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Fuzzy Based Breakdown Risk Evaluation of Engineering Facilities: A Case Study

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Authors' contributions

This work was carried out in collaboration between all authors. Author CCNO conceived the study and carried out the fuzzy analysis. Author SO helped in the analysis while author LN carried out the data gathering and helped to write up the paper. All authors read and approved the final manuscript.

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ABSTRACT

Breakdown is an ever present risk in engineering facilities and infrastructure. Effective maintenance reduces such risks and improves reliability of facilities, plants and infrastructure. This study introduces a new method of accessing breakdown risk using fuzzy set theory. It involves identifying twenty maintenance variables responsible for breakdown and selecting four linguistic variables to identify the conditions of the variable. Four linguistic variables were equally identified for rating the consequence/importance of the maintenance variables to breakdown. A case study, a vegetable oil refining plant, was used to test the new method. An assessment form was used to gather the conditions of the maintenance variables in the plant. Fuzzifying the conditions ratings and the consequences and using fuzzy arithmetic; a condition rating of fair was obtained for the plant. The interpretation of the result implies that the plant is expected to operate with a low reliability and fairly high risk of breakdown.

Keywords: Breakdown risk; fuzzy sets; refinery; maintenance variables; risk assessment; modeling.

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1. INTRODUCTION

Most decisions we take are taken under risk. The earliest attempt to use scientific principles to manage risk came with the discovery of the theory of probability [1]. The theory of probability was used by gamblers in managing risky actions associated with gambling [1]. For five centuries, the theory of probability formed the foundation of scientific principles for managing uncertainty. According to Ross [1], probability concepts date back to the 1500s, to the time of Cardano when gamblers recognized the rules of probability in games of chance. The theory of probability formed the basis for decision theory which was pioneered by Laplace, Hurwitz, and others [2,3]. As a matter of fact the basis of many economic theories and financial management principles is based on risk and uncertainties [4,5]. Hence, the theory of probability is at the heart of these theories and principles. Probability and stochastic models are prevalent in risk quantification and assessment. They have become the fundamental basis for informed decision-making related to risk in many areas. However, a probability model built upon classic set theory may not be able to describe some risks in the meaningful and practical way. Lack of experience data, enlarged cause-and–effect relationships and imprecise data make it difficult to assess the degree of exposure to certain risk types using only traditional probability models. Sometimes, even with a credible quantitative risk model calibrated to experience data, the cause of the risk and its characteristics may be incompletely understood.

In the mid 20th century, scientists started thinking of other ways of looking at uncertainties and vagueness. This effort paid off first with the introduction of the studies of vagueness by the philosopher Max Black in 1937 [1,6] and by the introduction of fuzzy logic by Lotfi Zadeh in 1965 [7]. The introduction of fuzzy logic has had a profound effect in our understanding and management of uncertainty. Yet there is not a perfect way of managing and averting the negative consequences of taking risky actions.

Finding a perfect way of managing risks would have averted the Asian Economic Crisis of 1997, the dot com burst of 1999, the global economic depression of 2008 etc [8,9,10]. Although there is presently no perfect way of managing risks, scientists and engineers have been making improvements in scientific tools for risk management.

The quest for improved scientific tools for managing risks and evaluating performance has led to the development of artificial neural and Bayesian network, fuzzy logic and neuro-fuzzy models, hidden Markov and decision tree models for risk management [1,11,12,13]. These models, according to Shang and Hossen [13] explicitly consider the underlying cause-and-effect relationship and recognize the unknown complexity. These newer models might do a better job in understanding and assessing certain risks such as operational risk.

As stated by Shang and Hossen [13], while well-accepted and complex quantitative models are available for risk management, these risks are normally outside the control of decision makers. If appropriate risk identification and risk control measures are in place, operational risk can be significantly mitigated, despite the lack of consensus concerning which quantitative models should be used [13]. Shang and Hossen, therefore, advocated that the use of newer approaches such as fuzzy logic may be beneficial to build and implement more appropriate operational risk models. Unlike probability theory, fuzzy logic theory admits the uncertainty of truth in an explicit way; it also can easily incorporate information described in the linguistic terms. Fuzzy logic models are more convenient for incorporating different expert opinions and more adapted to cases with insufficient and imprecise data [11,13]. They provide a framework in which experts' input and experience data can jointly assess the uncertainty and identify major issues. Using approximation and making inferences from ambiguous knowledge and data, fuzzy logic models may be used for modeling risks that are not fully understood. Some operational and emerging risks evolve quickly. According to Shang and Hossen [13], risk managers may not have enough knowledge or data for a full-blown assessment using models based on probability theory. Hence, they opined that Fuzzy logic models can be instrumental in assessing a business enterprises exposure to these risks.

Fuzzy sets and Fuzzy Logic have been applied to risk modelling and analysis in several fields. Xu et al. [14] used fuzzy synthetic evaluation approach to develop a risk assessment model for PPP projects in China. In their result, they concluded that investment in PPP highway projects in China may be considered as risky. Huang et al. [15] proposed a fuzzy decision tree approach for embedding risk assessment information into a software cost estimation model. Using his model, one may be able to determine the software cost estimate as well as the estimation error in the form of a fuzzy set. Tran et al. [16], Nieto-Morote and Ruz-Vila [17], Davis and Keller [18], Binaghi et al. [19], Gorsevski et al. [20], Ercanoglu and Gokceoglu [21] etc applied fuzzy sets to environmental hazard risk assessment, a very important application. For applications to condition monitoring of engineering facility, bridge condition assessment as an example, see Klir and Yuan [11].

This study focuses on the application of fuzzy logic and fuzzy set theory in assessing plant breakdown risk using a vegetable oil refinery in Nigeria, known as Life Vegetable Oil Company Limited, as a case study.

2. METHODOLOGY

Twenty maintenance variables responsible for plant/equipment breakdown were identified. The identified variables are shown in Table 1.

After identification, four linguistic variables namely: Poor, fair, good and excellent were created to rate the conditions of the variables. Membership functions for the four linguistic terms were developed as shown in Fig. 1.

After developing the membership functions, an assessment form was used to gather data on the performance rating of the variables of the identified case study: A vegetable oil plant.

Similarly, linguistic terms describing the importance/consequence of the variables on breakdown were developed. The linguistic terms/variables are: Low, medium, high and very high. The membership functions for the linguistic variables were developed as shown in Fig. 2.

A rating form was distributed to experts to seek their opinion on the consequences of the maintenance variables on maintenance.

Let C_i and W_i denote the fuzzy numbers representing the condition of breakdown factor i and its significance/importance respectively. Let n denote the number of breakdown factor, it follows that the fuzzy set, A, representing the general breakdown factor condition of the whole facility is given by:

$$A = \frac{\sum_{i=1}^{n} C_i W_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

Table 1. Identified maintenance variables/ breakdown factors

1. Poor work place design
2. Poor housekeeping
3. Fatigue
4. Poor motivation
5. Physical disability
6. Mental unfitness and behavioural factor
7. Poor on the job training
8. Unqualified personnel
9. Inadequate maintenance tools
10. Inexperience
11. Lack of predictive tools
12. Aged equipment
13. Poorly designed equipment
14. Low quality spares
15. Poor Communication
16. Poor interpretation of manuals
17. Unavailability of manuals
18. Maintenance procedure Violations
19. Behavioural violations
20. Poor supervision and work assignment
    work assignment

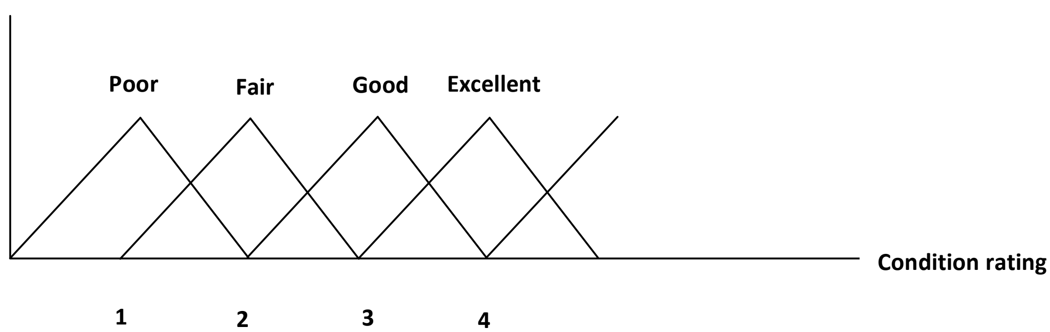

Fig. 1. Membership functions for the conditions of the maintenance variables

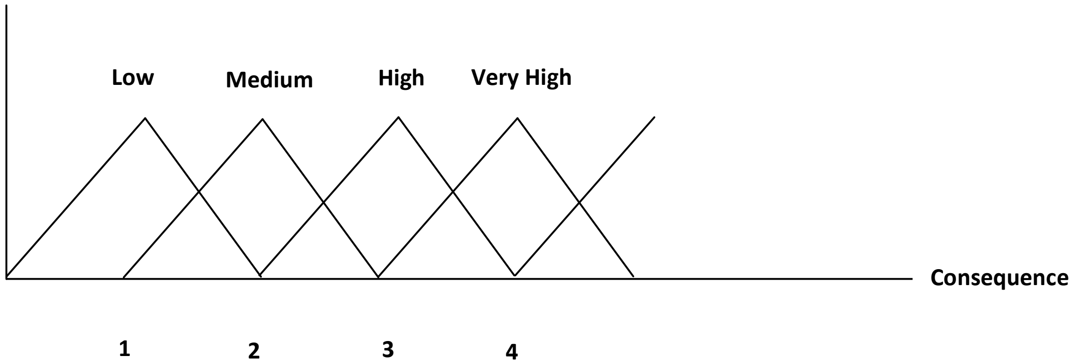

Fig. 2. Membership functions for the consequence

3. DATA PRESENTATION

The used for the fuzzy set analysis are presented in this section. The data presented in this chapter were used for the fuzzy set calculations presented in section 5.

Table 2 shows the ratings of the maintenance variables/breakdown factors and their consequence.

Table 2. Ratings of the maintenance variable in the plant

Variable	Rating	Consequence
1	2	2
2	4	3
3	3	2
4	4	1
5	2	4
6	2	4
7	3	4
8	2	4
9	1	2
10	2	3
11	2	4
12	3	3
13	2	4
14	1	4
15	2	1
16	2	2
17	2	3
18	2	4
19	2	2
20	2	3

Tables 3 and 4 show the ratings of the maintenance variables/breakdown factors and their frequency, as well as the product of the maintenance variables/breakdown factors and their consequences for the vegetable oil plant.

Table 3. Maintenance variables ratings and the frequency of occurrence

W	f
1	2
2	5
3	5
4	8

Table 4. The product (WC) and the frequency of occurrence

WC	f
1X2	2
1X4	2
2X2	3
2X3	4
2X4	6
3X3	1
3x4	2

3.1 Expert Opinion on Significance of Breakdown Causes

After gathering data from twenty experts, the average consensus among the experts on the significance or importance of the maintenance variables/ breakdown factors on plant/equipment breakdown is shown in Table 5.

4. RESULTS AND DISCUSSION

From the data presented in chapter four, fuzzy arithmetic was used to determine the overall assessment of the condition of the maintenance variables responsible for breakdowns in the plant. The computations are hereby presented.

Table 5. Breakdown factor and their significance/importance

Breakdown factor	Significance / Importance
1. Poor work place design	Medium
2. Poor housekeeping	High
3. Fatigue	Medium
4. Poor motivation	Low
5. Physical disability	Very High
6. Mental unfitness and behavioural factor	Very High
7. Poor on the job training	Very High
8. Unqualified personnel	Very High
9. Inadequate maintenance tools	Medium
10. Inexperience	High
11. Lack of predictive tools	Very High
12. Aged equipment	High
13. Poorly designed equipment	Very High
14. Low quality spares	Very High
15. Poor Communication	Low
16. Poor interpretation of manuals	Medium
17. Unavailability of manuals	High
18. Maintenance procedure Violations	Very High
19. Behavioural violations	Medium
20. Poor supervision and work assignment	High

Table 6. Fuzzy multiplication of membership functions

Fuzzy multiplication	Equivalence
Low X Poor	1 X 1
Low X Fair	1 X 2
Low X Good	1 X 3
Low X Excellent	1 X 4
Medium X Poor	2 X 1
Medium X Fair	2 X 2
Medium X Good	2 X 3
Medium X Excellent	2 X 4
High X Poor	3 X 1
High X Fair	3 X 2
High X Good	3 X 3
High X Excellent	3 X 4
Very High X Poor	4 X 1
Very High X Fair	4 X 2
Very High X Good	4 X 3
Very High X Excellent	4 X 4

Considering the fact that fuzzy multiplication is commutative, we obtain:
1 x 2 = 2 x 1, 1 x 3= 3 x 1, etc. Hence we hereby present the multiplication results

4.1 Preliminaries (Fuzzy Multiplication)

The preliminary computation involves obtaining the results of the fuzzy multiplication presented in Table 6.

4.1.1 Low X Poor (1X1)

Let A=Low and B= Poor

$$\mu_{A(\cdot)B}(x) = \begin{cases} 0, & x \le 0 \\ \sqrt{x}, & 0 < x \le 1 \\ 2 - \sqrt{x}, & 1 < x \le 2 \\ 0, & x > 2 \end{cases} \quad (2)$$

4.1.2 Low X Fair (1X2)

Let A=Low and B= Fair

$$\mu_{A(\cdot)B}(x) = \begin{cases} 0, & x \le 0 \\ -0.5 + \sqrt{0.25 + x}, & 0 < x \le 2 \\ 2.5 - \sqrt{0.25 + x}, & 2 < x \le 6 \\ 0, & x > 6 \end{cases} \quad (3)$$

4.1.3 Low X Good (1X3)

Let A=Low and B= Good

$$\mu_{A(\cdot)B}(x) = \begin{cases} 0, & x \le 0 \\ -1 + \sqrt{1 + x}, & 0 < x \le 3 \\ 3 - \sqrt{1 + x}, & 3 < x \le 8 \\ 0, & x > 8 \end{cases} \quad (4)$$

4.1.4 Low X Excellent (1X4)

Let A=Low and B= Excellent

$$\mu_{A(\cdot)B}(x) = \begin{cases} 0, & x \le 0 \\ -1.5 + \sqrt{2.25 + x}, & 0 < x \le 4 \\ 3.5 - \sqrt{2.25 + x}, & 4 < x \le 10 \\ 0, & x > 10 \end{cases} \quad (5)$$

4.1.5 Medium X Fair (2X2)

Let A=Medium and B= Fair

$$\mu_{A(\cdot)B}(x) = \begin{cases} 0, & x \le 1 \\ -1 + \sqrt{x}, & 1 < x \le 4 \\ 3 - \sqrt{x}, & 4 < x \le 9 \\ 0, & x > 9 \end{cases} \quad (6)$$

4.1.6 Medium X Good (2X3) or (3x2)

Let A=Medium and B= Good

$$\mu_{A(\cdot)B}(x) = \begin{cases} 0, & x \le 2 \\ -1.5 + \sqrt{0.25 + x}, & 2 < x \le 6 \\ 3.5 - \sqrt{0.25 + x}, & 6 < x \le 12 \\ 0, & x > 12 \end{cases} \quad (7)$$

4.1.7 Medium X Excellent (2X4) or (4x2)

Let A=Medium and B= Excellent

$$\mu_{A(\cdot)B}(x) = \begin{cases} 0, & x \leq 3 \\ -2+\sqrt{1+x}, & 3 < x \leq 8 \\ 4-\sqrt{1+x}, & 8 < x \leq 15 \\ 0, & x > 15 \end{cases} \quad (8)$$

4.1.8 High X Good (3X3)

Let A=High and B= Good

$$\mu_{A(\cdot)B}(x) = \begin{cases} 0, & x \leq 4 \\ -2+\sqrt{x}, & 4 < x \leq 9 \\ 4-\sqrt{x}, & 9 < x \leq 16 \\ 0, & x > 16 \end{cases} \quad (9)$$

4.1.9 High X Excellent (3X4) or (4X3)

Let A=High and B= Excellent

$$\mu_{A(\cdot)B}(x) = \begin{cases} 0, & x \leq 6 \\ -2.5+\sqrt{0.25+x}, & 6 < x \leq 12 \\ 4.5-\sqrt{0.25+x}, & 12 < x \leq 20 \\ 0, & x > 20 \end{cases} \quad (10)$$

4.1.10 Very High X Excellent (4X4)

Let A=Very High and B= Excellent

$$\mu_{A(\cdot)B}(x) = \begin{cases} 0, & x \leq 9 \\ -3+\sqrt{x}, & 9 < x \leq 16 \\ 5-\sqrt{x}, & 16 < x \leq 25 \\ 0, & x > 25 \end{cases} \quad (11)$$

4.2 Obtaining the Intervals for the Results of the Fuzzy Multiplication

Before fuzzy summation, the intervals for the product of the fuzzy multiplications according to Table 4, which was calculated in section 4.1, must be obtained. The obtained intervals are hereby presented.

4.2.1 Obtained interval for 1X2

$$1 \times 2 = [\alpha^2 + \alpha, \alpha^2 - 5\alpha + 6]$$

$$2 \times (1 \times 2) = [2\alpha^2 + 2\alpha, 2\alpha^2 - 10\alpha + 12]$$

4.2.2 Obtained interval for 1X4

$$1 \times 4 = [\alpha^2 + 3\alpha, \alpha^2 - 7\alpha + 10]$$

$$2 \times (1 \times 4) = [2\alpha^2 + 6\alpha, 2\alpha^2 - 14\alpha + 20]$$

4.2.3 Obtained interval for 2X2

$$2 \times 2 = [\alpha^2 + 2\alpha + 1, \alpha^2 - 6\alpha + 9]$$

$$3 \times (2 \times 2) = [3\alpha^2 + 6\alpha + 3, 3\alpha^2 - 18\alpha + 27]$$

4.2.4 Obtained interval for 2X3

$$2 \times 3 = [\alpha^2 + 3\alpha + 2, \alpha^2 - 7\alpha + 12]$$

$$4 \times (2 \times 3) = [4\alpha^2 + 12\alpha + 8, 4\alpha^2 - 28\alpha + 48]$$

4.2.5 Obtained interval for 2X4

$$2 \times 4 = [\alpha^2 + 4\alpha + 3, \alpha^2 - 8\alpha + 15]$$

$$6 \times (2 \times 4) = [6\alpha^2 + 24\alpha + 18, 6\alpha^2 - 48\alpha + 90]$$

4.2.6 Obtained interval for 3X3

$$3 \times 3 = [\alpha^2 + 4\alpha + 4, \alpha^2 - 8\alpha + 16]$$

4.2.7 Obtained interval for 3X4

$$3 \times 4 = [\alpha^2 + 5\alpha + 6, \alpha^2 - 9\alpha + 20]$$

$$2 \times (3 \times 4) = [2\alpha^2 + 10\alpha + 12, 2\alpha^2 - 18\alpha + 40]$$

4.3 Fuzzy Addition or Summation

Here the results of the multiplication and the membership functions representing the consequences of importance of the maintenance variable are summed.

4.3.1 Summation of consequences (W)

$$\sum W = 2 \times [\alpha, 2-\alpha] + 5 \times [\alpha+1, 3-\alpha] + 5 \times [\alpha+2, 4-\alpha] + 8 \times [\alpha+3, 5-\alpha]$$

$$\sum W = [2\alpha, 4-2\alpha] + [5\alpha+5, 15-5\alpha] + [5\alpha+10, 20-5\alpha] + [8\alpha+24, 40-8\alpha]$$

$$\sum W = [20\alpha + 39, 79 - 20\alpha]$$

4.3.2 Summation of WC

$$\sum WC = [2\alpha^2 + 2\alpha, 2\alpha^2 - 10\alpha + 12] + [2\alpha^2 + 6\alpha, 2\alpha^2 - 14\alpha + 20] + [3\alpha^2 + 6\alpha + 3, 3\alpha^2 - 18\alpha + 27] + [4\alpha^2 + 12\alpha + 8, 4\alpha^2 - 28\alpha + 48] + [6\alpha^2 + 24\alpha + 18, 6\alpha^2 - 48\alpha + 90] + [\alpha^2 + 4\alpha + 4, \alpha^2 - 8\alpha + 16] + [2\alpha^2 + 10\alpha + 12, 2\alpha^2 - 18\alpha + 40]$$

$$\sum WC = [20\alpha^2 + 64\alpha + 45, 20\alpha^2 - 144\alpha + 253]$$

4.4 Fuzzy Division

$$\frac{\sum WC}{\sum W} = [\frac{20\alpha^2 + 64\alpha + 45}{79 - 20\alpha}, \frac{20\alpha^2 - 144\alpha + 253}{20\alpha + 39}]$$

$$\frac{20\alpha^2 + 64\alpha + 45}{79 - 20\alpha} = x, \qquad \alpha = -(1.6 + 0.55x) \pm \sqrt{0.3025x^2 + 5.31625x + 0.31}$$

$$\frac{20\alpha^2 - 144\alpha + 253}{20\alpha + 39} = x, \qquad \alpha = (3.6 + 0.5x) \pm \sqrt{0.3025x^2 + 5.31625x + 0.31}$$

$$\mu_C(x) = \begin{cases} 0, & x \le 0.8 \\ = -(1.6 + 0.55x) + \sqrt{0.3025x^2 + 5.31625x + 0.31}, & 0.8 < x \le 3.2 \\ (3.6 + 0.50x) - \sqrt{0.3025x^2 + 5.31625x + 0.31}, & 3.2 < x \le 4.2 \\ 0, & x > 4.2 \end{cases} \qquad (12)$$

4.5 Overall Assessment

The membership function for the overall assessment of the facility (C), shown in Equation (12), could be rewritten as:

$$C = \left\{\frac{0}{0} + \frac{0.3}{1} + \frac{0.8}{2} + \frac{0.7}{3} + \frac{0.5}{4} + \frac{0.2}{5}\right\}$$

The membership functions for the conditions, Excellent (E), Good (G), Fair (F) and Poor (P) are given by:

$$E = \left\{\frac{0}{0} + \frac{0}{1} + \frac{0}{2} + \frac{0}{3} + \frac{1}{4} + \frac{0}{5}\right\}$$

$$G = \left\{\frac{0}{0} + \frac{0}{1} + \frac{0}{2} + \frac{1}{3} + \frac{0}{4} + \frac{0}{5}\right\}$$

$$F = \left\{\frac{0}{0} + \frac{0}{1} + \frac{1}{2} + \frac{0}{3} + \frac{0}{4} + \frac{0}{5}\right\}$$

$$P = \left\{\frac{0}{0} + \frac{1}{1} + \frac{0}{2} + \frac{0}{3} + \frac{0}{4} + \frac{0}{5}\right\}$$

In order to determine where amongst Excellent (E), Good (G), Fair (F) and Poor (P) that the overall assessment of the facility (C) belongs, the Euclidean distance technique, d, would be used here. Hence, for membership function excellent (E), the distance (d) to C is given by:

$$d(C,E) = (\sum_{k=1}^{5} [C(k) - E(k)]^2)^{\frac{1}{2}}$$

$$d(C,E) = (0^2 + 0.3^2 + 0.8^2 + 0.7^2 + 0.5^2 + 0.2^2)^{\frac{1}{2}}$$

$$d(C,E) = (1.51)^{\frac{1}{2}}$$

$$d(C,E) = 1.2288$$

For membership function Good (G), the distance (d) to C is given by:

$$d(C,G) = (\sum_{k=1}^{5} [C(k) - G(k)]^2)^{\frac{1}{2}}$$

$$d(C,G) = (0^2 + 0.3^2 + 0.8^2 + 0.3^2 + 0.5^2 + 0.2^2)^{\frac{1}{2}}$$

$$d(C,G) = (1.11)^{\frac{1}{2}}$$

$$d(C,G) = 1.0536$$

For membership function Fair (F), the distance (d) to C is given by:

$$d(C,F) = (\sum_{k=1}^{5}[C(k) - F(k)]^2)^{\frac{1}{2}}$$

$$d(C,F) = (0^2 + 0.3^2 + 0.2^2 + 0.7^2 + 0.5^2 + 0.2^2)^{\frac{1}{2}}$$

$$d(C,F) = (0.91)^{\frac{1}{2}}$$

$$d(C,F) = 0.9539$$

For membership function Poor (P), the distance (d) to C is given by:

$$d(C,P) = (\sum_{k=1}^{5}[C(k) - P(k)]^2)^{\frac{1}{2}}$$

$$d(C,P) = (0^2 + 0.7^2 + 0.8^2 + 0.7^2 + 0.5^2 + 0.2^2)^{\frac{1}{2}}$$

$$d(C,P) = (1.91)^{\frac{1}{2}}$$

$$d(C,P) = 1.3820$$

From the above calculations, C is closest to F, hence from the overall assessment, the condition of the maintenance variables in the facility is rated Fair. Thus the facility has a fairly high risk of breakdown.

4.6 Discussion

From the results, it is apparent that the facility is not very healthy, hence the overall rating of Fair for the conditions of the maintenance variables. The old age of the refinery may have contributed significantly to its low rating. Since the refinery was established in 1985, it is therefore expected that the refinery should undergo a major overhaul and turnaround maintenance. Also the quality of the spares may have played an important role because sourcing the original spare parts is not easy for the company since the machines are outdated and newer models of the machines, whose parts are readily available, are being used by newer refineries. As noted by Remy and Nwobi-Okoye [22], maintenance errors affect adversely the reliability and efficiency of plants and equipment and eliminating such errors would help to improve the overall rating of any plant or equipment with respect to breakdown risk.

In a similar application, fuzzy sets were used for bridge condition assessment [11]. In the bridge assessment case study, three linguistic variables namely: poor, fair and good were used for the condition assessment rating. The overall assessment rating for the case study was fair. Hence, the bridge was in a fair state and not in dire need of demolition and replacement. Comparing this result with the application for bridge assessment, the condition of the plant is in a worst state than the bridge. This method of assessment could be applied to several other fields such as software performance evaluation, material selection etc.

5. CONCLUSIONS

There is no perfect equipment, plant or facility. Hence, operators should expect breakdowns whenever plants are in operation. But the goal of management is to minimize such breakdowns as much as possible. Devising metrics for estimating the reliability or breakdown risks of plants would help managers improve plant performance. As many plants, especially in developing countries, keep little or no records, calculating plant reliability is often difficult. Fuzzy logic which requires minimal data would readily bridge the gap in breakdown risk assessment of plants.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ross T. Fuzzy logic with engineering applications. John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England; 2004.
2. Zima-Bockarjova M, Sauhats A, Vempers G, Tereskina I. On application of the cooperative game theory to energy supply system planning. 7th International Conference on the European Energy Market (EEM), 23-25 June; 2010.
3. Medjoudj R, Laifa A, Aissani D. Decision making on power customer satisfaction and enterprise profitability analysis using the analytic hierarchy process. International Journal of Production Research. 2012;50(17):4793-4805.
4. Pandey IM. Financial management. Vikas Publishing House Pvt Limited, Uttar Pradesh, India; 2009.
5. Mankiw NG, Taylor MP. Economics, Thomson Learning, London, UK; 2009.

6. Black M Vagueness. An exercise in logical analysis. Philosophy of Science. 1937;4(4): 427-455.
7. Zadeh L. Fuzzy sets. Inf. Control. 1965;8:338–353.
8. Higgott R. The Asian economic crisis: A study in the politics of resentment. New Political Economy. 1998;3(3):333-356.
9. Christopherson S, van Jaarsveld D. New media after the dot com bust. International Journal of Cultural Policy. 2006;11(1):77-93.
10. Kotz DM. The financial and economic crisis of 2008: A systematic crisis of neoliberal capitalism. Review of Radical Political Economics. 2009;41(3):305-317.
11. Klir G, Yuan B. Fuzzy sets and fuzzy logic: Theory and applications. Prentice Hall, Upper Saddle River, NJ; 1995.
12. Nwobi-Okoye CC, Okiy S, Igboanugo AC. Performance evaluation of Multi-Input-Single-Output (MISO) production process using transfer function and fuzzy logic: Case study of a Brewery. Ain Shams Engineering Journal; 2015. DOI: 10.1016/j.asej.2015.07.008
13. Shang K, Hossen Z. Applying fuzzy logic to risk assessment and decision-making. Casualty Actuarial Society, Canadian Institute of Actuaries, Society of Actuaries; 2013.
14. Xu Y, Yeung JF, Chan AP, Chan DW, Wang SQ, Ke Y. Developing a risk assessment model for PPP projects in China — A fuzzy synthetic evaluation approach. Automation in Construction. 2010;19:929–943.
15. Huang S, Lin C, Chiu N. Fuzzy decision tree approach for embedding risk assessment information into software cost estimation model. Journal of Information Science and Engineering. 2006;22:297-313.
16. Tran LT, Knight CG, O'neill RV, Smith ER, Riitters KH, Wickham J. Fuzzy decision analysis for integrated environmental vulnerability assessment of the mid-atlantic region. Environmental Management. 2002;29(6):845–859.
17. Nieto-Morote A, Ruz-Vila F. A fuzzy approach to construction project risk assessment. International Journal of Project Management. 2011;29:220–231.
18. Davis TJ, Keller CP. Modelling uncertainty in natural resource analysis using fuzzy sets and Monte Carlo simulation: Slope stability prediction. International Journal of Geographical Information Science. 1997;11(5):409-434.
19. Binaghi E, Luzi L, Madella P, Rampini A. Slope instability zonation: A comparison between certainty factor and fuzzy Dempster-Shafer approaches. Natural Hazards. 1998;17:77–97.
20. Gorsevski PV, Gessler PE, Jankowski P. Integrating a fuzzy k-means classification and a Bayesian approach for spatial prediction of landslide hazard. Journal of Geographical Systems. 2003;5(3):223-251.
21. Ercanoglu M, Gokceoglu C. Assessment of landslide susceptibility for a landslide-prone area (north of Yenice, NW Turkey) by fuzzy approach. Bull. Eng, Gol. Env. 2001;41(6):720–730.
22. Remy U, Nwobi-Okoye CC. Maintenance error oriented reliability determination model. Pacific Journal of Science and Technology. 2009;10(2):303-310. Available:http://www.akamaiuniversity.us/PJST10_2_303.pdf

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