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Failure analysis of pump piping system using DEMATEL SVN methodology

R. Sundareswaran[1*], S. Vijayan[2], Sneha S[2], Srinath Venkatesh[2], Vishnu Prasad P R[2], Viswapriya G[2] , Lakshmi Narayan Mishra[3] and Said Broumi [4]

[1]Department of Mathematics, Sri Sivasubramaniya Nadar College of Engineering, Chennai, India

[2]Department of Mechanical Engineering, Sri Sivasubramaniya Nadar College of Engineering, Chennai, India

[3]Department of Mathematics, School of Advanced Sciences, Vellore Institute of Technology (VIT, Vellore), India

[4]Laboratory of Information Processing, Faculty of Science Ben M'Sik, University Hassan II, B.P 7955, Sidi Othman, Casablanca, Morocco., e-mail: broumisaid78@gmail.com

* Correspondence: sundareswaranr@ssn.edu.in

Abstract: Piping systems tend to malfunction when a set parameter goes off the mark. The parameters which directly affect the structure and working of a pump piping system are known as critical factors. The processes influenced by these factors and consequently the underlying cause of failure have been thoroughly investigated through research. The interrelationship between them, however, remains a mystery. The ability of the plant supervisor or worker to combine their vast theoretical knowledge with actual data will be enhanced by exposing these cause-effect correlations among the problems commonly encountered in pump piping systems. The SVN DEMATEL (Decision-Making Trial-and-Evaluation Laboratory) approach is used in this study to determine the predominant causes of pump piping system failures. By considering a group of expert perspectives to create a cause-and-effect relationship diagram, the DEMATEL approach allows one to determine and assess the most significant element. SVN sets in DEMATEL, likewise, eliminate uncertainty when making conclusions concerning failure relationships from the judgements provided by experts [1]. The focus of the failure analysis was divided into six groups: selection of pump, design of pump, construction, operation/maintenance, piping errors and commissioning of the system. A total of 26 factors were identified and were assigned to a relevant group. Each factor was further categorized into four levels based on the degree of influence using the methodology presented in this study. It was found that "Temperature" has the highest degree of influence over the other criteria whereas criteria like "Pressure" and "Power Supply" tend to be influenced by other factors. The proposed SVN-DEMATEL method would be suitable for qualitative analysis of different industrial systems.

Keywords: DEMATEL model; Pump piping system; failure analysis; single-valued neutrosophic sets; linguistic variable.

1. Introduction

The decision-making trial and evaluation laboratory (DEMATEL) is a comprehensive analytical method for constructing a structural model indicating the causal relationships existent between complex factors [3]. The initial goal was to identify integrated solutions employing matrices and graphs to the fragmented and conflicting phenomena of world civilizations [4], because it is practical to see the structure of complicated causal interactions. The DEMATEL approach has become quite popular among diverse fields. It is based on digraphs, which may split the related components into two groups: cause and effect. Digraphs, or directed graphs, are more useful than directionless graphs which can show the directed links between subsystems. A digraph can be used to show a communication network or a dominance relationship between people [5]. The digraph depicts a basic notion of contextual relation among the system's elements, with the numeral indicating the degree of influence [6]. Hence, this method can convert the relationship between the causes and effects of factors into an intelligible structural model of the system.

The DEMATEL approach uses linguistic variables to perform a weighted analysis of the decision maker's opinion. It was conclusively shown that DEMATEL has a higher Spearman ranking coefficient in comparison to other multi criteria decision making (MCDM) analysis [7]. This implies that the relationship between two variables can be described using a monotonic function. This makes it more relevant to the industry as most of the parameters under the scope of analysis have a nonlinear connection and regressive in nature.

However, the linguistic terms pose a major setback. To begin with, linguistic terms are not ideally suited to provide an in-depth analysis and a judgement further on since the information provided is often vague and incomplete [8]. Because of this incomplete information, the judgements of the decision makers might be misconstrued. To deal with the ambiguities that come with such estimation, it's a good idea to transform these linguistic terms into fuzzy numbers. A linguistic variable contains unique values (linguistic values) that depict the form of phrases or sentences one can find in a natural language [9]. This is commonly known as the fuzzy set. The generalization of fuzzy set lead to the development of another important analysis tool called "neutrosophic set". To curtail its application to real life scientific problems, it was further developed to single values neutrosophic set (SVNS). Owing to the ease in application of SVNSs, they sets have been adapted in other scientific areas such as information technology, information system and decision support system for example, relational database systems, semantic web services, financial data set detection, new economy's growth, decline analysis and etc [10-15].

1.1. Literature Review

The following section summarizes the results and gaps identified by various other research work related to neutrosophic sets, DEMATEL and pipeline failure analysis. Previous work mainly focuses on the integration of DEMATEL with other MCDM analysis methods. However, SVNS were seldom included. There has been certain research work aimed at different applications which used SVNS, but it was still lacking in proficiency as quadrant analysis was not used. The table given below summarizes the recent research and the corresponding research gaps. Owing to these limitations, this paper aims to provide an integrated SVN-DEMATEL method to investigate pipeline failure.

The eight-step procedure of DEMATEL is followed wherein the linguistic variables are designated by truth, indeterminacy, and falsity membership [16].

Table 1. Literature Review Summary.

Authors	**Method**	**Application**	**Research gap**
Betty Chang [17]	Fuzzy DEMATEL method	Supply chain management (SCM)	Does not employ SVNs to state assumptions in the dataset– No quadrant analysis
GülçinBüyüközkan [18]	Integrated DEMATEL-ANP approach	Renewable energy resources	Integration of DEMATEL with fuzzy logic – No quadrant analysis
EmreAkyuz [19]	fuzzy DEMATEL method	Shipboard operations (Operational hazards)	Shows only cause-effect diagram – does not portray the basic concept of contextual relationship and strengths of influence among the elements or criteria.
Yuan-WeiDu [20]	Hierarchical DEMATEL method	Complex Systems	Integration of DEMTEL with other methods (fuzzy logic, SVNs) This paper establishes a method to approach complex problems with several factors.

1.2. Future Scope

The presented study can be used as a basis for ranking data based on their significance, which consecutively can be used to generate machine learning models for the system. The output of this method could be used to further train an AI model to make an informed decision about a certain process. This could be incorporated in adaptive control systems. On a much rudimentary level, the machine can be trained to display the most significant control parameters that can be controlled to reduce errors using which, a trained professional can make the decisions.

2. SVN-DEMATEL

The algorithm used in DEMATEL is the framework of the proposed SVN-DEMATEL. Instead of real numbers representing the linguistic variables as seen in the traditional methodology, SVNS are used to deal with uncertainty. Apart from the inclusion of SVNS, the proposed method also incorporates the relative importance of the decision-maker weight. Boran et al. [21] suggested a proportion equation to approximate the relative weights of each decision maker. This bears accurate and crisper computational results rather than using equal weights for all decision makers. The three memberships of the linguistic variables are re-defined into real numbers to aid mathematical calculations. Radwan and Fouda [22] proposed the concept of average as an equation which is employed in this proposed method. Unlike the original DEMATEL, this method rules out the need to find multiplicative inverse of a matrix. The establishment of four types of criteria, also known as quadrant analysis, is extended by this method using causal-effect diagram.

2.1 Proposed SVN-DEMATEL algorithm:

Step-1. Construction of direct-relation matrix

The critical factors relevant to the study are identified and group into a matrix X of size M x M where M is the number of criteria. This matrix depicts the interrelation between pairs of elements using a linguistic scale. Hence, a total of N^2 relations are obtained [23].

Step-2. Finding the relative weights of decision-makers.

The aggregated crisp matrix is formulated in consideration of the weight of each decision-maker's judgment. Based on the importance of each decision maker, an SVNN is assigned which is used to calculate the overall distinctive weights [24]. Because decision-makers' work experience and expertise fluctuate regularly, this is critical to the success of research analysis.

The linguistic variables used for relative importance weights of decision-makers and their respective SVNNs are shown in Table 2 [25]. If the SVNN for the kth expert's relative importance is $\lambda_k = (T_k, I_k, F_k)$, then the value of the relative weight for the kth expert can be calculated using the equation:

$$\lambda_k = \frac{T_k(x) + I_k(x)\big((T_k(x)/T_k(x) + F_k(x))\big)}{\sum_{k=1}^{l} T_k(x) + I_k(x)\big((T_k(x)/T_k(x) + F_k(x))\big)} \quad \text{------------(1)}$$

($\lambda_k \geq 0, \sum_{k=1}^{l} \lambda_k = 1$, l is the number of decision makers)

Sample Calculation:

Value of denominator $(A) = [0.9 + 0.1(0.9/1)] + [0.5 + 0.4(0.5/0.95)] + [0.35 + 0.6(0.35/1.05)] = 2.250526316$

For example, substituting the values of Linguistic Variable "Very important" and that of A

$$\lambda_{k1} = [0.9 + 0.1(0.9/1)]/A = \mathbf{0.4398971001}$$

Step-3. Construction of aggregated direct-relation matrix (AGDRM)

The opinions of each decision makers are compiled into initial direct relation matrices. By including the relative weights, they can be merged into a collective matrix that represent the overall correlations between the factors. Let the SVN given by the kth expert on the assessment of criterion i on j be $z_k\ (i,j)\ =\ (T_k\ (i,j), I_k\ (i,j), F_k\ (i,j))$ [20]. The procedure of Single Valued Neutrosophic Set Weighted Aggregation (SVNSWA) is used [21]. Note that x(i,j) represents the influence level of criterion i on j.

$$a_{ij}\ =\ SVNSWA\ (z_1\ [i,j], z_2\ [i,j], \ldots, z_k\ [i,j]\ )$$

$$= \sum \lambda_k z_{ij}^k\ =\ [1 - \prod_{k=1}^{l}(1 - T_j)^{w_j}, \prod_{k=1}^{l}(I_j)^{w_j}, \prod_{k=1}^{l}(F_j)^{w_j}\ ] \quad \text{------------(2)}$$

$$i\ =\ 1, 2, 3, 4, \ldots, m;\ j\ =\ 1, 2, 3, 4, \ldots, n,$$

Step-4.. Convert the SVNNs to real numbers

Using the following equation, convert the aggregated single neutrosophic relation matrix to a real number matrix:

$$P(z)\ =\ [3\ +\ T\ -\ 2I - F]\ /\ 4 \quad \text{-------------(3)}$$

Step-5. Normalization of AGDRM

Normalized DRM (matrix N) is computed using the equation:

$$N\ =\ k\ \times\ R \quad \text{-------------(4)}$$

where, $k = \min((1/max \sum_{j=1}^{n}|a_{ij}|\ ),\ (1/max \sum_{i=1}^{n}|a_{ij}|\ ))$, i, $j \in$ {1,2,3, . . ., n}
and R is the Aggregated DRM with real numbers. -------------(5)

Step-6.. The Total Relation Matrix, T, is computed using the equation below:

$$T\ =\ N\ (I\ -\ N)^{-1} \quad \text{-------------(6)}$$

('I' is an identity matrix of rank M)

Step-7. Construct a causal diagram. Using the following equation, calculate H and V from TRM.

Given T,

$$T\ =\ \left[\ t_y\right]_{n\,X\,n} \quad i,j\ =\ 1,2, \ldots . n,\ \textit{and using the following equation:}$$

$$\text{H}= \left[\sum_{i=1}^{n} t_y\right]_{l\,X\,n}\ =\ [t(j)]_{l\,X\,n}, \quad \text{------------(7)}$$

$$\text{V}=\left[\sum_{i=1}^{n} t_y\right]_{n\,X\,l} = [t(i)]_{n\,X\,l} \quad \text{------------(8)}$$

where H signifies the total number of rows in the matrix and V denotes the total number of columns. As a result, the values of $(H + V)$ and $(H - V)$ are computed separately in different columns. If (H-V) is positive and $(H + V)$ is large, a criterion is classified as a cause group. It's classified as an effect group if $(H - V)$ is negative and $(H + V)$ is small [28].

8. Segregation of criteria

The values of $(H + V)$ and $(H - V)$ are employed as Cartesian plane coordinates $(H + V, H - V)$ to divide the criteria into four classes [29].

The case of a pump piping system failure is presented in detail.

2.2 Criteria and Linguistic scale

Criteria that influence the pump piping system are identified and it is represented in the form of fish bone diagram shown in Figure 1. There are 26 such criteria based on:

Selection of pump: Working fluid (F1), Design pressure (F2), Temperature (F3), Geographical location (F4),

Construction: Misalignment (F5), Support placement (F6), Valve placement (F7), Pipe strain (F8), Coupling (F9),

Operation and Maintenance: Power overloading (F10), Instrument malfunction (F11), Pressure head (F12), Lubrication (F13), Temperature (F14),

Piping errors: Valve placement (F15), Temporary strainer (F16), Layout (F17), Pipe run (F18), Water hammering (F19),

Design of Pump: Working fluid (F20), Vibration damping (F21), Material of casing (F22), Pressure head (F23),

Commissioning: Nature of priming (F24), Power supply (F25) and Strainer clogging (F26).

Table 2 represents the five-point linguistic scale using which these criteria will be assessed. The pairwise comparison method is made use in judgments.

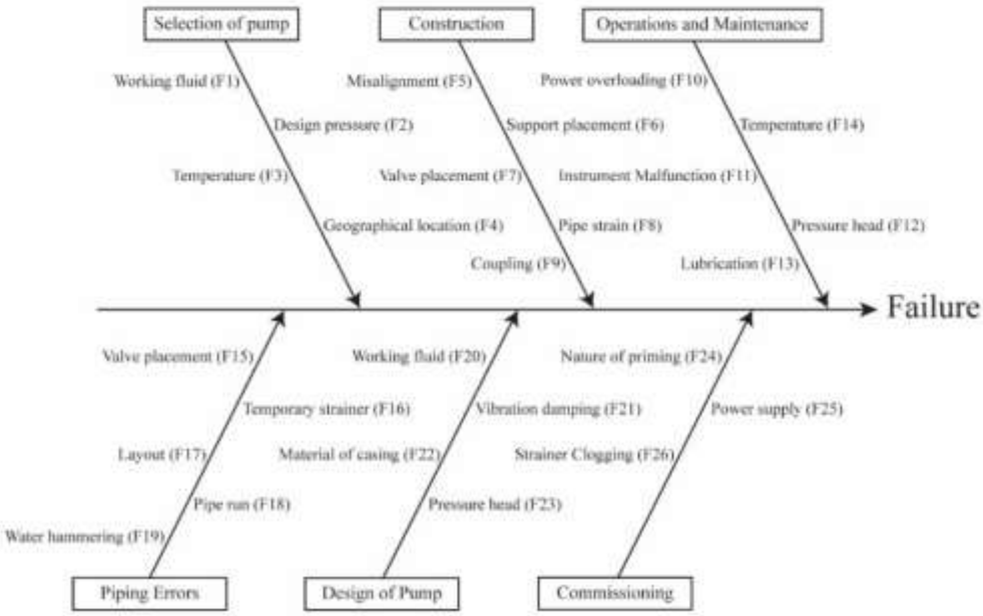


Fig. 1. Ishikawa Diagram of the Pump piping system failures.

Linguistic variable for relative importance	SVNN {T, I, F }
Very important (VI)	{0.90, 0.10, 0.10}
Important (I)	{0.80, 0.20, 0.15}
Medium (M)	{0.50, 0.40, 0.45}
Unimportant (UI)	{0.35, 0.60, 0.70}
Very unimportant (VUI)	{0.10, 0.80, 0.90}

Table 2 Linguistic Variable for relative importance of decision makers [19]

Linguistic terms for level of influence	SVNS {T, I, F }
None (1)	{0.00, 1.00, 1.00}
Low (2)	{0.20, 0.85, 0.80}
Medium (3)	{0.40, 0.65, 0.60}
High (4)	{0.60, 0.35, 0.40}
Very high (5)	{0.80, 0.15, 0.20}

Table 3 Linguistic Scale used in study [24]

2.3 Illustrations

Piping Engineer:

Piping engineers are engineering professionals who are responsible for the design of piping systems that transport fluids such as oil, gas, water, and waste from one location to another. Their work involves design, material selection, stress analysis and commissioning of piping systems.

Project Manager:

Project managers oversee planning, procurement, and execution of any activity with a defined scope, start, and end date.

Quality Engineer:

A quality engineer is a professional who manages and implements the quality assurance and control systems of a company. Piping engineers don't work independently but rather work as a team comprising of members from piping, mechanical, process instrumentation divisions. To ensure the smooth coordination within the team as well as suggest corrective measures, a quality engineer is crucial to the team.

Maintenance Engineer:

In industries, maintenance engineers oversee keeping equipment and machinery working smoothly. They are required to constantly upkeep the support equipment such as valves and FRL while keeping an eye on the pipe layout. Since long maintenance times could prove to be a costly affair to the company, maintenance engineers need to have a solid understanding about the system to perform quick actions when needed.

All decision-makers specialize in assessing pump piping system. The decision-makers were formally approached by letter to rank criteria based on the degree of influence over other factors utilizing the linguistic scale to evaluate pipeline failures. The data thus obtained from them are applied to the proposed SVNS-DEMATEL method.

2.4 Implementation

The following computations are carried out using the suggested algorithm:

Step - 1. Construction of Direct Relation Matrix for each individual decision-maker i.e., DM1, DM2 and DM3 give their judgment regarding the influence of the criteria on failure in pump piping systems. The following table shows the initial direct relation matrix i.e., judgments of one of the decision-maker. Linguistic terms are involved in the matrix to represent the correlations between the criteria as mentioned below.

Step -2. Finding the relative weights of decision-makers. λ, which represents the relative weights of decision-makers are computed using equation 1.

Table 4. Judgments of criteria (DM1)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
1	x	5	5	5	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	5	5	5	5	2	2	2
2	5	X	5	5	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	5	5	5	5	2	2	2
3	5	5	x	5	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	5	5	5	5	2	2	2
4	3	3	3	x	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3
5	1	1	1	1	x	5	5	5	5	5	5	5	5	5	2	2	2	2	2	2	2	2	2	4	4	4
6	1	1	1	1	5	x	5	5	5	3	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3
7	1	1	1	1	3	3	x	3	3	3	3	3	3	3	4	4	4	4	4	1	1	1	1	3	3	3
8	3	3	3	3	3	3	3	x	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	3	3	3
9	3	3	3	3	3	3	3	3	x	3	3	3	3	3	2	2	2	2	2	3	3	3	3	4	4	4
10	3	3	3	3	3	3	3	3	4	x	5	5	5	5	1	1	1	1	1	2	2	2	2	5	5	5
11	1	1	1	1	4	4	4	4	4	5	x	5	5	5	3	3	3	3	3	1	1	1	1	5	5	5
12	5	5	5	5	5	5	5	5	5	5	5	x	5	5	3	3	3	3	3	5	5	5	5	5	5	5
13	3	3	3	3	3	3	3	3	3	4	4	4	x	4	2	2	2	2	2	1	1	1	1	2	2	2
14	5	5	5	5	2	2	2	2	2	4	4	4	4	X	2	2	2	2	2	5	5	5	5	2	2	2
15	2	2	2	2	3	3	3	3	3	3	3	3	3	3	x	4	4	4	4	1	1	1	1	3	3	3
16	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	X	2	2	2	2	2	2	2	4	4	4
17	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	x	4	4	2	2	2	2	3	3	3
18	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	x	3	2	2	2	2	3	3	3
19	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	X	3	3	3	3	4	4	4
20	5	5	5	5	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	x	5	5	5	2	2	2
21	2	2	2	2	3	3	3	3	3	4	4	4	4	4	2	2	2	2	2	2	x	2	2	3	3	3
22	4	4	4	4	3	3	3	3	3	2	2	2	2	2	1	1	1	1	1	5	5	x	5	2	2	2
23	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	5	5	5	x	5	5	5
24	3	3	3	3	5	5	5	5	5	4	4	4	4	4	3	3	3	3	3	1	1	1	1	x	5	5
25	4	4	4	4	4	4	4	4	4	5	5	5	5	5	1	1	1	1	1	4	4	4	4	5	X	5
26	1	1	1	1	4	4	4	4	4	5	5	5	5	5	2	2	2	2	2	1	1	1	1	5	5	x

From Table 4, note that the diagonal elements are taken as x, purely for programming purposes only.

Step -**3. Construct the AGDRM using Equation (2)**

Table 5. Aggregated DRM

Criteria	F1	F2 -----------	F25	F26
F1	0.0000 1.0000 1.0000	0.6648 0.2932 0.3352	0.1998 0.8380 0.8002	0.5640 0.3958 0.4360
F2	0.6061 0.3359 0.3939	0.000 1.000 1.000	0.1998 0.8380 0.8002	0.1998 0.8380 0.8002
F3	0.7051 0.2412 0.2949	0.6648 0.2932 0.3352	0.1998 0.8380 0.8002	0.1998 0.8380 0.8002
F4	0.2949 0.7448 0.7051	0.2949 0.7448 0.7051	0.2949 0.7448 0.7051	0.2949 0.7448 0.7051
F5 . .	0.2006 0.7738 0.7994	0.2006 0.7738 0.7994	0.5583 0.4072 0.4417	0.5583 0.4072 0.4417
F22	0.5999 0.3501 0.4001	0.5999 0.3501 0.4001	0.2543 0.7961 0.7457	0.2543 0.7961 0.7457
F23	0.7630 0.1846 0.2370	0.7630 0.1846 0.2370	0.7383 0.2147 0.2617	0.7383 0.2147 0.2617
F24	0.3999 0.6501 0.6001	0.3999 0.6501 0.6001	0.7383 0.2147 0.2617	0.7383 0.2147 0.2617
F25	0.5583 0.4072 0.4417	0.5583 0.4072 0.4417	0.0000 1.0000 1.0000	0.7383 0.2147 0.2617
F26	0.1173 0.9001 0.8827	0.1173 0.9001 0.8827	0.7383 0.2147 0.2617	0.0000 1.0000 1.0000

Step -4. Construction of DRM with real numbers.

Using equation (3), the aggregated neutrosophic matrix is translated into a DRM with real numbers. The matrices are tabulated as below [25].

Table 6. DRM with real numbers

	F1	F2	F3…………………….	F25	F26
F1	0.00	0.6	0.59	0.33	0.55

F2	0.58	0.00	0.58	0.33	0.33
F3 . .	0.63	0.6	0.00	0.33	0.33
F25	0.55	0.55	0.55	0.00	0.64
F26	0.3	0.3	0.3	0.64	0.00

Step -5. Construct normalized DRM.

To begin with, the summation of rows and columns of DRM is made to construct the normalized.

Table 7. Summation of Rows and Columns

Criteria	Row Sum	Column Sum
F1	11.00	23.68
F2	11.12	23.76
F3 . .	11.25	23.94
F24	12.21	23.50
F25	13.13	23.58
F26	11.38	24.06

The maximum number derived from the summation of rows and the summation of columns is determined. Then, equation (5) is used to compute k using these maximum numbers.

By multiplying the aggregated DRM by the value of k, the DRM is normalised (equation (4)). The normalised DRM with real values is represented as a 26 x 26 matrix as shown in the table below.

Table 8. Normalized DRM

	F1	F2	F3 ………	F25	F26
F1	0.00	0.04	0.04	0.02	0.04
F2	0.04	0.00	0.04	0.02	0.02
F3 . .	0.04	0.04	0.00	0.03	0.03
F25	0.04	0.04	0.04	0.00	0.04
F26	0.02	0.02	0.02	0.04	0.00

Step -6. Obtaining total-relation matrix (TRM)

Equation (6) is used to compute TRM. TRM is calculated by multiplying the inverse of DRM with the difference of identity matrix and DRM The results are tabulated as follows:

Table 9. Total Relation Matrix

	F1	F2	F3	F21	F22
F1	0.137452	0.17820384	0.17853866	0.1590871	0.17605889

F2	0.17801681	0.13949323	0.17950661	0.1603709	0.16320226
F3 . .	0.18218722	0.18071384	0.14142555	0.16118724	0.16408375
F21	0.19875082	0.19925168	0.2004106	0.1620496	0.20802736
F22	0.16159569	0.16198612	0.16307218	0.18533314	0.14491719

Step -7. Plot casual diagram.

The sum of rows (H) and the sum of columns (V) are calculated to obtain the Cause-and-Effect diagram. $H+V$ and $H-V$ are calculated using these two summations. The results can be acquired by translating the $(H+V, H-V)$ data set onto the cartesian plane. Table 5 gives the calculated performance of criteria.

Table 5 Performance of the Criteria

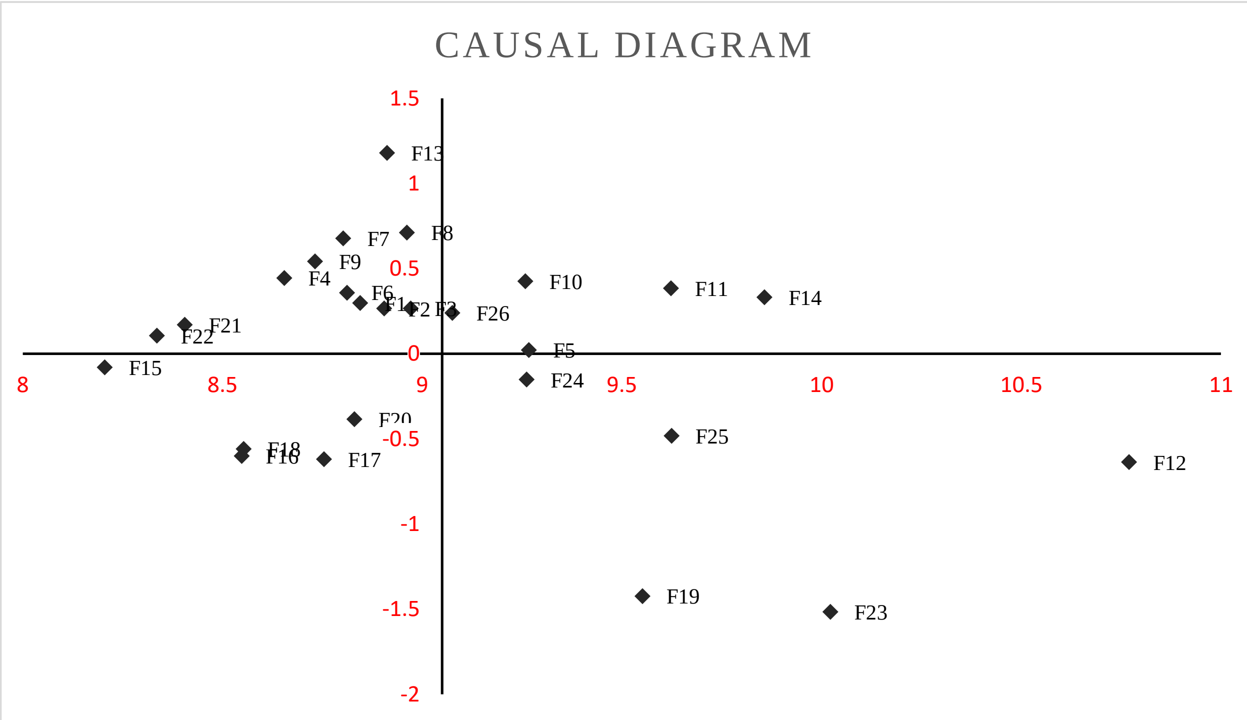
Summation of Rows of TRM [H]	Summation of Columns of TRM [V]	[H+V]	[H-V]
4.273448111482863	4.571708319732535	8.845156431215397	0.2982602082496717
4.319454924785043	4.585681466062835	8.905136390847877	0.266226541277792
4.35176372479797	4.619417399098856	8.971181123896827	0.2676536743008855
4.104556749171913	4.550125169053278	8.65468191822519	0.445568419881365
4.622340474030425	4.645100601369393	9.267441075399818	0.022760127338967706
4.226040326244855	4.586126600106721	8.812166926351576	0.36008627386186554
4.061933426960683	4.740230474655422	8.802163901616105	0.6782970476947394
4.124326337331055	4.837887343076521	8.962213680407576	0.7135610057454667
4.094015191818948	4.63753832340008	8.731553515219028	0.5435231315811322
4.416001893528742	4.842298184588803	9.258300078117546	0.42629629106006117
4.619182296562277	5.003907315135014	9.623089611697292	0.38472501857273667
5.7028723886376484	5.0671875895313025	10.770059978168952	-0.6356847991063459
3.865264956267218	5.046966406364441	8.912231362631658	1.181701450097223
4.761954782723879	5.09534063462179	9.857295417345668	0.33338585189791115
4.141719045979212	4.063762855590824	8.205481901570035	-0.07795619038838808
4.573492093775418	3.9744198005428304	8.547911894318249	-0.599072293232588

4.68620928200716	4.067925222137253	8.754134504144414	-0.6182840598699064
4.555388693643281	3.9973845247800885	8.55277321842337	-0.5580041688631927
5.486932197999035	4.064814466974208	9.551746664973244	-1.4221177310248274
4.606972932704049	4.223800692369891	8.83077362507394	-0.383172240334158
4.116863397367269	4.288953433924168	8.405816831291437	0.1720900365568987
4.114405090712399	4.22123009801596	8.335635188728359	0.10682500730356104
5.768493768672305	4.253444220034323	10.021937988706629	-1.5150495486379816
4.70633151280972	4.555342307719526	9.261673820529246	-0.15098920509019376
5.053124279140549	4.571215860265098	9.624340139405646	-0.48190841887545144
4.417188040006047	4.658466610008801	9.075654650014847	0.24127857000275377

3. Result and Discussion

The $\boldsymbol{H}+\boldsymbol{V}$ and $\boldsymbol{H}-\boldsymbol{V}$ values are plotted into a casual diagram. The Fig. 2 shows the casual diagram between the cause- and-effect group of criteria, being separated by the $\boldsymbol{H}+\boldsymbol{V}$ axis

Fig. 2 Casual diagram for Criteria



The causal diagram helps us in visualizing the cause criteria and the effect criteria. The cause criteria are Working fluid**,** Design pressure, Temperature, Geographical location, Misalignment, Support placement, Pipe strain, Coupling, Power overloading, Instrument malfunction, Lubrication, Temperature, Vibration damping, Material of casing, Strainer clogging **as their H-V values is positive. The effect criteria** Pressure head, Valve placement, Temporary strainer, Layout, Pipe run, Water hammering, working fluid, Pressure head, Nature of priming, Power supply **as their H-V values are negative.**

3.1 Segregation of criteria.

The coordinates of $(H + V, H - V)$ can be used to better analyze the figure. There are four different sorts of criterion. Based on the coordinates of $(H + V, H - V)$, all criteria in this study may be divided into four quadrants. There are four basic types of instances. Fig. 3 shows the criteria details in quadrant analysis. Note that the value of $(H + V)$ is taken as large or small in comparison to the mean of all the values (9.0523)

Case(i): When $(H + V)$ is large and $(H + V)$ is positive, the first kind occurs. This suggests that the factors are cause criteria, as well as a driving factor to resolve critical issues. Hence, the criterion "Temperature" is the most governing element on other factors.

Case(ii): When $H - V$ is positive and $H + V$ is small. It demonstrates that factors are self-contained and can only impact a small number of others. In the selection of the factor for studying the pump piping system failure, the criterion "Material of casing" is a stand-alone criterion that has no bearing on other factors.

Case(iii): When $H - V$ is negative and $H + V$ is large. It shows that the factors turn out to be an effect criterion, which can be enhanced. The factor "Pressure head" is an effect criterion which is highly contingent to other factors.

Case(iv): When $H - V$ is negative and $H + V$ is small. It demonstrates that the factors are self-contained and are scarcely affected by other factors. In our case, "Valve placement" is considered as an independent criterion.

From the above cases, we can conclude that "Temperature" and "Pressure head" are the most important factors which have to be taken into consideration while making pump piping system failure analysis.

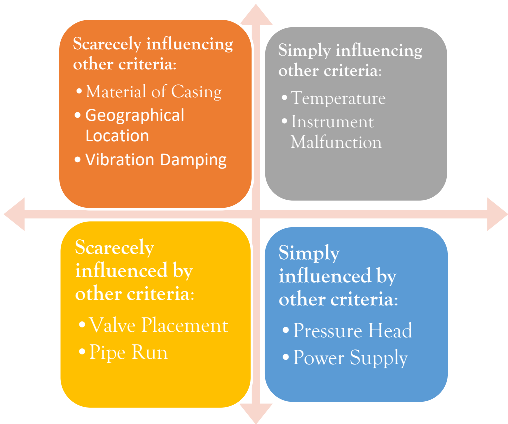


Fig.3 Quadrant Analysis

4. Conclusion

The DEMATEL method has proved itself to be a powerful tool in the industry ever since it was first proposed. It is applicable to almost all engineering systems and provides comprehensible results which can be used to improve the system. A study indicated that DEMATEL is most used in conjunction with ANP. This is followed by the integrated Fuzzy-DEMATEL method which has a major advantage in situations dealing with uncertainty. The present study proposes an incorporation of neutrosophic sets into the classical DEMATEL to understand the fundamentals of the application in a much more sophisticated manner. More specifically, Single Valued Neutrosophic (SVN) sets are used which has the advantage of its three membership functions to tackle indeterminacy. However, the method is not without limitations. Despite the incorporation of neutrosophic sets to reduce 'vagueness', the opinions of the decision makers may vary based on their mood, judgement, and accuracy of perception. The reliability of the input data needs to be verified before proceeding with the analysis. In this paper, the proposed method is utilized in assessing the piping failure where a total of 26 critical factors were identified. The extensive review of criteria by the Truth, Indeterminacy, and Falsity memberships of SVNS successfully divides these criteria into two groups: cause and effect. The results indicate that the criterion "Temperature" is the most important cause in influencing other factors that must be studied during the pump piping system failure. This is in line with the available theoretical knowledge. Temperature change creates expansion or contraction which can lead to thermal stresses thus altering the entire working conditions of the piping system. Higher temperatures can also imply increased corrosion rate. The criterion "Pressure" on the other hand, is highly influenced by changes in other factors. This is a particularly useful detail since by placing tighter control mechanisms on the pressure head, the efficiency of the entire system can be directly improved. The results also show that even though factors like material, pipe layout and valve placement can directly contribute to the failure of the system, their inter-relationship with other factors are negligibly low and need not be prioritised over others. The procedure implemented in this paper can be successfully applied to various other systems and obtain intelligible results despite any level of uncertainty involved.

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