6	0.2	0.3	0.37	0.32	0.317	0.494	0.566	1.377	0.16
R38	0.54	0.29	0.34	0.08	0.61	0.2	0.21	0.11	0.33	0.265	0.269	0.574	1.108	0.11
R39	0.65	0.35	0.13	0.03	0.62	0.21	0.3	0.02	0.34	0.317	0.115	0.583	1.015	0.1
R40	1.24	0.67	0.07	0.02	0.63	0.21	1.09	0	0.35	0.603	0	0.592	1.195	0.13
R41	1.14	0.62	0.9	0.22	0.65	0.22	0.92	0.76	0.37	0.554	0.708	0.608	1.87	0.24
R42	1.14	0.62	0.43	0.11	0.65	0.22	0.92	0.17	0.37	0.554	0.335	0.608	1.497	0.18
R43	0.65	0.35	0.64	0.16	0.66	0.22	0.3	0.38	0.39	0.317	0.501	0.624	1.442	0.17
R44	0.54	0.29	0.16	0.04	0.67	0.22	0.21	0.02	0.4	0.265	0.115	0.632	1.012	0.1
R45	1.84	1	0.52	0.13	0.68	0.23	2.39	0.25	0.41	0.893	0.406	0.64	1.939	0.26
R46	0.54	0.29	0.66	0.16	0.68	0.23	0.21	0.41	0.41	0.265	0.52	0.64	1.425	0.17
R47	0.65	0.35	1.19	0.3	0.68	0.23	0.3	1.33	0.41	0.317	0.937	0.64	1.894	0.25

Table 4
The result of ABC analysis from different methods and comparative field

Item no.	Proposed Model	ABC	EDAS	R model	Correlated field
S2	A	A	A	A	A
S4	A	A	B	A	A
S1	A	A	A	A	A
S3	A	A	A	A	A
S29	A	C	A	C	A
S10	A	A	A	A	A
S34	A	C	C	C	C
S45	A	C	C	B	C
S27	A	C	C	B	C
S47	A	C	C	C	C
S6	B	A	B	A	B
S7	B	A	B	A	B
S41	B	C	C	B	B
S5	B	A	A	A	A
S9	B	A	A	A	A
S14	B	B	C	C	B
S25	B	C	C	B	B
S11	B	B	C	C	B
S13	B	B	A	C	B
S28	B	C	B	C	B
S42	B	C	C	B	B
S43	B	C	C	C	C
S46	B	C	C	C	C
S30	B	C	C	B	B
S37	C	C	C	C	C
S31	C	C	B	C	C
S40	C	C	C	C	C
S26	C	C	C	C	C
S24	C	B	C	B	C
S32	C	C	C	C	C
S36	C	C	C	B	C
S38	C	C	C	C	C
S17	C	B	C	B	C
S18	C	B	B	C	C
S23	C	B	B	C	C
S39	C	C	B	C	C
S44	C	C	C	B	C
S12	C	B	B	C	C
S21	C	B	C	C	C
S33	C	C	C	C	C
S8	C	A	A	A	A
S35	C	C	C	B	C
S19	C	B	B	B	B
S15	C	B	B	C	C
S16	C	B	C	C	C
S22	C	B	B	C	C
S20	C	B	B	B	B

3.2 Correlative Analysis

After using the TODIM approach to generate results, it is essential to compare them with the outcomes obtained through other methods, such as the traditional ABC analysis. This comparison can help us to understand the similarities and differences between the two approaches and provide insights into their strengths and limitations.

By comparing the results, we can assess the effectiveness of the TODIM approach in identifying the most appropriate alternatives based on multiple criteria. It can also help us to identify any discrepancies or inconsistencies between the results of different methods and enable us to explore potential causes for such differences. Moreover, the comparison can aid in verifying the validity and reliability of the TODIM approach and provide a benchmark for evaluating its performance in various contexts.

Table 4 represents the categorization of items using different methods. From this data, the similarity ratio is calculated for comparing categorization overall results. The ratio is defined as represented in equation 9.

$$s_r = \frac{\sum_{i=1}^{n} \omega_i(x_i, y_i)}{n}$$

$$\text{where, } (x_i, y_i) \in \{A, B, C\} \text{ and } \omega(x, y) = \begin{cases} 1 \text{ if } x = y \\ 0 \text{ if } x \neq y \end{cases} \tag{9}$$

n denotes the item number, x_i is the class of i^{th} item within first comparison method and y_i denotes the class of i^{th} item in the second comparison method.

The calculated similarity ratio using Eq. (9) and Table 4 is $\frac{36}{47}$, 0.766.

3.2 Sensitivity Analysis

Sensitivity analysis is done to ensure the stability of the model prepared using the Pythagorean Fuzzy TODIM method. The results examined were produced by selecting items whose correlated field differs from the proposed model and modifying the attenuation factor. If it agrees with the proposed model, it is said to produce stable outcomes.

From the correlated analysis, only 11 items (S5, S8, S9, S19, S20, S27, S34, S43, S45, S46, S47) give different categories. After selecting random values of attenuation factor θ, the value is calculated again from which the categorization results for these items are obtained. The calculated matrix after the introduction of θ is shown in Table 5. The results obtained after applying the sensitivity analysis are shown in Table 5. From the data obtained, the stability ratio is calculated, which is $\frac{7}{11}$, 0.636.

Table 5
Matrix formed for sensitivity analysis

	θ = 1.5						θ = 2.5					
Item No.	w_{jr}= 0.22	w_{jr} = 0.44	w_{jr} = 0.67	A_i	**Value**	**Category**	w_{jr} = 0.13	w_{jr}= 0.26	w_{jr} = 0.4	A_i	**Value**	**Category**
S19	0.257	0.258	0.258	0.773	0.35	C	0.197	0.088	0.2	0.485	0.16	C
S20	0	0	0	0	0	C	0	0.051	0.237	0.288	0	C
S27	0.681	0.685	0.685	2.051	0.94	B	0.524	0.382	0.29	1.196	0.74	B
S34	0.725	0.73	0.73	2.185	1	A	0.557	0.608	0.346	1.511	1	A
S43	0.257	0.258	0.258	0.773	0.35	C	0.197	0.314	0.395	0.906	0.51	C
S45	0.725	0.73	0.73	2.185	1	A	0.557	0.255	0.405	1.217	0.76	A
S46	0.215	0.216	0.216	0.647	0.3	C	0.165	0.326	0.405	0.896	0.5	C
S47	0.257	0.258	0.258	0.773	0.35	C	0.197	0.588	0.405	1.19	0.74	B
S5	0.215	0.216	0.216	0.647	0.3	C	0.165	0.051	0.908	1.124	0.68	B
S8	0	0	0	0	0	C	0	0	0.587	0.587	0.24	C
S9	0.49	0.493	0.493	1.476	0.68	B	0.376	0.245	0.502	1.123	0.68	B

Table 6
Categorization results obtained after sensitivity analysis

S. No.	Item No.	Proposed	Correlated	theta = 1.5	theta = 2.5	analysis
1	S34	A	C	A	A	A
2	S45	A	C	A	A	A
3	S27	A	C	B	B	B
4	S47	A	C	C	B	C
5	S5	B	A	C	B	B
6	S9	B	A	B	B	B
7	S43	B	C	C	C	C
8	S46	B	C	C	C	C
9	S8	C	A	C	C	C
10	S19	C	B	C	C	C
11	S20	C	B	C	C	C

The calculations for the proposed model were performed using Microsoft – excel using the system with 7th Generation intel CORE PROi5 processor.

4. Results

This research demonstrated the effectiveness of the Pythagorean fuzzy TODIM approach through sensitivity analysis, which tested the model's robustness under different scenarios. The proposed method has shown a high level of consistency with the results obtained from other methods, indicating that it is a stable approach for achieving accurate results with stability of 63.67%. The variation in the categorization can only be seen in a few items, the graphical representation shown in Fig. 4. Additionally, the accuracy of our model has been determined to be 76.67%, which implies that it is a highly effective tool for achieving accurate results in the context of the task it has been designed for. The model improves the aggregation of the annual usage price of each item, which is used in the categorization of items in A, B & C groups as different criteria are considered while calculating the values.

The proposed method has shown a high level of consistency with the results obtained from other methods, indicating that it is a stable approach for achieving accurate results with stability of 63.67%. Additionally, the accuracy of our model has been determined to be 76.67%, which implies that it is a highly effective tool for achieving accurate results in the context of the task it has been designed for. Further analysis shows that the items in category A are the same but there is a slight change in the score of other items that changes their categories, which can be neglected as the change is not that significant and it can be said that the model proposed is stable.

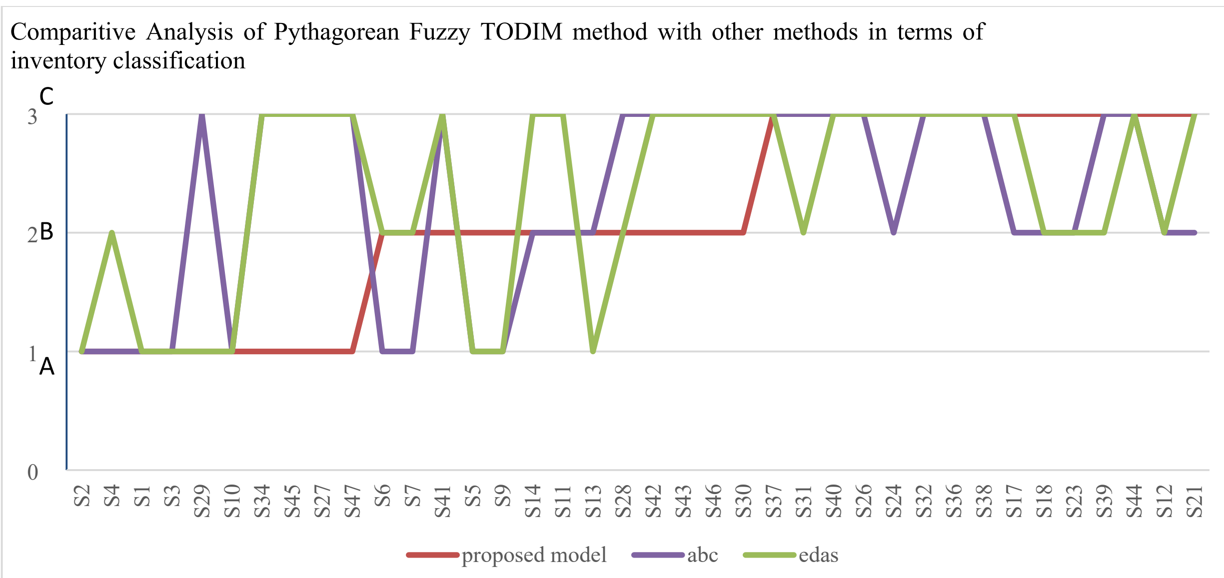

Fig. 4. Variation in categorization of items through proposed model and other models

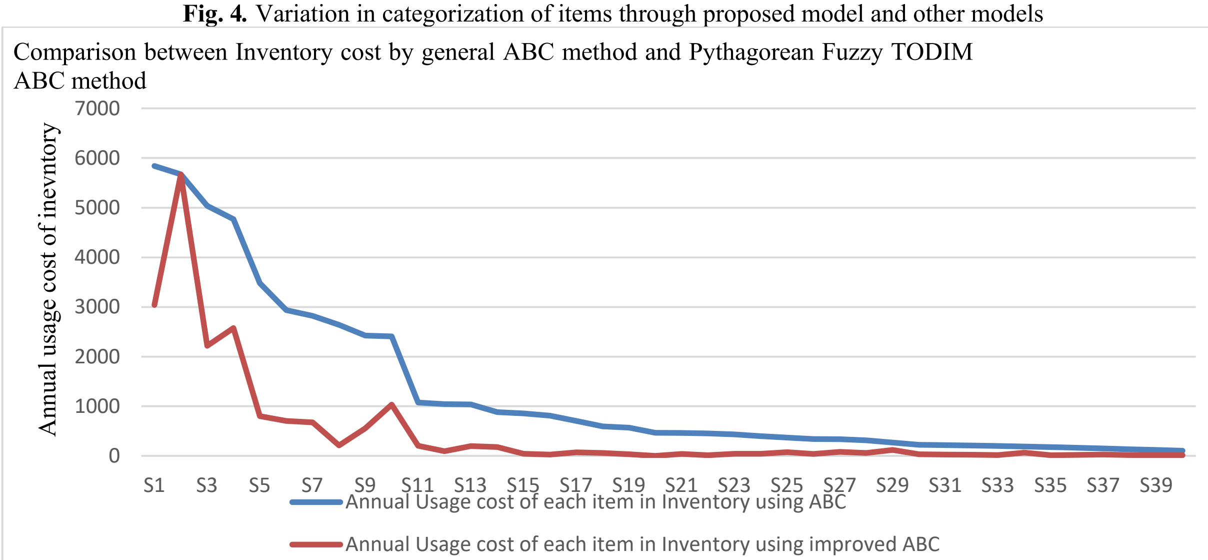

Fig. 5. Comparison of general ABC and improvised ABC

It is observed from the comparison of cumulative percentage (as shown in Table 7) in all three categories A, B, and C of the used model (Pythagorean Fuzzy TODIM) with the EDAS model and traditional ABC analysis, that our model could reduce the inventory cost as category A consist of the items with greater value (cost) has the highest sum of cumulative percentage of annual usage cost. Additionally, the stability of the model proposed has increased from the traditional ABC method and the other existing model. When compared to ABC analysis, the stability increased by 27.66% while when compared with other models mentioned in the literature, the stability increased by 2.13 %. The overall inventory cost has also been reduced by using the model prepared by the Pythagorean Fuzzy TODIM (PFTODIM) approach. After developing the model, the average inventory usage cost of each item is reduced. More criteria are considered while calculating the cost, ultimately decreasing the overall inventory cost. Fig. 5 shows this representation of reduction in the cost of inventory in graphical format, where the comparison between the cost of keeping the item in inventory with the general ABC method. The overall cost has been reduced by 62.77%. Overall, comparing the derived results from the TODIM approach with those obtained through the traditional ABC analysis can be a valuable exercise in assessing the suitability and effectiveness of the Pythagorean Fuzzy TODIM approach for decision-making purposes.

Table 7
Results Comparison

Parameters improved	Proposed model	Literature (EDAS model)	ABC
Similarity ratio:	76.66	74.47	NA
Stability ratio:	91.49	89.36	63.83
	Improvement in ABC analysis		
A	0.91	0.89	0.74
B	0.07	0.1	0.19
C	0.02	0.02	0.07
	Improved Inventory Cost		
Total Inventory Cost	19241.039	NA	51684.78

5. Conclusion

This paper demonstrates the effectiveness of the Pythagorean fuzzy TODIM approach through sensitivity analysis, which tests the model's robustness under different scenarios. The TODIM method which is based on the prospect principle effectively explains the underlying psychological actions of the decision makers whereas PFS perfectly represents the ambiguity. The reason for choosing the TODIM method over other MCDM methods (e.g.: TOPSIS, VIKOR, etc.) is the lesser complications in the involved calculations. The proposed method has shown a high level of consistency with the results obtained from other methods. The accuracy of this model has been determined to be 76.67%, which implies that it is a highly effective tool for achieving accurate results. Further, the application of the TODIM method remains a huge potential for future research and can be applied in. As clients increasingly demand more precise decision information for decision problems, the development of fuzzy numbers as well as the MCDM method continues.

In this paper Pythagorean fuzzy TODIM method has been applied to ABC analysis to optimize the considered inventory management technique for the given dataset and sensitivity analysis was done. The results were compared to the existing results obtained with different MCDM methods such as general ABC analysis, EDAS method, and R-model for validation. The Pythagorean fuzzy TODIM method which has been applied is a very useful method when it comes to dealing with MCDM problems that involve the psychological risks of the decision-maker.

The prospect principle-based TODIM technique efficiently describes the psychological processes that underlie decision-makers behaviors, whereas PFS perfectly captures ambiguity. Due to the simpler computations required, the TODIM approach is preferred over other MCDM methods (such as TOPSIS, VIKOR, etc.). Multi-criteria decision-making analysis (MCDA) has gained popularity because of the fact that psychological factors and personal biases can affect how decisions are made. It works well to produce precise results for the particular purpose it was intended to handle.

1. This research presents a Pythagorean fuzzy TODIM MCDM method to optimize the ABC inventory categorization method.
2. The results obtained by the proposed model were compared with different MCDM methods for validation.
3. A comparison of the traditional ABC analysis method and the proposed model is done.
4. The proposed method is a stable approach for achieving accurate results, with an accuracy rate of 76.6% which has been validated through correlative analysis.
5. Sensitivity analysis was performed with two different values of attenuation factor to check the stability of the model.
6. The advancement in cost reduction of inventory is shown in Table 7. The overall inventory cost has been reduced by 62.77% after applying the Pythagorean fuzzy TODIM approach.

To advance research in this field, it is crucial to lay the groundwork for identifying common MCDM techniques, evaluating their effectiveness, and developing new approaches to improve sustainable decision-making. With advancements in technology, various methodologies are being combined to reduce the chances of biased decisions. Further, the application of the TODIM method remains a huge potential for future research and can be applied to sustainable solutions.

References

Ali, A., Soni, M., Javaid, M., & Haleem, A. (2020). A comparative analysis of different rapid prototyping techniques for making intricately shaped structure. *Journal of Industrial Integration and Management*, *5*(03), 393-407.

Antosz, K., & Ratnayake, R. C. (2016). Classification of spare parts as the element of a proper realization of the machine maintenance process and logistics-case study. *IFAC-PapersOnLine*, *49*(12), 1389-1393.

Atanassov, K. T. (1994). New operations defined over the intuitionistic fuzzy sets. *Fuzzy sets and Systems*, *61*(2), 137-142.

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., & Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European journal of Operational research*, *200*(1), 198-215.

Braglia, M., Grassi, A., & Montanari, R. (2004). Multi-attribute classification method for spare parts inventory management. *Journal of quality in maintenance engineering*, *10*(1), 55-65.

Büyüközkan, G., & Çifçi, G. (2012). A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. *Expert Systems with Applications*, *39*(3), 3000-3011.

Celik, E., Gumus, A. T., & Alegoz, M. (2014). A trapezoidal type-2 fuzzy MCDM method to identify and evaluate critical success factors for humanitarian relief logistics management. *Journal of Intelligent & Fuzzy Systems*, *27*(6), 2847-2855.

Chanda, A. K., Chawla, V. K., & Angra, S. K. (2018). A modified memetic particle swarm optimization algorithm for sustainable multi-objective scheduling of automatic guided vehicles in a flexible manufacturing system. *International Journal of Computer Aided Manufacturing*, *4*(1), 33-47.

Chawla, V. K., Chanda, A. K., & Angra, S. (2019a). Automatic guided vehicle systems in flexible manufacturing system–A review. *International Journal of Industrial Engineering: Theory, Applications and Practice*, *26*(5).

Chawla, V. K., Chanda, A. K., Angra, S., & Rani, S. (2019b). Effect of nature-inspired algorithms and hybrid dispatching rules on the performance of automatic guided vehicles in the flexible manufacturing system. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *41*, 1-17.

Chawla, V. K., Chhabra, D., Gupta, P., & Naaz, S. (2021). Evaluation of green operations management by fuzzy analytical hierarchy process. *Materials Today: Proceedings*, *38*, 274-279.

Chawla, V., Angra, S., Suri, S., & Kalra, R. (2020). A synergic framework for cyber-physical production systems in the context of industry 4.0 and beyond. *International Journal of Data and Network Science*, *4*(2), 237-244.

Chawla, V., Chanda, A., & Angra, S. (2018). Sustainable multi-objective scheduling for automatic guided vehicle and flexible manufacturing system by a grey wolf optimization algorithm. *International Journal of Data and Network Science*, *2*(1), 27-40.

Chawla, V., Chanda, A., & Angra, S. (2019c). Material handling robots fleet size optimization by a heuristic. *Journal of Project Management*, *4*(3), 177-184.

de Paula Vidal, G. H., Caiado, R. G. G., Scavarda, L. F., Ivson, P., & Garza-Reyes, J. A. (2022). Decision support framework for inventory management combining fuzzy multicriteria methods, genetic algorithm, and artificial neural network. *Computers & Industrial Engineering*, *174*, 108777.

Diaby, V., Campbell, K., & Goeree, R. (2013). Multi-criteria decision analysis (MCDA) in health care: a bibliometric analysis. *Operations Research for Health Care*, *2*(1-2), 20-24.

Dodgson, J. S., Spackman, M., Pearman, A., & Phillips, L. D. (2009). Multi-criteria analysis: a manual.

Dwivedi, P., Siddiquee, A. N., & Maheshwari, S. (2021). Issues and requirements for aluminum alloys used in aircraft components: state of the art. *Russian Journal of Non-Ferrous Metals*, *62*, 212-225.

Fan, Z. P., Zhang, X., Chen, F. D., & Liu, Y. (2013). Extended TODIM method for hybrid multiple attribute decision making problems. *Knowledge-Based Systems*, *42*, 40-48.

Ghorabaee, M. K., Zavadskas, E. K., Amiri, M., & Turskis, Z. (2016). Extended EDAS method for fuzzy multi-criteria decision-making: an application to supplier selection. *International journal of computers communications & control*, *11*(3), 358-371.

Gomes, L. F. A. M., & Lima, M. M. P. P. (1991). TODIMI: Basics and application to multicriteria ranking. *Found. Comput. Decis. Sci*, *16*(3-4), 1-16.

Gomes, L. F. A. M., Rangel, L. A. D., & Maranhão, F. J. C. (2009). Multicriteria analysis of natural gas destination in Brazil: An application of the TODIM method. *Mathematical and Computer Modelling*, *50*(1-2), 92-100.

Gupta, P., Chawla, V., Jain, V., & Angra, S. (2022). Green operations management for sustainable development: An explicit analysis by using fuzzy best-worst method. *Decision Science Letters*, *11*(3), 357-366.

Hadi-Vencheh, A., & Mohamadghasemi, A. (2011). A fuzzy AHP-DEA approach for multiple criteria ABC inventory classification. *Expert Systems with Applications*, *38*(4), 3346-3352.

Hayashi, K. (2000). Multicriteria analysis for agricultural resource management: a critical survey and future perspectives. *European journal of operational research*, *122*(2), 486-500.

Huang, J. J., Tzeng, G. H., & Liu, H. H. (2009). A revised VIKOR model for multiple criteria decisions making-The perspective of regret theory. In *Cutting-Edge Research Topics on Multiple Criteria Decision Making: 20th International*

Conference, MCDM 2009, Chengdu/Jiuzhaigou, China, June 21-26, 2009. Proceedings (pp. 761-768). Springer Berlin Heidelberg.

Huang, J., Li, Z. S., & Liu, H. C. (2017). New approach for failure mode and effect analysis using linguistic distribution assessments and TODIM method. *Reliability Engineering & System Safety*, *167*, 302-309.

Kaabi, H., Jabeur, K., & Ladhari, T. (2018). A genetic algorithm-based classification approach for multicriteria ABC analysis. *International Journal of Information Technology & Decision Making*, *17*(06), 1805-1837.

Kahraman, C., Keshavarz Ghorabaee, M., Zavadskas, E. K., Cevik Onar, S., Yazdani, M., & Oztaysi, B. (2017). Intuitionistic fuzzy EDAS method: an application to solid waste disposal site selection. *Journal of Environmental Engineering and Landscape Management*, *25*(1), 1-12.

Kaur, P., Pradhan, B. L., & Priya, A. (2022). TODIM approach for selection of inventory policy in supply chain. *Mathematical Problems in Engineering*, *2022*.

Li, M., Wu, C., Zhang, L., & You, L. N. (2015). An intuitionistic fuzzy-TODIM method to solve distributor evaluation and selection problem. *International Journal of Simulation Modelling*, *14*(3), 511-524.

Liang, D., Zhang, Y., Xu, Z., & Jamaldeen, A. (2019). Pythagorean fuzzy VIKOR approaches based on TODIM for evaluating internet banking website quality of Ghanaian banking industry. *Applied soft computing*, *78*, 583-594.

Mulliner, E., Malys, N., & Maliene, V. (2016). Comparative analysis of MCDM methods for the assessment of sustainable housing affordability. *Omega*, *59*, 146-156.

Naeini, A. B., Mojaradi, B., Zamani, M., & Chawla, V. K. (2019). Prevention of cardiovascular diseases by combining GIS with fuzzy best-worst decision-making algorithm in areas of Tehran. *International Journal of Industrial Engineering and Production Research*, *30*(3), 255-271.

Opricovic, S. (2016). A comparative analysis of the DEA-CCR model and the VIKOR method. *Yugoslav Journal of Operations Research*, *18*(2).

Opricovic, S., & Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European journal of operational research*, *156*(2), 445-455.

Parashar, S., & Chawla, V. (2023). Kenaf-Coir based hybrid nano-composite: an analytical and representative volume element analysis. *Engineering Solid Mechanics*, *11*(1), 103-118.

Parashar, S., & Chawla, V. K. (2021). A systematic review on sustainable green fibre reinforced composite and their analytical models. *Materials Today: Proceedings*, *46*, 6541-6546.

Partovi, F. Y., & Anandarajan, M. (2002). Classifying inventory using an artificial neural network approach. *Computers & Industrial Engineering*, *41*(4), 389-404.

Partovi, F. Y., & Burton, J. (1993). Using the analytic hierarchy process for ABC analysis. *International Journal of Operations & Production Management*.

Pol, A., Malagi, R., & Munshi, G. (2022). Identification of mechanical properties of an araldite LY556 blended with DNR composite and polyacetal: A comparative study for sustainable future. *Journal of Future Sustainability*, *2*(4), 149-156.

Rabbani, A., Zamani, M., Yazdani-Chamzini, A., & Zavadskas, E. K. (2014). Proposing a new integrated model based on sustainability balanced scorecard (SBSC) and MCDM approaches by using linguistic variables for the performance evaluation of oil producing companies. *Expert systems with applications*, *41*(16), 7316-7327.

Rahman, M. Z., Siddiquee, A. N., Khan, Z. A., & Ahmad, S. (2022). Multi-response optimization of FSP parameters on mechanical properties of surface composite. *Materials Today: Proceedings*, *62*, 5-8.

Rauf, M., Guan, Z., Sarfraz, S., Mumtaz, J., Almaiman, S., Shehab, E., & Jahanzaib, M. (2018, September). Multi-criteria inventory classification based on multi-criteria decision-making (MCDM) technique. In *Advances in Manufacturing Technology XXXII: Proceedings of the 16th International Conference on Manufacturing Research, incorporating the 33rd National Conference on Manufacturing Research, September 11–13, 2018, University of Skövde, Sweden* (Vol. 8, p. 343). IOS Press.

Ren, L., Zhang, Y., Wang, Y., & Sun, Z. (2007). Comparative analysis of a novel M-TOPSIS method and TOPSIS. *Applied Mathematics Research eXpress*, *2007*.

Sadjadi, S. (2021). A survey on the effect of plastic pollution in the Great Lakes. *Journal of Future Sustainability*, *1*(1), 5-8.

Sadjadi, S. S., & Ghaderi, S. F. (2023). The role of interest rate and inflation on oil stock prices: Evidence from Ukraine-Russia war. *Journal of Industrial and Systems Engineering*, *14*(4), 174-181.

Sánchez-Lozano, J. M., Teruel-Solano, J., Soto-Elvira, P. L., & García-Cascales, M. S. (2013). Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. *Renewable and sustainable energy reviews*, *24*, 544-556.

Saxena, T., & Chawla, V. K. (2021). Banana leaf fiber-based green composite: An explicit review report. *Materials Today: Proceedings*, *46*, 6618-6624.

Saxena, T., & Chawla, V. K. (2022). Evaluation of mechanical properties for banana-carbon fiber reinforced nano-clay epoxy composite using analytical modeling and simulation. *Research on Engineering Structures and Materials, 8(4),* 773-798.

Shyur, H. J., & Shih, H. S. (2006). A hybrid MCDM model for strategic vendor selection. *Mathematical and computer modelling*, *44*(7-8), 749-761.

Touni, Z., Makui, A., & Mohammadi, E. (2019). A MCDM-based approach using UTA-STRAR method to discover

behavioral aspects in stock selection problem. *International Journal of Industrial Engineering and Production Research*, *30*(1), 93-103.
Van den Berg, J. P., & Zijm, W. H. (1999). Models for warehouse management: Classification and examples. *International journal of production economics*, *59*(1-3), 519-528.
Wang, P., Zhu, Z., & Wang, Y. (2016). A novel hybrid MCDM model combining the SAW, TOPSIS and GRA methods based on experimental design. *Information Sciences*, *345*, 27-45.
Wang, S., & Liu, J. (2017). Extension of the TODIM method to intuitionistic linguistic multiple attribute decision making. *Symmetry*, *9*(6), 95.
Wu, Q., Lin, W., Zhou, L., Chen, Y., & Chen, H. (2019). Enhancing multiple attribute group decision making flexibility based on information fusion technique and hesitant Pythagorean fuzzy sets. *Computers & Industrial Engineering*, *127*, 954-970.
Yadav, E., & Chawla, V. K. (2022a). An explicit literature review on bearing materials and their defect detection techniques. *Materials Today: Proceedings*, *50*, 1637-1643.
Yadav, E., & Chawla, V. K. (2022b). Fault detection in rotating elements by using fuzzy integrated improved local binary pattern method. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *44*(12), 596.
Yager, R. R., & Abbasov, A. M. (2013). Pythagorean membership grades, complex numbers, and decision making. *International Journal of Intelligent Systems*, *28*(5), 436-452.
Zadeh, L. (1965). Fuzzy sets. *Inform Control*, *8*, 338-353.
Zanakis, S. H., Solomon, A., Wishart, N., & Dublish, S. (1998). Multi-attribute decision making: A simulation comparison of select methods. *European journal of operational research*, *107*(3), 507-529.
Zavadskas, E. K., Mardani, A., Turskis, Z., Jusoh, A., & Nor, K. M. (2016). Development of TOPSIS method to solve complicated decision-making problems—An overview on developments from 2000 to 2015. *International Journal of Information Technology & Decision Making*, *15*(03), 645-682.