Prediction of Failure Rate in Long Distance Oil and Gas Pipelines Using Soft Computing Techniques

Tahyr Garlyyev, Srinivasa Rao Pedapati, and K. Venkateswara Rao

Abstract—**Long distance oil and gas pipelines are the major transporters of crude oil and other petroleum products which are highly expensive and earning millions of dollars' income. Considered that they are the secure way of transporting those products pipelines fail leaving catastrophic consequences behind. The aim of this study was to build a fuzzy-based model to forecast the type of failure in the future utilizing the historical data of the pipeline records. This paper presents the fuzzy risk analysis method proposed which is the IS appraisal, the LIF evaluation, and the risk analysis. Fuzzy model showed that all inputs and factors have significant influence on the output results. Results obtained using this model exhibits more accurate prediction compared to other methods.**

Index Terms—**Oil and gas, pipelines, failure rate prediction, fuzzy logic.**

I. Introduction

Numerous tries performed in the past 20 years for oil and gas pipelines corrosion rate, seepage, flaw type, and dud possibility predictions. Transport of oil and gas products through pipelines takes a major role in various branches of industry and manufacturing. Pipelines known as the safest, economical and yet efficient way of transporting oil and gas products comparing to other methods, like rail and road [1]. For example, pipelines transport most of oil and gas. As oil and gas transporting pipelines are buried subversive and various tainted elements influence them. some of the major causes consist of corrosion, third party intrusion, material fault, natural hazard and malfunction [2,3]. The elimination or loss of such structures would have attenuate brunt on economic and national safety, community health and several combos of those things [4]. Thus, appraisal of risk can aid establishments to resolve dangerous mechanisms and construct an applicable response and approach to decrease and/or discard it. Accomplishing the target, an appropriate approach needs that could help the current hazards and risks more accurate, precise and clear. Considering the interest and usefulness of pipelines, some studies are conducted to identify risks issued through pipelines. A methodology connected with transiting unsafe materials in long distance was presented by Dziubinski et.al [5]. Han & Weng [6] presented a cohesive significant risk appraisal technique for gas pipeline system. The technique consists of possible estimation of mishaps, consequences analysis and appraisal of risk.

Manuscript received July 29, 2019; revised November 1, 2019. This work was supported by the Universiti Teknologi PETRONAS under URIF Grant.

Tahyr Garlyyev and Srinivasa Rao Pedapati are with the Dept. of Mechanical Engineering, Universiti Teknologi PETRONAS, 32610, Perak, Malaysia (e-mail: tahyrgarlyyev@gmail.com, srnivasa.pedapati@utp.edu.my).

K. Venkateswara Rao is with Petroleum and Chemical Engineering Department, University College of Engineering, JNTUK, Kakinada, India (e-mail: profkvrao@gmail.com).

A. Fuzzy Logic Tool Modelling

The fuzzy logic tool method should aim to achieve the close values for the results but should not complicate too much on the process as this will take additional simulation time. In numerous practical issues, the experts face with lack of data or inadequate information in demonstrating actual world phenomena; nebulousness and vulnerability are indivisible parts of information. Fuzzy logic, presented by Zadeh [7], a strong instrument to handle such cases. This system implements linguistic styles to give a conclusion structure to displaying practical and complicated edifices. A fuzzy set is an over-all procedure of a crisp set that fits to the closed interval 0 to 1; in order to, 1 shows full membership and 0 indicates non- membership [8]. When in fact, crisp sets only allow 0 or 1. The tool will be to aid engineers to ascertain riskier parts and make a suitable reaction based on the situation and strategize to decrease or even eliminate it. To achieve the goal, a necessary method is needed to evaluate the subsisting hazards more accurately and precisely. However, some errors might occur during the building this tool from the results of human error, variable input errors or lack of information. Poor understanding of the failure mechanism can cause several problems at some stage of this project. Difficulties might occur during the modelling of the system due to the deficiency of dependable fundamental data for calculation. Big amount of inter-related variables influencing the modelling procedure. Low accuracy of field data can play big role in identifying problems. One of the problems might occur is the poor record of operating conditions.

B. Fuzzy Tool Application

By applying the data from the pipeline inspection records, one believes that after inserting variables into fuzzy logic model can give us precise results. For example, gathering data about types of failures occur in long distance oil and gas pipelines tool can predict the failure type might be occurring in future. However, it is taken into consideration that some data might be not as good to be simulated. In this paper, long distance oil and gas failure type forecast using fuzzy logic tool are critically reviewed and analyzed for their viability and steps for effective implementation suggested.

The resolutions for Soft Computing (SC) are indistinct and random, between 0 and 1. In the early 1990s, Soft Computing became an official field of study in Computer Science. Prior computational approaches could model and

doi: 10.18178/ijcea.2020.11.1.777

accurately analyse only relatively straightforward systems. Further multifaceted systems arise in biology, medicine, the humanities, management sciences, and alike fields often continued to be intractable to conservative mathematical and analytical methods. However, straightforwardness and complexity of systems are comparative, and several conservative mathematical models have been both problematic and extremely constructive. Elusiveness, doubts, incomplete truth, estimation to attain feasibility, heftiness and low solution cost are approximately the things that Soft Computing deals with. Amongst soft computing and possibility, there are main highlighted differences. It is important to notify that less sufficient of data was obtained to solve the problem when the possibility was used, moreover, minimum information of the problem itself upon used of soft computing. Zadeh [7] was the first to present fuzzy logic that is a capable modelling method intended to knob natural language and inexact reasoning. Processing linguistic inputs to create output or decision can be dealt with fuzzy logic- based systems. A compilation of fuzzy membership functions and rules are utilized by fuzzy expert systems (FES), rather than to reason about information by Boolean logic [9]. The way of building FES comprises the subsequent steps as illustrated in Fig. 1:

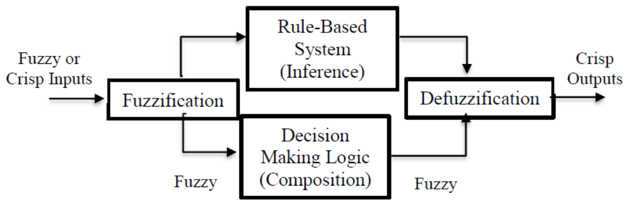


Fig. 1. Fuzzy expert system (FES).

Fuzzification: this step in fuzzy logic tool changes the crisp input to a linguistic value by adopting and using the membership functions held in the fuzzy knowledge base. It determines the degree of truth for each fuzzy rule;

Inference Engine: utilizing if-then type of fuzzy logic rules it converts all fuzzy inputs to fuzzy outputs. It computes the true values for each fuzzy rule and applies to the concluded part of each rule;

Composition: integrate all of fuzzy subgroups to each output variable to arrange a single subset for all output variables;

Defuzzification: changes the fuzzy set output sets to a crisp value.

This paper consists of several objectives corresponding to the problem statement of the research. Firstly, to design a condition appraisal and forecast archetype and develop anticipated deterioration curves for long/short distance oil and gas pipelines. Besides, to have aptitude to handle inaccurate and vague information about the phenomenon. Furthermore, to not depend on comprehensive understanding of the problem and to assist human operators, taking additional consistent and reproducible verdict by simulating their expert knowledge.

The predominant focus of this paper is on the failure predicting in the future for long/short distance oil and gas pipelines. Research will be split into 4 stages. The first stage will include itself literature review and data collection. In this stage it will be worked on literature review and collection of data for our project which will be used later. Data collection stage will include itself identifying factors which affect oil and gas pipelines stipulation and collection of past inspection data for oil and gas pipelines. Next stage will take model development where we will need to build models with respect to diameter and product type. Third stage will take place when the model will be tested and validated. This stage is very important as it consists of the main scope of this project. The last stage will be conclusion and recommendation base on deterioration curves obtained from the tested results of the model. The data from respected company need to be analysed and studied. The reason why it needs to be studied so that datum for this project can be set.

II. Methodology

A. Research Framework

As mentioned before that there are stages in this paper. Herein study includes the three stages of fuzzy risk analysis method proposed which is the IS appraisal, the LIF evaluation, and the risk analysis. The first two stages are shaped founded on notions of fuzzy logic. To handle the hesitation entailed in the procedure of modelling, fuzzy logic is applied. A desegregated archetype founded on qualitative and quantitative methods for pipeline risk appraisal is a feature of the suggested archetype. A comprehensive and more precise appraisal of risks linked with dangerous sources can be resulted in this. Fuzzy logic tool doesn't limit the number of inputs and outputs. The focal indicators or contributions of the fuzzy model are the components that affect the prediction of oil pipeline failure sorts. Recognized as: (1) sort of outcome transmitted by pipeline (service), (2) site of pipeline (facility), (3) pipeline service period, (4) land use, and (5) diameter of pipeline. Then again, the output will be anticipated type of failure, as appeared in Fig. 3. The methodology which will be operated construct the fuzzy model is explained in Fig. 2.

B. Fuzzy Inputs and Output

The linguistic variables of inputs such as land use, service and facility deprived of containing a palpable mean of measure, they can only be expressed as categories will be signified by crisp value as illustrated in Table 1. For example, an input like facility is expressed by either subversive, airborne, or pump station; which there is no possible additional significances in between. The linguistic variables of the output failure type are used by the same concept, as illustrated in Table I.

C. Data Collection

Since 1971 CONCAWE Oil Management Group (OPMG) has composed data on the environmental and safety performance of oil pipelines in Europe. Using on-line questionnaires Concawe has collected spillage incidents, traffic and annual throughput.

The results studied and put out every year. After 20 and 30 years total summary reports were composed. The report includes 44 years of European cross-country oil pipelines data, containing volume of spill, recovery and clean up, environmental affects, and root of incidents. Over period of 44 years it studied many ways including large and net spillage volumes and spillage root. The pipeline failures were gathered into five fundamental classifications, mechanical, operational, corrosion, natural hazard, and third party. For 2015 63 operators gave data representing more than 141 pipeline systems and joined length of 33, 900 km (report no. 7/17; Performance of European cross- country oil pipelines; Statistical summary of reported incidents in 2015 and since 1971). The revealed volume transported in 2015 was 765 Mm3 of unrefined petroleum and refined products, higher than the 2012 figure. The summary of traffic volume in 2015 was reported at 121×109.m3.km.

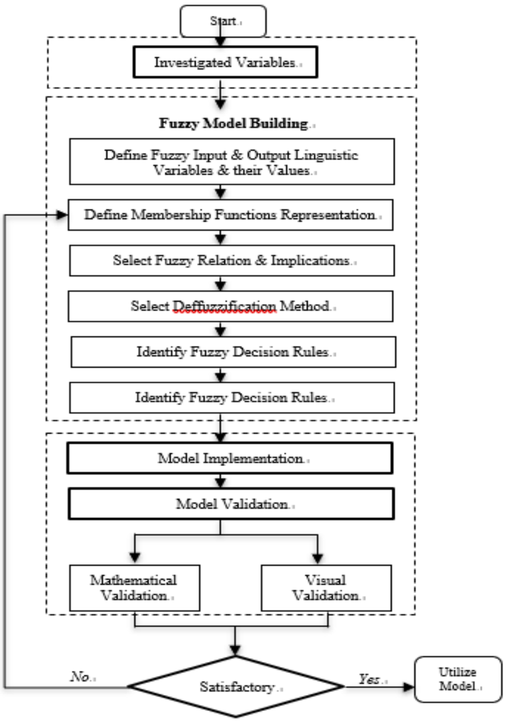


Fig. 2. Analysis framework.

TABLE I: INPUTS AND OUTPUT LINGUISTIC VARIABLES AND FUZZY/CRISP VALUES

Input/output	**Linguistic var.**	**Crisp value**
Product (service)	Crude-oil White prod. Fuel oil Crude prod. Lubes	1.5 2.5 3.5 4.5 5.5
Facility	Underground Above-ground Pump station	1.5 2.5 3.5
Land use	Res-ial high density Res-ial low density Agricultural Indust-commercial Jungle hills	1.5 2.5 3.5 4.5 5.5
Pipeline age	New Medium Old	1.5 2.5 3.5
Pipeline diameter	Small Medium Old	1.5 2.5 3.5
Failure type	**Mechanical** **Operational** **Corrosion** **Natural hazard** **Third party**	**1.5** **2.5** **3.5** **4.5** **5.5**

D. Fuzzy Rules

Fuzzy Expert System (FES) should have a group of rules which will define the value or level of a prediction-maker encountering uncertain results. Total group of rules is generally accepted as a rule base or awareness base, which must screen the full universe of discourse of input and crop fuzzy membership variables. The fuzzy rules utilized are in the style of if-then rules:

IF Q is qn
AND W is wn
AND E is en
AND R is rn
AND U is un
THEN FT is f tn

where Q = service; W = facility; E = age; R = land use; U = diameter; FT = failure category; qn = service category n (e.g., crude oil, white product, fuel product, crude product, or lubes); wn = facility category n (e.g., underground, above ground, or pump station); en = age category n (e.g., new, medium and old); rn = land use type n (e.g., residential low density, res. High density, agronomic, manufacturing/commercial and jungle hills); un = diameter category n (e.g., small, medium and large); and $f\ tn$ = failure type n (e.g., mechanical, operational, corrosion, natural hazard and third party).

III. RESULTS

Throughout this project, the failure type prediction for oil and gas pipeline was obtained with the approach of mathematical modelling software MATLAB Simulink to estimate pipelines' condition in the future. Model outcome mapping between 5 inputs which are service type, facility, land use, pipeline age and pipeline diameter and 1 output as shown in Fig. 3 and 4. Failure type will be based on the input values. In other words, based on the historical data we generated rules which makes decision. FIS editor was used for this model which handles the high-level issues for the system such as number of inputs and output variables names.

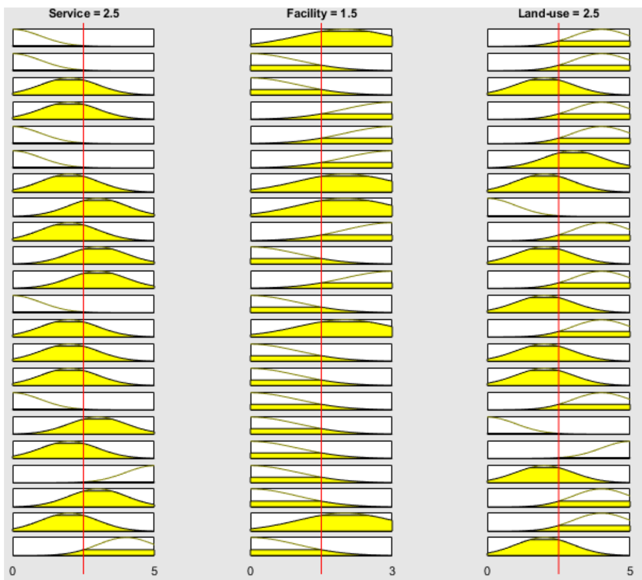


Fig. 3. Graphical indication of model reasoning mechanism.

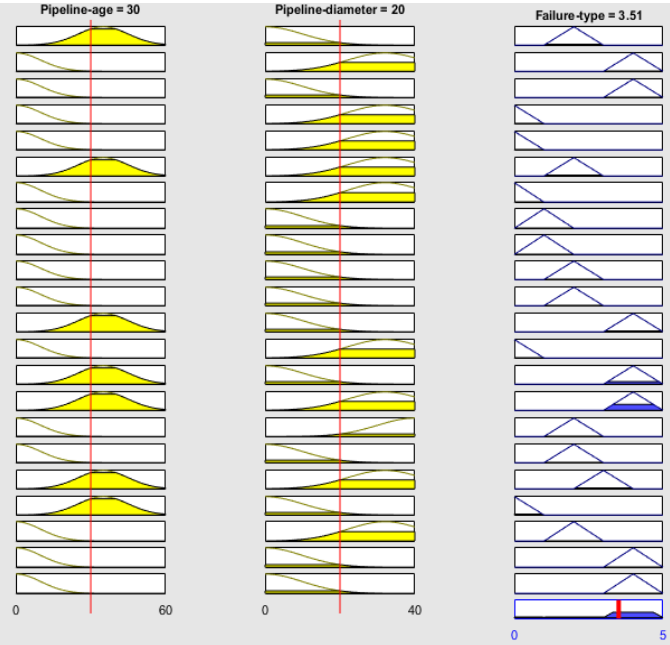


Fig. 4. Graphical indication of model reasoning mechanism.

TABLE II: FUZZY RULES

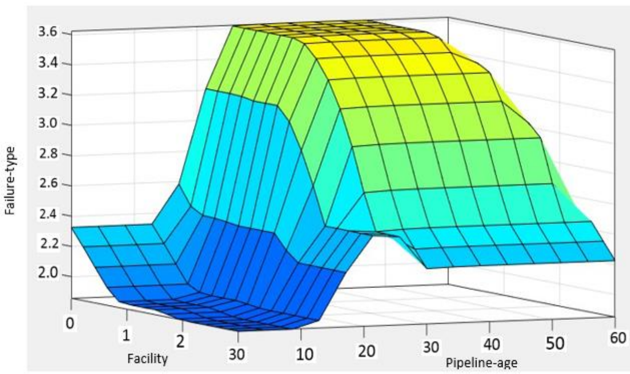
Rule No	IF service is	AND facility is	AND age is
1	White product	Above ground	Medium
2	White product	Pump station	Medium
3	Fuel oil	Underground	Medium
4	Fuel oil	Underground	Medium
5	Crude oil	Above ground	Medium
6	Crude oil	Above ground	New
7	Lubes	Underground	New
8	Crude product	Underground	New
9	Crude product	Underground	New
10	White product	Pump station	New
11	White product	Pump station	Medium
12	Fuel oil	Above ground	Medium
13	Fuel oil	Underground	Medium
14	Crude product	Underground	New
15	Crude product	Underground	New
16	Lubes	Underground	Medium
17	Lubes	Underground	Medium
18	Crude oil	Above ground	New
19	Fuel oil	Above ground	Old
20	Crude product	Above ground	New
21	White product	Pump station	Medium
22	Fuel oil	Pump station	Medium
23	Crude oil	Underground	Old
24	White product	Underground	New
25	Fuel oil	Underground	New
26	Lubes	Underground	New
27	Crude product	Medium	New
28	White product	Above ground	Medium
29	Fuel oil	Underground	New

Each row in Fig. 3 and 4 represents fuzzy rules developed for failure prediction and each column shows the set of membership functions for an input. For the service input we ranged it from 1 to 5. For each input values we assigned crisp values, which is also called firing strength of the input. Likewise, for facility input we ranged it from 1 to 3, land use been ranged from 1 to 3, pipeline age from 0 to 60 and for pipeline dimeter the range was given from 0 to 40 inches. By changing the trigger point (red line) on input variables, outcome of the failure type can be changed which makes the model simulation (Senouci, El-Abbasy, Zayed, & M.ASCE, 2014) is easy. For the output value we ranged it from 1 to 5. Since fuzzy logic model output doesn't gives the results in integer numbers the output numbers are not integer values.

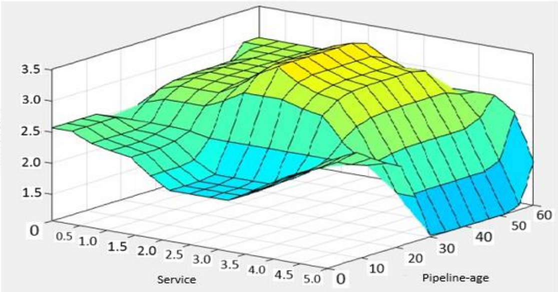
Surface view of the shows the failure type output based on 5 input values. It displays the surface that represents the mapping from pipeline age, pipeline diameter, service type, land use and facility type to failure type. We can select any 2 inputs to view on one surface map. In this case we have 5 inputs and 1 output, and they are shown in Fig. 5. The results obtained from this model met the expectations and hence the model is viable and can be utilized in future studies. It shows high value and low values for output based on input values.

TABLE III: FUZZY OUTPUTS

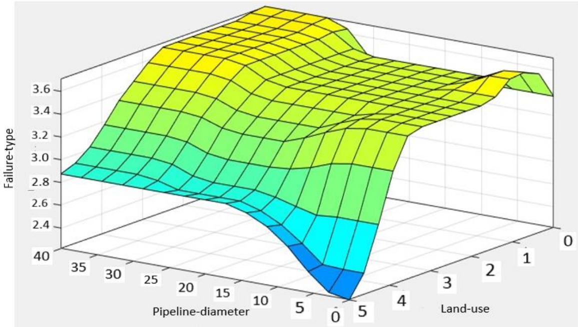
AND land use is	AND diameter is	THEN failure type is
Industrial or commercial	Small	Third party
Industrial or commercial	Medium	Corrosion
Agricultural	Medium	Third party
Industrial or commercial	Medium	Operational
Industrial or commercial	Small	Corrosion
Residential high density	Medium	Third party
Industrial or commercial	Small	Mechanical
Residential low density	Medium	Third party
Residential high density	Medium	Natural hazard
Industrial or commercial	Small	Corrosion
Agricultural	Small	Third party
Jungle hills	Medium	Operational
Industrial or commercial	Medium	Natural hazard
Industrial or commercial	Medium	Mechanical
Industrial or commercial	Small	Operational
Agricultural	Small	Third party
Industrial or commercial	Large	Third party
Residential low density	Medium	Third party
Residential low density	Small	Operational
Industrial or commercial	Large	Mechanical
Industrial or commercial	Small	Natural hazard
Jungle hills	Small	Operational
Industrial or commercial	Large	Third party
Industrial or commercial	Medium	Third party
Residential low density	Medium	Corrosion
Residential low density	Medium	Operational
Jungle hills	Large	Third party
Residential high density	Medium	Mechanical
Industrial or commercial	Medium	Third party



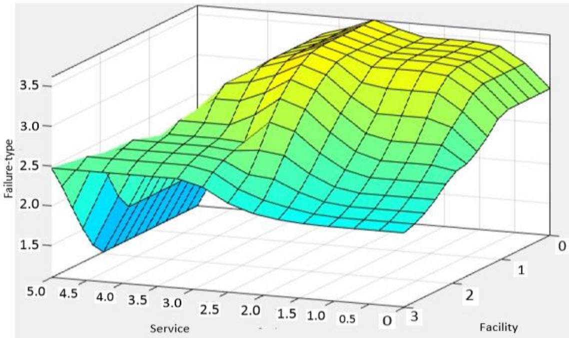
(i) Control surface of facility-pipeline age on



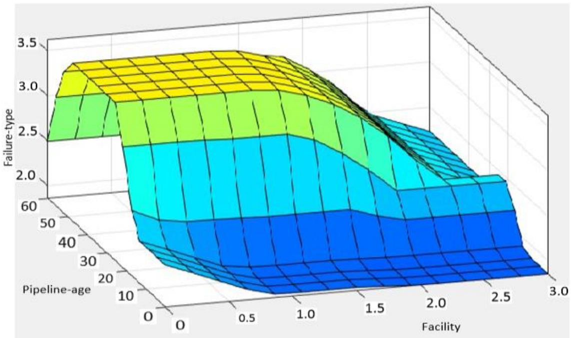
(ii) Service- pipeline age on



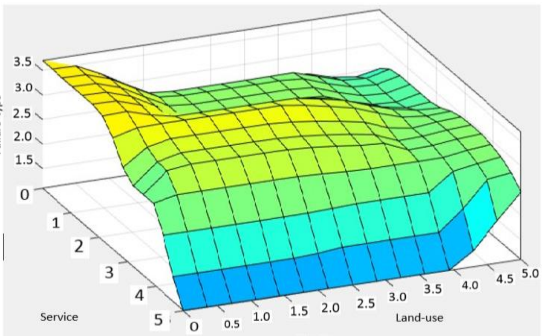
(iii) Pipeline diameter-land use



(iv) Service- facility on



(v) Pipeline age-facility on



(vi) Service-land use on

Fig. 5. Control surface of facility-pipeline age on, service- pipeline age on, pipeline diameter-land use, service- facility on, pipeline age-facility on, and service-land use on.

IV. Model Validation

As an additional validation for the modelled system, the results obtained from this simulation were compared to those which was obtained in previous studies by Senuoci et al [2]. Using linear regression, previous models were developed and tested by applying the same data which was used for this work. The total number of 40 accidents were used for model validation. As a result, fuzzy logic model can be considered best among other tools. The second reason is that the model is powerful in obtaining closest outputs especially in diameter and age inputs. The aim of stage is to assess and test the model which has predicted and to check the effectiveness of it using numerical validation. Overall 30 incidents extracted from the CONCAWE 1971-2015 report utilized to validate the model. Eqs. (1) and (2) show one way for determining the average validity and average invalidity ratios for predict the error percentage. The model is robust for an AIP value near to 0.1 and not applicable for an AIP value near to 99 [10]. Likewise, the RMSE is predicted using Eq. (3). If the value of the RMSE is near to 0, the validation is sound and the other way around. In Eq. (4) defined the MAE and it ranges from 0 to limitlessness. For good results MAE must be close to zero [11].

$$AIP = \left\{\sum_{i=1}^{n} 1 - \left(\frac{E_i}{C_i}\right)\right\}\frac{100}{n} \quad (1)$$

$$AVP = 100 - AIP \quad (2)$$

$$RMSE = \sqrt{\sum_{i=1}^{n}\left(C_i - E_i^2\right)/n} \quad (3)$$

$$MAE = \frac{\sum_{i=1}^{n}[C_i - E_i]}{n} \quad (4)$$

Developed fuzzy model predicted results with AVP percent = 82 %, MAE = 0.11 and RMSE = 0.15

Another way to calculate the AIP is applied to test. The approach is simply summing the number of wrong predictions (n_{ip}) and divide it by the sum of events (n) as shown in Eq. (5). Then we can calculate the value of AVP referring to Eq. (2) as earlier mentioned.

$$AIP = {}^{n_{ip}}/_{n} \quad (5)$$

This approach showed that AVP value of 70%. We shall take note that this approach gave AVP values lesser than achieved in the first way. This is because the second way takes that an event is totally wrong if its anticipated failure type was unlike from the real one.

V. Conclusion

This study shows the advancement of a fuzzy archetype to predict types of failures of oil and gas pipelines given many predictors especially the service type, land use, facility, location, age, and diameter of the pipe. The best in class in oil and gas pipeline failures was audited including the sorts of failures and the basic components influencing these failure sorts. Moreover, fuzzy rules of the archetype, fuzzy input and output variables will be constructed to cap mainly the oil pipeline failure types. The industrialized archetype will be authenticated and certified. Results showed in this project were satisfactory due to the optimal validities. Obtained AVP, MAE, and RMSE equal to 70%, 0.11, and 0.15, respectively. Fuzzy model showed that all inputs and factors have significant influence on the output results. Results obtained using this model beat the results taken from other two methods (ANN and regression analysis). Service input values is the most sensitive factor in modelling this approach while facility was the slightest. In addition, model was not trained well enough to predict natural hazards failure type due to that actual results in CONCAWE report was limited to this failure type. Therefore, studies in the future for this project need to be done including pipeline material specifications for input variables. Another confinement is that demonstrate can't give yield an incentive in whole number qualities frame, which is imperative in choice yield number. Overall, this study helps the researchers and operators in the future to predict the condition of pipeline and failure types considering all inputs and giving precise output.

To get more accurate results it advisable to collect more data about the pipeline in further studies. Finally, simulation with Fuzzy logic approach is gave more accurate and good results compared to other models.

Conflict of Interest

The authors declare no conflict of interest

Author Contributions

Tahyr Garlyyev conducted the research and prepared the manuscript; Srinivasa Rao supervised the research and verified the data; Venkateswara Rao analyzed the data; all authors had approved the final version.

Acknowledgements

Author would like to take this opportunity to thank Universiti Teknologi PETRONAS and URIF grant for supporting and assistance throughout this project.

References

[1] A. Markowski and M. Mannan, "Fuzzy logic for piping risk assessment," *Journal of Loss Prevention in the Process Industries*, vol. 22, pp. 921-927, 2009.

[2] A. Senouci, M. El-Abbasy, T. Zayed, and M. Asce, "Fuzzy-based model for predicting failure of oil pipelines," *American Society of Civil Engineers*, 2014.

[3] Y. Dong and Y. Datao, "Estimation of failure probability of oil and gas transmission pipelines by fuzzy fault tree analysis," *Journal of Loss Prevention in the Process Industries*, pp. 83-88, 2004.

[4] N. I. Nipp. (2009). *Homeland Security*. Partnering to enhance protection and resiliency. [Online]. Available: https://www.dhs.gov/xlibrary/assets/NIPP_Plan.pdf

[5] M. Dziubinski, M. Fratczak, and A. S. Markowski, "Aspects of risk analysis associated with major failure of fuel pipelines," *Journal of Loss Prevention in the Process Industries*, pp. 399-408, 2006.

[6] Y. Han and F. Weng, "Comparison of two transmittance algorithms in the community radiative transfer model: Apllication to AVHRR," *Journal of Geophysical Research Atmospheres*, vol. 6206, 2012.

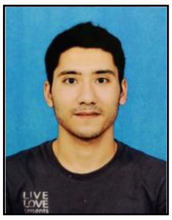
[7] L. Zadeh, "Fuzzy sets," *Information and Control*, pp. 338-353, 1965.

[8] A. Y. Chamzini and S. H. Yakhchali, "Handling equipment Selection in open pit mines by using an intergrated model based on group decision making," *International Journal of Industrial Engineering Computations*, vol. 5, 2012.

[9] T. Zayed, *Selecting Pile Contruction Method using Fuzzy Approach*, 2005.

[10] P. Davis, J. Dubois, F. Gambardella, and F. Uhlig, "Performance of European cross-country oil pipelines," *Concawe Oil Pipelines Management Group, Special Task Force, Brussels*, 2010.

[11] A. Detyniecki, B. Moubeche, and B. Bouchon-Meunier, "On the paradoxical success of mamdani's minimum-based inference," *Studies in Fuzziness and Soft Computing, Combining Experimentation and Theory*, pp. 259-270, 2012.



Tahyr Garlyyev was born in Turkmenistan. He was an undergraduate student of Mechanical Engineering in Universiti Teknologi Petronas. He obtained his bachelor's degree in mechanical engineering in the year 2018. Presently he is working as a trainee engineer in Malaysia

Srinivasa Rao Pedapati was born in Andhra Pradesh, India. He obtained his bachelor's degree in mechanical engineering from Nagrajuna University, and masters in mechanical engineering with design and production engineering specialization from Regional Engineering College, Warangal, India. He obtained Ph. D in mechanical engineering from Indian Institute of Technology, Kharagpur in the year 2004. His area of research includes GMA Welding, Friction Stir Welding, FSP and applications of soft computing techniques.

He is presently working as an associate professor of mechanical engineering in Universiti Teknologi Petronas, Seri Iskandar, Malaysia. He has 28 years of teaching and research experience. Prior to current job, he worked as a professor and principal of Engineering colleges in India. He has published 40 research papers in various journals/conferences and 3 book chapters on advances in Friction Stir Welding.

Dr. Srinivasa Rao is a fellow of Institution of Engineers (India) since 2008 and member of ASME, IIW, ISTE and other professional bodies. He is a reviewer for many journals and conferences in manufacturing area.

K. V. Rao is presently a program director for petroleum engineering and petrochemical engineering courses. He served Andhra University at various levels till he attained superannuation in 2005. Later, he worked in the University of Petroleum and Energy Studies, Dehra Dun as a distinguished professor until July 2010. In his academic career, he taught most of the chemical engineering as well as several core subjects in petroleum and natural gas engineering. He has a rich experience especially in experimental phase equilibrium thermodynamics and published over 150 research papers in national and international journals