Defuzzified Strategy of Interval Valued Triskaidecagonal Fuzzy Number Assigning in the Failure of Marine Main Engine

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Abstract. This paper illustrates the various representation of interval-valued Triskaidecagonal fuzzy number. In order to attain the failure mode in Marine Main Engine, the Fault analysis method has been used. The whole concept of application on interval valued Triskaidecagonal fuzzy number approaches the cause and effect of failure modes to make convenient with deffuzied methods.

Keywords: Fuzzy number · Triskaidecagonal · Interval-valued fuzzy number Signed distance · Fault tree method · Triskaidecagonal fuzzy number

1 Introduction

This article has been indicated as a case study of fault tree analysis (FTA) method in marine engineering application. The two stroke engine is mainly used for the force of the ship in reliability testing facility. Due to the uncontrollable working conditions or weather conditions, it is difficult to get the failure value of the undesired event of FTA. In [6], Cai et al. Proposed system failure by use of fuzzy methodology. Fault tree analysis is used to get more reliable and reasonable results based on influencing factors of experts. Fault tree is built based on a top event with cause and effect presents the intermediate event with shows graphically as a rectangle. The subsequent intermediate events correlates lead to the top event. In [7], Singer approached FTA concept in reliability analysis. The main engine's fault tree are faults of the multi cylinder, failure to the turbocharger and common components. Fuzzy set theory is applied in Fault tree method. In 1965, L.A Zadeh proposed degree of membership for fuzzy sets is a real numbers between [0, 1]. Determining the degree of membership in practical application is very difficult. Since approximate reasoning, many scholars have used the concept of interval valued fuzzy numbers and gave the expression of interval valued fuzzy numbers.

The fault tree of cylinder unit includes cylinder cover piston liner group failure, piston rod and combustion and start air components failure. The fault of piston cylinder is the main faults is the groups includes failures of cylinder head, piston, piston rings, liner and jacket. In [4], Rafat presented a Marine main engine's fault tree to find the minimal cut set of first order. The faults of piston crank group are illustrated among the specific components are the piston rod, the stuffing box, crosshead bearings, a connecting rod and crankpin bearings. The starting and combustion process are highlighted

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includes faults to the exhaust valve, the air starting value, fuel injectors with high pressure pipes and fuel pump. The turbocharger is classified in to fault of turbine functioning components, compressor and common elements. The fault of crank system contains the damage to main bearings, thrust bearing and the shaft. The fault sub tree analyzed main engine is the tree of camshaft.

2 Preliminaries

2.1 Definition

An interval valued fuzzy set $\tilde{R}$ on R is given by $\tilde{R} = \left\{(x, [\mu_{\tilde{R}^L}(x), \mu_{\tilde{R}^U}(x)])\right\}$ $\forall x \varepsilon R$ Where $0 \leq \mu_{\tilde{R}^L}(x) \leq \mu_{\tilde{R}^U}(x) \leq 1$ and $\mu_{\tilde{R}^L}(x), \mu_{\tilde{R}^U}(x) \varepsilon [0, 1]$ denoted by $\mu_{\tilde{R}}(x) = [\mu_{\tilde{R}^L}(x), \mu_{\tilde{R}^U}(x)]$, $x \varepsilon R$ or $\tilde{R} = \left[\tilde{R}_L, \tilde{R}_U\right]$

2.2 Definition

An interval valued Triskaidecagonal fuzzy number ϖ on R is given $\varpi = \{(x, [\mu_{\varpi^L}(x), \mu_{\varpi^U}(x)])\}$ $\forall x \varepsilon R$ Where $0 \leq \mu_{\varpi^L}(x) \leq \mu_{\varpi^U}(x) \leq 1$ and $\mu_{\varpi^L}(x), \mu_{\varpi^U}(x) \varepsilon [0, 1]$ as $\mu_{\tilde{A}}(x) = [\mu_{\varpi^L}(x), \mu_{\varpi^U}(x)]$, $x \varepsilon R$ or $\varpi = [\varpi_L, \varpi_U]$

Assume $\varpi^L = (\ell_1, \ell_2, \ell_3, \ell_4, \ell_5, \ell_6, \ell_7, \ell_8, \ell_9, \ell_{10}, \ell_{11}, \ell_{12}, \ell_{13}; \delta)$ and $\varpi^U = (\varsigma_1, \varsigma_2, \varsigma_3, \varsigma_4, \varsigma_5, \varsigma_6, \varsigma_7, \varsigma_8, \varsigma_9, \varsigma_{10}, \varsigma_{11}, \varsigma_{12}, \varsigma_{13}; \gamma)$ where $0 < \delta \leq \gamma \leq 1$

$\varsigma_1 < \ell_1 < \varsigma_2 < \ell_2 < \varsigma_3 < \ell_3 < \varsigma_4 < \ell_4 < \varsigma_5 < \ell_5 < \varsigma_6 < \ell_6 < \varsigma_7 < \ell_8 < \varsigma_8 < \ell_9 < \varsigma_9 < \ell_{10} < \varsigma_{10} < \ell_{11} < \varsigma_{11} < \ell_{12} < \varsigma_{12} < \ell_{13} < \varsigma_{13}$

$\ell_1, \ell_2, \ldots, \ell_{13}, \varsigma_1, \varsigma_2 \ldots \varsigma_{13} \varepsilon R$. The membership function of ϖ_L, ϖ_U is defined as follows

$$\mu_{\varpi_{\overline{\mathrm{TD}}}}L(x) = \begin{cases} \delta\left(\frac{1}{6}\frac{x-\ell_1}{\ell_2-\ell_1}\right) & \ell_1 \leq \mathrm{x} \leq \ell_2 \\ \delta\left(\frac{1}{6} + \frac{1}{6}\frac{x2-\ell_2}{\ell_3-\ell_2}\right) & \ell_2 \leq \mathrm{x} \leq \ell_3 \\ \delta\left(\frac{2}{6} + \frac{1}{6}\frac{x-\ell_3}{\ell_4-\ell_3}\right) & \ell_3 \leq \mathrm{x} \leq \ell_4 \\ \delta\left(\frac{3}{6} + \frac{1}{6}\frac{x-\ell_4}{\ell_5-\ell_4}\right) & \ell_4 \leq \mathrm{x} \leq \ell_5 \\ \delta\left(\frac{4}{6} + \frac{1}{6}\frac{x-\ell_5}{\ell_6-\ell_5}\right) & \ell_5 \leq \mathrm{x} \leq \ell_6 \\ \delta\left(\frac{5}{6} + \frac{1}{6}\frac{x-\ell_6}{\ell_7-\ell_6}\right) & \ell_6 \leq \mathrm{x} \leq \ell_7 \\ \delta\left(1 - \frac{1}{6}\frac{x-\ell_7}{\ell_8-\ell_7}\right) & \ell_7 \leq \mathrm{x} \leq \ell_8 \\ \delta\left(\frac{5}{6} - \frac{1}{6}\frac{x-\ell_8}{\ell_9-\ell_8}\right) & \ell_8 \leq \mathrm{x} \leq \ell_9 \\ \delta\left(\frac{4}{6} - \frac{1}{6}\frac{x-\ell_9}{\ell_{10}-\ell_9}\right) & \ell_9 \leq \mathrm{x} \leq \ell_{10} \\ \delta\left(\frac{3}{6} - \frac{1}{6}\frac{x-\ell_{10}}{\ell_{11}-\ell_{10}}\right) & \ell_{10} \leq \mathrm{x} \leq \ell_{11} \\ \delta\left(\frac{2}{6} - \frac{1}{6}\frac{x-\ell_{11}}{\ell_{12}-\ell_{11}}\right) & \ell_{11} \leq \mathrm{x} \leq \ell_{12} \\ \delta\left(\frac{1}{6}\frac{\ell_{13}-x}{\ell_{13}-\ell_{12}}\right) & \ell_{12} \leq \mathrm{x} \leq \ell_{13} \\ 0 & \mathrm{x} > \ell_{13} \end{cases}$$

$$\mu_{\varpi_{\overline{\mathrm{TD}}}}U(x) = \begin{cases} \gamma\left(\frac{1}{6}\frac{x-\varsigma_1}{\varsigma_2-\varsigma_1}\right) & \varsigma_1 \leq \mathrm{x} \leq \varsigma_2 \\ \gamma\left(\frac{1}{6}+\frac{1}{6}\frac{x2-\varsigma_2}{\varsigma_3-\varsigma_2}\right) & \varsigma_2 \leq \mathrm{x} \leq \varsigma_3 \\ \gamma\left(\frac{2}{6}+\frac{1}{6}\frac{x-\varsigma_3}{\varsigma_4-\varsigma_3}\right) & \varsigma_3 \leq \mathrm{x} \leq \varsigma_4 \\ \gamma\left(\frac{3}{6}+\frac{1}{6}\frac{x-\varsigma_4}{\varsigma_5-\varsigma_4}\right) & \varsigma_4 \leq \mathrm{x} \leq \varsigma_5 \\ \gamma\left(\frac{4}{6}+\frac{1}{6}\frac{x-\varsigma_5}{\varsigma_6-\varsigma_5}\right) & \varsigma_5 \leq \mathrm{x} \leq \varsigma_6 \end{cases}$$

$$\begin{cases} \gamma\left(\frac{5}{6}+\frac{1}{6}\frac{x-\varsigma_6}{\varsigma_7-\varsigma_6}\right) & \varsigma_6 \leq \mathrm{x} \leq \varsigma_7 \\ \gamma\left(1-\frac{1}{6}\frac{x-\varsigma_7}{\varsigma_8-\varsigma_7}\right) & \varsigma_7 \leq \mathrm{x} \leq \varsigma_8 \\ \gamma\left(\frac{5}{6}-\frac{1}{6}\frac{x-\varsigma_8}{\varsigma_9-\varsigma_8}\right) & \varsigma_8 \leq \mathrm{x} \leq \varsigma_9 \\ \gamma\left(\frac{4}{6}-\frac{1}{6}\frac{x-\varsigma_9}{\varsigma_{10}-\varsigma_9}\right) & \varsigma_9 \leq \mathrm{x} \leq \varsigma_{10} \\ \gamma\left(\frac{3}{6}-\frac{1}{6}\frac{x-\varsigma_{10}}{\varsigma_{11}-\varsigma_{10}}\right) & \varsigma_{10} \leq \mathrm{x} \leq \varsigma_{11} \\ \gamma\left(\frac{2}{6}-\frac{1}{6}\frac{x-\varsigma_{11}}{\varsigma_{12}-\varsigma_{11}}\right) & \varsigma_{11} \leq \mathrm{x} \leq \varsigma_{12} \\ \gamma\left(\frac{1}{6}\frac{\varsigma_{13}-x}{\varsigma_{13}-\varsigma_{12}}\right) & \varsigma_{12} \leq \mathrm{x} \leq \varsigma_{13} \\ 0 & \mathrm{x} \ > \varsigma_{13} \end{cases}$$

Then

$$\varpi = \left[\varpi^L, \varpi^U\right] = \left[\left[\begin{matrix} (\ell_1, \ell_2, \ell_3, \ell_4, \ell_5, \ell_6, \ell_7, \ell_8, \ell_9, \ell_{10}, \ell_{11}, \ell_{12}, \ell_{13}; \delta), \\ (\varsigma_1, \varsigma_2, \varsigma_3, \varsigma_4, \varsigma_5, \varsigma_6, \varsigma_7, \varsigma_8, \varsigma_9, \varsigma_{10}, \varsigma_{11}, \varsigma_{12}, \varsigma_{13}; \gamma) \end{matrix}\right]\right]$$

is called the level (δ, γ) Interval valued Triskaidecagonal fuzzy number (Fig. 1).

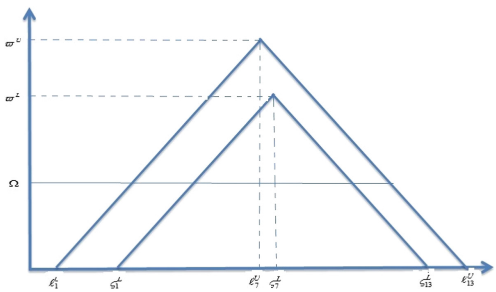


Fig. 1. Interval valued Triskaidecagonal fuzzy number

3 Application of Marine Main Engine Failure Using Interval Valued Triskaidecagonal Fuzzy Number

ʯ 1-Indicates the system failure to start of Main Engine.

ʯ 2-Indicates the failure to start of Engine due to cylinder unit 1 Failure

ʯ3-Indicates the failure to start of Engine due to cylinder unit 2 Failure. (Table 1)

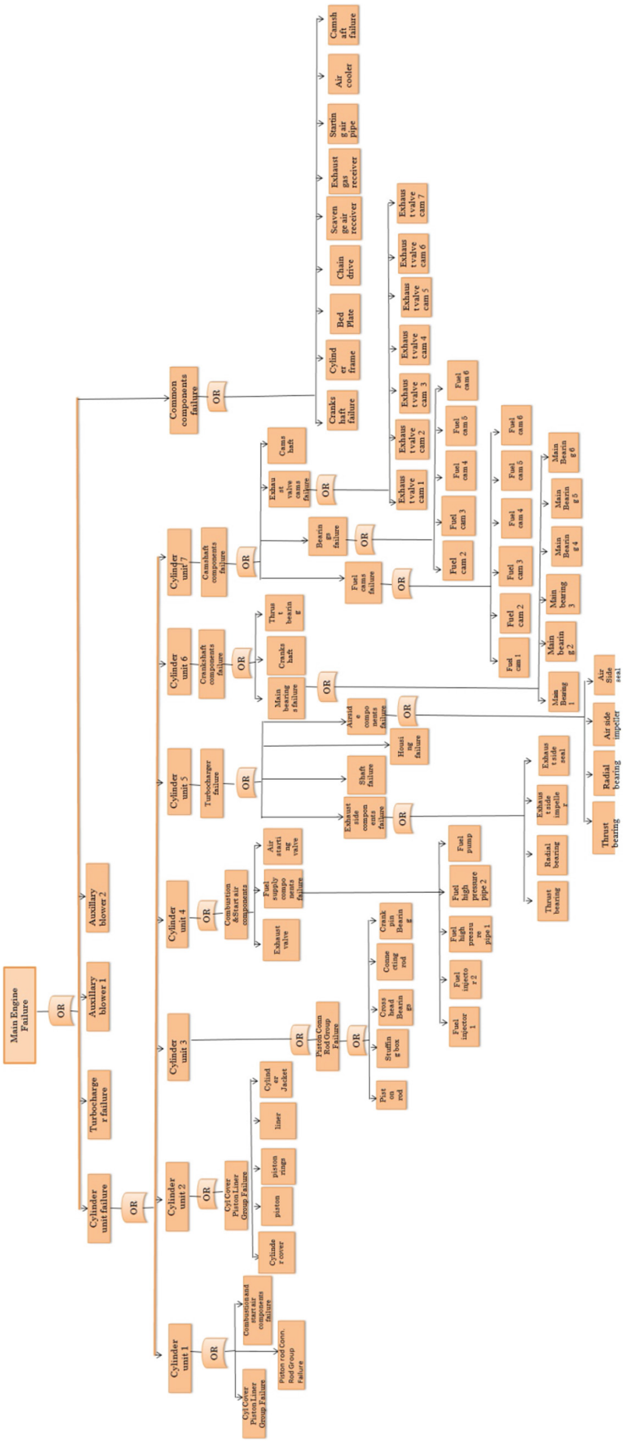
Table 1. Components of marine main engine

Name of the components			
ʯ 77- Fuel cams	ʯ16- Bed Plate	ʯ 30-Crankshaft components	ʯ 54-Exhaust valve Cam
ʯ38- Stuffing box	ʯ40-Piston rod-connecting rod	ʯ5- Auxiliary blowers	ʯ 46-Shaft Failure
ʯ32- Cylinder cover	ʯ44- Air Starting valve	ʯ22- Camshaft	ʯ23-Cylinder cover-piston-liner group failure
ʯ39- Crosshead Bearing	ʯ56- Fuel injection	ʯ18- Scavenge air receiver	ʯ53- Bearings
ʯ17- Chain Drive	ʯ62-Radial Bearing	ʯ58- High pressure pipe	ʯ 49-Main Bearings
ʯ42- Exhaust Valve	ʯ51- Thurst Bearing	ʯ36-Cylinder Jacket	ʯ 14-Crankshaft
ʯ33- Piston &Piston rings	ʯ35- Liner	ʯ 60-Fuel Pump	ʯ21- Air Cooler

Parallel System: The fuzzy reliability R *ps* of the parallel system shown below can be evaluated by using the expression as follows:

$$\tilde{R}^{i}_{ps} = 1 \ominus \prod_{j=1}^{n} (1 \ominus \tilde{R}^{i}_{j}) = 1 \ominus [(1 \ominus (r_{11}, r_{12}, r_{13}\,;\, r'_{11}, r_{12}, r'_{13})) \Box \;\ldots\ldots\ldots\ldots$$

$$\Box \;(1 \ominus (r_{n1}, r_{n2}, r_{n3}\,;\, r'_{n1}, r_{n2}, r'_{n3}))\,]$$


Main Engine Failure
OR
Cylinder unit failure
Turbocharger failure
Auxillary blower 1
Auxillary blower 2
Common components failure
Cranks haft failure
Cylind er frame
Bed Plate
Chain drive
Scaven ge air receiver
Exhaust gas receiver
Startin g air pipe
Air cooler
Camsh aft failure
Cylinder unit 1
Cylinder unit 2
Cylinder unit 3
Cylinder unit 4
Cylinder unit 5
Cylinder unit 6
Cylinder unit 7
Cyl Cover Piston Liner Group Failure
Combustion and start air components failure
Piston rod Conn. Rod Group Failure
Cylinde r cover
piston
piston rings
liner
Cylind er Jacket
Piston Conn Rod Group Failure
Pist on rod
Stuffin g box
Cross head Bearin gs
Conne cting rod
Crank pin Bearin g
Combustion &Start air components
Exhaust valve
Fuel supply compo nents failure
Air starti ng valve
Fuel injector 1
Fuel injecto r 2
Fuel high pressu re pipe 1
Fuel high pressure pipe 2
Fuel pump
Turbocharger failure
Exhaust side compon ents failure
Shaft failure
Housi ng failure
Airsid e compo nents failure
Thrust bearing
Radial bearing
Exhaus t side impelle r
Exhaus t side seal
Air side impeller
Air Side seal
Crankshaft components failure
Main bearing s failure
Cranks haft
Thrus t bearin g
Main Bearing 1
Main bearin g 2
Main bearing 3
Main Bearin g 4
Main Bearin g 5
Main Bearin g 6
Camshaft components failure
Fuel cams failure
Bearin gs failure
Exhau st valve cams failure
Cams haft
Fuel cam 1
Fuel cam 2
Fuel cam 3
Fuel cam 4
Fuel cam 5
Fuel cam 6
Exhaus t valve cam 1
Exhaus t valve cam 2
Exhaus t valve cam 3
Exhaus t valve cam 4
Exhaus t valve cam 5
Exhaus t valve cam 6
Exhaus t valve cam 7

Step-1:

ɥ 7= 1Θ (1 Θ ɥ 23) (1 Θ ɥ 24) (1 Θ ɥ 25)
ɥ 8= 1Θ (1 Θ ɥ 26)
ɥ 26= 1Θ (1 Θ ɥ 32) (1 Θ ɥ 33) (1 Θ ɥ 34) (1 Θ ɥ 35) (1 Θ ɥ 36)
ɥ 9= 1Θ (1 Θ ɥ 27)
ɥ 27= 1Θ (1 Θ ɥ 37) (1 Θ ɥ 38) (1 Θ ɥ 39) (1 Θ ɥ 40)(1 Θ ɥ 41)

ɥ 10= 1Θ (1 Θ ɥ 28)
ɥ 28= 1Θ (1 Θ ɥ 42) (1 Θ ɥ 43) (1 Θ ɥ 44)
ɥ 43= 1Θ (1 Θ ɥ 56) (1 Θ ɥ 57) (1 Θ ɥ 58) (1 Θ ɥ 59) (1 Θ ɥ 60)
ɥ 11= 1Θ (1 Θ ɥ 29)
ɥ 29= 1Θ (1 Θ ɥ 45) (1 Θ ɥ 46) (1 Θ ɥ 47) (1 Θ ɥ 48)
ɥ 45= 1Θ (1 Θ ɥ 61) (1 Θ ɥ 62) (1 Θ ɥ 63) (1 Θ ɥ 64)
ɥ 48= 1Θ (1 Θ ɥ 65) (1 Θ ɥ 68) (1 Θ ɥ 69) (1 Θ ɥ 70)

ɥ 12= 1Θ (1 Θ ɥ 30)
ɥ 30= 1Θ (1 Θ ɥ 49) (1 Θ ɥ 50) (1 Θ ɥ 51)
ɥ 49= 1Θ(1 Θ ɥ 71)(1 Θ ɥ 72)(1 Θ ɥ 73)(1 Θ ɥ 74)(1 Θ ɥ 75)(1 Θ ɥ 76)
ɥ 13= 1Θ (1 Θ ɥ 31)
ɥ 31= 1Θ (1 Θ ɥ 52) (1 Θ ɥ 53) (1 Θ ɥ 54)(1 Θ ɥ 55)
ɥ 52= 1Θ(1 Θ ɥ 77)(1 Θ ɥ 78)(1 Θ ɥ 79)(1 Θ ɥ 80)(1 Θ ɥ 81)(1 Θ ɥ 82)(1 Θ ɥ83)
ɥ 53= 1Θ(1 Θ ɥ 84)(1 Θ ɥ 85)(1 Θ ɥ 86)(1 Θ ɥ 87)(1 Θ ɥ 88)(1 Θ ɥ 89)
ɥ 54= 1Θ(1 Θ ɥ 90)(1 Θ ɥ 91)(1 Θ ɥ 92)(1 Θ ɥ 93)(1 Θ ɥ 94)(1 Θ ɥ 95)(1 Θ ɥ96)

Step-2:

ɥ 2= 1Θ(1 Θ ɥ 7)(1 Θ ɥ 8)(1 Θ ɥ 9)(1 Θ ɥ 10)(1 Θ ɥ 11)(1 Θ ɥ 12)(1 Θɥ 13)
ɥ 6= 1Θ(1 Θ ɥ 14)(1 Θ ɥ 15)(1 Θ ɥ 16)(1 Θ ɥ 17)(1 Θ ɥ 18)(1 Θ ɥ 19)(1 Θ ɥ 20) (1 Θ ɥ 21)(1 Θ ɥ 22)

Step-3:

ɥ 1= 1Θ (1 Θ ɥ 2) (1 Θ ɥ 3) (1 Θ ɥ 4) (1 Θ ɥ 5) (1 Θ ɥ 6)

Similarly linguistic values can frame out for all the components. (Table 2)

Table 2. Linguistic values of marine main engine failure using Fault tree analysis method with Interval valued Triskaidecagonal fuzzy number

Component	Lower bound	Upper bound
ɥ3	(0.003,0.005,0.007,….0.025,0.027;δ)	(0.001,0.004,0.006,…0.024,0.026;γ)
ɥ4	(0.005,0.009,0.014,…..0.034,0.035;δ)	(0.003,0.005,0.007,…0.034,0.036;γ)
ɥ5	(0.007,0.008,0.009,….0.028,0.030;δ)	(0.006,0.008,0.010,…0.035,0.037;γ)
ɥ14	(0.010,0.012,0.014,….0.032,0.034;δ)	(0.009,0.011,0.014,….0.035,0.037;γ)
ɥ15	(0.012,0.014,0.016,….0.038,0.039;δ)	(0.011,0.013,0.015,….0.040,0.042;γ)
ɥ16	(0.015,0.017,0.018,….0.040,0.042;δ)	(0.013,0.015,0.016,….0.042,0.044;γ)
ɥ17	(0.017,0.019,0.021,….0.042,0.044;δ)	(0.016,0.018,0.020,….0.043,0.045;γ)
ɥ18	(0.024,0.026,0.028,….0.046,0.048;δ)	(0.020,0.022,0.024,….0.047,0.049;γ)
ɥ19	(0.028,0.030,0.032,….0.050,0.052;δ)	(0.024,0.027,0.030,….0.052,0.054;γ)
ɥ20	(0.030,0.032,0.034,….0.052,0.054;δ)	(0.026,0.028,0.032,….0.055,0.059;γ)
ɥ21	(0.036,0.038,0.040,….0.058,0.060;δ)	(0.032,0.035,0.038,….0.061,0.063;γ)
ɥ22	(0.038,0.040,0.042,….0.060,0.062;δ)	(0.034,0.036,0.038,….0.064,0.066;γ)
ɥ23	(0.041,0.043,0.045,….0.065,0.067;δ)	(0.039,0.042,0.044,….0.067,0.069;γ)
ɥ24	(0.053,0.055,0.057,….0.075,0.077;δ)	(0.045,0.047,0.049,….0.078,0.080;γ)
ɥ25	(0.057,0.059,0.061,….0.079,0.081;δ)	(0.050,0.052,0.054,….0.083,0.085;γ)
ɥ32	(0.059,0.063,0.067,….0.085,0.087;δ)	(0.055,0.057,0.059,….0.088,0.090;γ)
ɥ33	(0.061,0.062,0.063,….0.072,0.073;δ)	(0.059,0.060,0.061,….0.079,0.080;γ)
ɥ34	(0.063,0.065,0.067,….0.085,0.087;δ)	(0.060,0.062,0.064,….0.088,0.089;γ)
ɥ35	(0.066,0.068,0.070,….0.088,0.090;δ)	(0.063,0.065,0.067,….0.089,0.091;γ)
ɥ36	(0.069,0.070,0.072,….0.090,0.092;δ)	(0.065,0.067,0.069,…0.091,0.093;γ)
ɥ37	(0.071,0.073,0.075,….0.093,0.095;δ)	(0.069,0.072,0.074,…0.095,0.097;γ)
ɥ38	(0.072,0.073,0.074,….0.083,0.084;δ)	(0.070,0.071,0.072,…0.086,0.087;γ)
ɥ39	(0.074,0.076,0.077,….0.091,0.092;δ)	(0.071,0.073,0.075,…0.092,0.093;γ)
ɥ40	(0.077,0.078,0.079,….0.094,0.095;δ)	(0.073,0.075,0.077,…0.094,0.096;γ)
ɥ41	(0.080,0.081,0.082,….0.091,0.092;δ)	(0.077,0.079,0.081,…0.096,0.098;γ)
ɥ42	(0.084,0.086,0.087,….0.096,0.097;δ)	(0.080,0.082,0.083,…0.098,0.099;γ)
ɥ44	(0.086,0.087,0.088,….0.098,0.099;δ)	(0.083,0.085,0.086,…0.099,0.101;γ)
ɥ46	(0.090,0.091,0.092,….0.102,0.103;δ)	(0.087,0.089,0.091,…0.106,0.107;γ)
ɥ47	(0.093,0.095,0.097,….0.113,0.115;δ)	(0.090,0.092,0.094,…0.117,0.119;γ)
ɥ50	(0.103,0.105,0.107,….0.125,0.127;δ)	(0.096,0.099,0.103,…0.127,0.129;γ)
ɥ51	(0.107,0.109,0.121,….0.139,0.141;δ)	(0.102,0.104,0.106,…0.143,0.145;γ)
ɥ55	(0.120,0.122,0.124,….0.142,0.144;δ)	(0.118,0.122,0.123,…0.144,0.146;γ)
ɥ56	(0.125,0.126,0.128,….0.146,0.148;δ)	(0.120,0.122,0.125,…0.150,0.152;γ)
ɥ57	(0.130,0.132,0.134,….0.152,0.154;δ)	(0.127,0.130,0.133,…0.157,0.159;γ)
ɥ58	(0.133,0.135,0.137,….0.158,0.160;δ)	(0.130,0.133,0.135,…0.159,0.162;γ)
ɥ59	(0.137,0.139,0.141,….0.163,0.166;δ)	(0.135,0.137,0.140,…0.166,0.169;γ)
ɥ60	(0.140,0.142,0.144,….0.168,0.170;δ)	(0.136,0.138,0.141,…0.172,0.174;γ)

Step-1:

ʯ7=(0.143593,0.148993,0.154369,0.159724,0.165055,0.171238,0.177392,0.182648,0.187882,0.193094,0.198283,0.20345,0.208595;0.128133,0.134501,0.139938,0.148961,0.157924,0.164157,0.177392,0.187019,0.192235,0.198297,0.205175,0.211173,0.216284)

ʯ8=(0.280068,0.287716,0.296063,0.302837,0.310303,0.316969,0.323584,0.330148,0.33594,0.342409,0.348828,0.355198,0.361518;0.267681,0.27467,0.281607,0.290763,0.302838,0.31327,0.323584,0.33375,0.340945,0.350209,0.358668,0.365646,0.37119)

ʯ9=(0.322102,0.327213,0.331569,0.336623,0.340932,0.345931,0.352316,0.358654,0.362849,0.367718,0.372558,0.377366,0.381465;0.311776,0.31916,0.325755,0.331575,0.337351,0.343797,0.352316,0.36075,0.367017,0.37255,0.37873,0.384855,0.390265)

ʯ10=(0.589893,0.595466,0.600996,0.606461,0.610955,0.61944,0.625547,0.631598,0.637995,0.643452,0.648844,0.65375,0.659007;0.578592,0.586177,0.593697,0.601534,0.608816,0.615482,0.625547,0.634556,0.642123,0.648797,0.655766,0.661803,0.667722)

ʯ11=(0.793355,0.798159,0.803099,0.808164,0.812886,0.817942,0.823087,0.827913,0.832403,0.836404,0.840088,0.844484,0.848024;0.784462,0.79142,0.799392,0.805934,0.811852,0.818423,0.823087,0.830636,0.836356,0.841789,0.846876,0.85018,0.853602)

ʯ12=(0.794586,0.798558,0.805166,0.809671,0.813856,0.817732,0.822443,0.825941,0.829379,0.832759,0.83608,0.838925,0.842139;0.786281,0.791674,0.798197,0.803791,0.810137,0.814946,0.822443,0.828087,0.832336,0.83627,0.840152,0.844329,0.847847)

ʯ13=(0.997980.998099,0.99823,0.998352,0.99847,0.998587,0.998722,0.998814,0.998896,0.998982,0.999054,0.999121,0.999176;0.997741,0.99795,0.998159,0.998325,0.998476,0.998614,0.998722,0.998863,0.998954,0.999041,0.999115,0.999181,0.999244)

Step-2:

ʯ2=(0.999985,0.999987,0.999989,0.999991,0.999992,0.999993,0.999995,0.999995,0.999996,0.999997,0.999997,0.999998,0.999998;0.999981,0.999984,0.999987,0.99999,0.999992,0.999993,0.999995,0.999996,0.999997,0.999997,0.999998,0.999998,0.999998)

ʯ6=(0.191794,0.20657,0.220311,0.23306,0.251,0.250303,0.28357,0.296844,0.311321,0.3241350.336737,0.348452,0.359984;0.169938,0.18592,0.204085,0.223502,0.241709,0.258729,0.28357,0.304869,0.318502,0.335373,0.349842,0.36269,0.375977)

Step-3:

ɥ1=(0.9999883,0.99999,0.999992,0.999993,0.999994,0.999995,0.999996,0.999997,0.999997,0.999998,0.999998,0.999999,0.999999;0.999984,0.999987,0.99999,0.999992,0.999994,0.999995,0.999996,0.999997,0.999998,0.999998,0.999999,0.999999,0.999999)

Case:1 If $0 \leq \Omega < \delta$, then

$$\varpi_l^L(\alpha) = \frac{6\Omega}{\delta}(\ell_2 - \ell_1) + \ell_1$$
$$\varpi_r^L(\alpha) = \frac{6\Omega}{\delta}(\ell_{13} - \ell_{12}) + \ell_{13}$$
$$\varpi_l^U(\alpha) = \frac{6\Omega}{\gamma}(\varsigma_2 - \varsigma_1) + \varsigma_1$$
$$\varpi_r^U(\alpha) = \frac{6\Omega}{\gamma}(\varsigma_{13} - \varsigma_{12}) + \varsigma_{13}$$

Where $\left\{\varpi_l^L(\Omega), \varpi_l^U(\Omega)\right\}, \left\{\varpi_r^L(\Omega), \varpi_r^U(\Omega)\right\}$ are the $\Omega-$ cuts of left and right side of level (δ, γ) Interval valued Triskaidecagonal fuzzy number.

Case:2
If $\delta \leq \Omega \leq \gamma$, then

$$\varpi_l^U(\Omega) = 6\alpha(\varsigma_7 - \varsigma_6) - 5\varsigma_7 + 6\varsigma_6$$
$$\varpi_r^U(\Omega) = 6\alpha(\varsigma_9 - \varsigma_8) - 4\varsigma_8 + 5\varsigma_9$$

Definition: Signed distance
$\kappa_0(h, 0), h\varepsilon R$ is define as $\kappa_0(h, 0) = h$ and is called the signed distance from k to 0. κ_0 meant is When (i) h > 0, $\kappa_0(h, 0) = h > 0$ (i.e.) h is the right and distance from 0 is h. (ii) h < 0, $\kappa_0(h, 0) = h < 0$ (i.e.) h is the left and distance from 0 is -h.

When $0 < \delta < \gamma$, we obtain the signed distance of from 0

$$\varpi = \begin{bmatrix} (\ell_1, \ell_2, \ell_3, \ell_4, \ell_5, \ell_6, \ell_7, \ell_8, \ell_9, \ell_{10}, \ell_{11}, \ell_{12}, \ell_{13}; \delta), \\ (\varsigma_1, \varsigma_2, \varsigma_3, \varsigma_4, \varsigma_5, \varsigma_6, \varsigma_7, \varsigma_8, \varsigma_9, \varsigma_{10}, \varsigma_{11}, \varsigma_{12}, \varsigma_{13}; \gamma) \end{bmatrix}$$

Case: 1 $0 \leq \Omega \leq \delta$

$$\kappa_0(\varpi_l^U(\Omega), 0) = \varpi_l^U(\Omega), \kappa_0(\varpi_l^L(\Omega), 0) = \varpi_l^L(\Omega),$$
$$\kappa_0(\varpi_r^L(\Omega), 0) = \varpi_r^L(\Omega), \kappa_0(\varpi_r^U(\Omega), 0) = \varpi_r^U(\Omega)$$

The signed distance of the interval $[\varpi^L(\Omega), \varpi^U(\Omega)]$ from 0 is given by

$$\kappa_0\left[(\varpi_l^L(\Omega),\varpi_l^U(\Omega)),0\right]=\frac{1}{2}\left[\kappa_0(\varpi_l^U(\Omega),0)+\kappa_0(\varpi_l^L(\Omega),0)\right]=\frac{1}{2}\left[\varpi_l^U(\Omega)+\varpi_l^L(\Omega)\right]$$
$$=\frac{1}{2}\left[\ell_1+\varsigma_1+\frac{6\Omega}{\gamma}(\varsigma_2-\varsigma_1)+\frac{6\Omega}{\delta}(\ell_2-\ell_1)\right] \quad (1)$$

$$\kappa_0[(\varpi_r^L(\Omega),\varpi_r^U(\Omega)),0]=\frac{1}{2}[\kappa_0(\varpi_r^U(\Omega),0)+\kappa_0(\varpi_r^L(\Omega),0)]=\frac{1}{2}\left[\varpi_r^U(\Omega)+\varpi_r^L(\Omega)\right]$$
$$=\frac{1}{2}\left[\ell_{13}+\varsigma_{13}+\frac{7\Omega}{\gamma}(\varsigma_{13}-\varsigma_{12})+\frac{7\Omega}{\delta}(\ell_{13}-\ell_{12})\right] \quad (2)$$

The signed distance of $\left[\varpi_l^L(\Omega),\varpi_l^U(\Omega)\right]\cup[\varpi_r^L(\Omega),\varpi_r^U(\Omega)]$ from 0 is given by

$$\kappa_0\left(\left[\varpi_l^L(\Omega),\varpi_l^U(\Omega)\right]\cup[\varpi_r^L(\Omega),\varpi_r^U(\Omega)],0\right)=\frac{1}{2}\left[\kappa_0\left((\varpi_l^L(\Omega),\varpi_l^U(\Omega)),0\right)+\kappa_0\left((\varpi_r^L(\Omega),\varpi_r^U(\Omega)),0\right)\right]$$
$$=\frac{1}{4}\left[\ell_1+\varsigma_1+\frac{6\Omega}{\gamma}(\varsigma_2-\varsigma_1)+\frac{6\Omega}{\delta}(\ell_2-\ell_1)+\ell_{13}+\varsigma_{13}+\frac{6\Omega}{\gamma}(\varsigma_{13}-\varsigma_{12})+\frac{6\Omega}{\delta}(\ell_{13}-\ell_{12})\right]$$
$$=\frac{1}{4}\left[\ell_1+\varsigma_1+\ell_{13}+\varsigma_{13}+\frac{6\Omega}{\gamma}(\varsigma_2-\varsigma_1+\varsigma_{13}-\varsigma_{12})+\frac{6\Omega}{\delta}(\ell_2-\ell_1+\ell_{13}-\ell_{12})\right] \quad (3)$$

The function in Eq. 3 is continuous on $0\leq\Omega\leq\delta$ with respect to Ω, we can find the average value by integration

$$\frac{1}{\delta}\int_0^{\lambda}\kappa_0\left(\left[\varpi_l^L(\Omega),\varpi_l^U(\Omega)\right]\cup[\varpi_r^L(\Omega),\varpi_r^U(\Omega)],0\right)d\alpha$$
$$=\frac{1}{8}(-4\ell_1+2\varsigma_1+8\ell_{13}+2\varsigma_{13}+6\ell_2-6\ell_{12}+\frac{6\delta}{\gamma}(\varsigma_2-\varsigma_1+\varsigma_{13}-\varsigma_{12})$$

$$\kappa_0(\dot{P}_1,0)=0.999996205$$

Case: 2 $\delta\leq\Omega\leq\gamma$ The signed distance of $[\varpi_l^U(\alpha),\varpi_r^U(\alpha)]$ from 0 is given

$$d_0[(\varpi_l^U(\Omega),\varpi_l^U(\Omega)),0]=\frac{1}{2}[d_0(\varpi_l^U(\Omega),0)+d_0(\varpi_l^U(\Omega),0)]=\frac{1}{2}\left[\varpi_l^U(\Omega)+\varpi_l^U(\Omega)\right]$$
$$=\frac{1}{2}[6\Omega(\varsigma_7-\varsigma_6)-5\varsigma_7+6\varsigma_6+6\Omega(\varsigma_8-\varsigma_7)+5\varsigma_9-4\varsigma_8]$$
$$=\frac{1}{2}[6\Omega(\varsigma_7-\varsigma_6+\varsigma_8-\varsigma_7)-5\varsigma_7+6\varsigma_6+5\varsigma_9-4\varsigma_8]$$

This function is also continuous function and the average value is calculated by integration.

$$\frac{1}{\gamma-\delta}\int_{\lambda}^{\rho}(\kappa_0(\varpi_l^U(\Omega),\varpi_r^U(\Omega)),0)d\Omega$$
$$=\frac{1}{\gamma-\delta}\frac{1}{4}\begin{bmatrix}6\gamma^2(\varsigma_7-\varsigma_6+\varsigma_9-\varsigma_8)+(-10\varsigma_7+12\varsigma_6+10\varsigma_9-8\varsigma_8)\gamma\\ -6\delta^2(\varsigma_7-\varsigma_6+\varsigma_9-\varsigma_8)+(-10\varsigma_7+12\varsigma_6+14\varsigma_9-14\varsigma_8)\delta\end{bmatrix}$$

$$\kappa_0(\grave{P}_1,0)=0.99999837594$$

Centroid Distance for lower bound:

$$\frac{\delta}{12}[-\ell_1+2\ell_7-2\ell_{12}+\ell_{13}]+\frac{\delta}{6}[-\ell_3-\ell_2-\ell_4-\ell_5-\ell_6+5\ell_7+\ell_9 \\ -5\ell_8+\ell_{10}+\ell_{11}+2\ell_{12}]+\delta[\ell_8-\ell_7]$$

$$\int\mu_A(x)dx=0.00000112602 \qquad \text{(i)}$$

$$\frac{\delta}{12}[-\ell_3^2-\ell_2^2-\ell_4^2-\ell_5^2-\ell_6^2-\ell_7^2+\ell_8^2+\ell_9^2+\ell_{10}^2+\ell_{11}^2+2\ell_{12}^2]+\frac{\delta}{36}[\frac{2\ell_2^3-3\ell_1\ell_2^2+\ell_1^3}{\ell_2-\ell_1}+\frac{2\ell_3^3-3\ell_2\ell_3^2+\ell_2^3}{\ell_3-\ell_2}+\frac{2\ell_4^3-3\ell_3\ell_4^2+\ell_3^3}{\ell_4-\ell_3} \\ +\frac{2\ell_5^3-3\ell_4\ell_5^2+\ell_4^3}{\ell_5-\ell_4}+\frac{2\ell_6^3-3\ell_5\ell_6^2+\ell_5^3}{\ell_6-\ell_5}+\frac{2\ell_7^3-3\ell_6\ell_7^2+\ell_6^3}{\ell_7-\ell_6}-\frac{2\ell_8^3-3\ell_7\ell_8^2+\ell_7^3}{\ell_8-\ell_7}-\frac{2\ell_9^3-3\ell_8\ell_9^2+\ell_8^3}{\ell_9-\ell_8}-\frac{2\ell_{10}^3-3\ell_9\ell_{10}^2+\ell_9^3}{\ell_{10}-\ell_9} \\ -\frac{2\ell_{11}^3-3\ell_{10}\ell_{11}^2+\ell_{10}^3}{\ell_{11}-\ell_{10}}-\frac{2\ell_{12}^3-3\ell_{11}\ell_{12}^2+\ell_{11}^3}{\ell_{12}-\ell_{11}}+\frac{2\ell_{12}^3-3\ell_{13}\ell_{12}^2+\ell_{13}^3}{\ell_{13}-\ell_{12}}]$$

$$\int X\mu_A(x)dx=0.00000182933 \qquad \text{(II)}$$

Centroid distance for lower bound = 1.62459814

Centroid distance for upper bound:

$$\frac{\gamma}{12}[-\varsigma_1+2\varsigma_7-2\varsigma_{12}+\varsigma_{13}]+\frac{\gamma}{6}[-\varsigma_3-\varsigma_2-\varsigma_4-\varsigma_5-\varsigma_6+5\varsigma_7+\varsigma_9 \\ -5\varsigma_8+\varsigma_{10}+\varsigma_{11}+2\varsigma_{12}]+\gamma[\varsigma_8-\varsigma_7]$$

$$\int\mu_A(x)dx=0.0000027 \qquad \text{(i)}$$

$$\frac{\gamma}{12}[-\varsigma_3^2-\varsigma_2^2-\varsigma_4^2-\varsigma_5^2-\varsigma_6^2-\varsigma_7^2+\varsigma_8^2+\varsigma_9^2+\varsigma_{10}^2+\varsigma_{11}^2+2\varsigma_{12}^2]+\frac{\gamma}{36}[\frac{2\varsigma_2^3-3\varsigma_1\varsigma_2^2+\varsigma_1^3}{\varsigma_2-\varsigma_1}+\frac{2\varsigma_3^3-3\varsigma_2\varsigma_3^2+\varsigma_2^3}{\varsigma_3-\varsigma_2}+\frac{2\varsigma_4^3-3\varsigma_3\varsigma_4^2+\varsigma_3^3}{\varsigma_4-\varsigma_3} \\ +\frac{2\varsigma_5^3-3\varsigma_4\varsigma_5^2+\varsigma_4^3}{\varsigma_5-\varsigma_4}+\frac{2\varsigma_6^3-3\varsigma_5\varsigma_6^2+\varsigma_5^3}{\varsigma_6-\varsigma_5}+\frac{2\varsigma_7^3-3\varsigma_6\varsigma_7^2+\varsigma_6^3}{\varsigma_7-\varsigma_6}-\frac{2\varsigma_8^3-3\varsigma_7\varsigma_8^2+\varsigma_7^3}{\varsigma_8-\varsigma_7}-\frac{2\varsigma_9^3-3\varsigma_8\varsigma_9^2+\varsigma_8^3}{\varsigma_9-\varsigma_8}-\frac{2\varsigma_{10}^3-3\varsigma_9\varsigma_{10}^2+\varsigma_9^3}{\varsigma_{10}-\varsigma_9} \\ -\frac{2\varsigma_{11}^3-3\varsigma_{10}\varsigma_{11}^2+\varsigma_{10}^3}{\varsigma_{11}-\varsigma_{10}}-\frac{2\varsigma_{12}^3-3\varsigma_{11}\varsigma_{12}^2+\varsigma_{11}^3}{\varsigma_{12}-\varsigma_{11}}+\frac{2\varsigma_{12}^3-3\varsigma_{13}\varsigma_{12}^2+\varsigma_{13}^3}{\varsigma_{13}-\varsigma_{12}}]$$

$$\int X\mu_A(x)dx=0.00000258 \qquad \text{(II)}$$

Centroid distance for upper bound = 0.955555556

Euclidean distance: $\sqrt{\sum_{i=1}^{n}|x_i - y_i|^2}$, $\mathbf{ED} = \sqrt{(x_1-y_1)^2+(x_2-y_2)^2+(x_3-y_3)^2+(x_4-y_4)^2+\ldots\ldots(x_{13}-y_{13})^2}$

ED $= \sqrt{0.00000000032}$, **where n = 13**

Failure Modes & Effects Analysis of Marine Main engine:

- Tabulation of components, consequences and safeguards are they associated with failure modes.
- Identification/assessment of risk is derived from looking at each component in the case of multi-unit cylinder)
- FTA- approach is commonly referred (Table 3).

Table 3. Failure mode and Effect analysis

Identification	Failure of marine main engine		
Description	A distance approach of Triskaidecagonal interval valued fuzzy number analyzed with fault detection of marine main engine		
Acceptance level of failure modes	[0.999983, 0.999999]		
Risk priority level of failure	0.999996		
Distance method	**SD**	**CD**	**ED**
	Case-1: 0.999996202 **Case:**2 0.99999837594	**LB:**1.62459814 **UB:** 0.955555556	$\sqrt{0.00000000032}$
Effects	Ship accident		
Safeguards	Prevent the malfunctions of common components and main cylinder		

4 Conclusion

Thus Having the importance of distance for Interval valued Triskaidecagonal fuzzy number; a effective distance formula is presented for its computation. The performance of the Fault tree of marine main engine is analyzing using distance formula have compared with Centroid distance, Euclidean distance, and Signed distance to appeared as a appropriate condition for Interval valued Triskaidecagonal fuzzy number and conveniently distance methods presented in the approach of FTA in Marine Ship to find the effect and causes of failure modes. Further research is needed to propose distance formula for Interval valued Triskaidecagonal fuzzy number to find out more accuracy.

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