Evaluation of Fuzzy Method to determine probability of failure compared with RBI analysis for pressure vessel in oil and gas company

C Laurent¹, A A B Dinariyana¹, and D Priyanta¹

¹Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

E-mail: christianlaurent36@gmail.com

Abstract. Maintenance activities conduct to manage and preserve assets integrity. Risk assessment is used to develop interval inspection hence, maintenance strategy can arrange perfectly. On the other hand, prescriptive inspection is still used as the main consideration to determine the inspection schedule. The consequence is an ineffective inspection activity. Past expert judgement was a major consideration in resulting prescriptive schedule which probably has not been reassessed and updated at present. A quantitative assessment can cover the probability and consequence of failure through a detailed assessment. The assessment takes time to be developed which complex systems and formulas are adjusted to the actual condition. Somehow, this task might be conducted by an external party who has expert knowledge. Therefore, within this schedule vacancy, any deterioration might occur in the system. A qualitative assessment can be done to estimate risk. Local engineers, who have basic knowledge of corrosion and other damage factors, can do the qualitative assessment. The result shall update the previous prescriptive methods. In processing qualitative assessment, fuzzy methods are chosen due to their ability to cover linguistic tasks and numerical value. In this paper, fuzzy logic was used to determine the probability of failure of equipment. The result was compared to API 581 RBI assessment. At the latter, risk value from both methods was evaluated to determine the inspection interval. Both types of equipment have close results from inspection interval calculation. Mostly, the inspection interval from the fuzzy method was earlier than RBI methods. From this calculation, the fuzzy results can be used as an estimation for the local engineer's consideration to determine any inspection based on qualitative assessment. If the result compared with an 8-years prescriptive inspection interval, inspection interval from qualitative assessment earlier conducted. It means asset integrity could be maintained more precisely. The equipment is pressure vessels in the utility area to support the boiler system from an Indonesian oil and gas company.

1. Introduction

LNG companies operate with complex equipment which support production of LNG. These equipment have to be monitored through maintenance schedule to have sustainability of its lifetime and reliable during periods of operation. Prescriptive inspection depends on time-based which number of next year inspection can be resulted from past engineers’ judgement. Though this method has lack due to maintenance cost, oil and gas industry worldwide using it as main determination of inspection schedule.
Maintenance costs being fluently high due to routine inspection, moreover, wrong inspection activities may lead to ineffective inspection [1]. Mechanical integrity has to be ensured by inspected at the intervals provided in international codes or based on a risk-based assessment [2]. The present method to determine the time interval for inspection is time-based which has been used in a long time. This determination has not been renewed or reassessed. Hence, an appropriate calculation of risk-based is required to replace traditional methods. It may allow previously established inspection interval to be updated.

A big number of companies are started to realize RBI assessment as an advantage to minimize maintenance costs and maximize the efficiency of inspection. Mostly RBI assessment is conducted by the contractor. Although API 581 RBI has already proven methods, in practical condition RBI assessment needs time to develop. Therefore, within this schedule vacancy, a qualitative assessment could be done as research to estimate the risk of assets. It helps to analyze the probability of any damage to occur or spread by doing a prevention activity. Therefore, local engineers with basic knowledge of corrosion are able to do the assessment.

Also, this prescriptive method shall be evaluated. A qualitative assessment can be a solution to this problem. Fuzzy logic is able to cover from linguistic tasks to a numerical value. Therefore, it is possible to do a risk assessment using the fuzzy method. In this paper, the determination of the inspection interval is explained with fuzzy logic compared with RBI analysis. The relevant uncertainties and producing a more precise method are confidently distributed by fuzzy approach [3].

This paper describes the methodology of a risk-based assessment conducted on 8 pressure vessels used in the utility area for supplying steam in the boiler system at an Indonesian oil and gas company. Qualitative assessment using fuzzy logic to determine the probability of failure is compared with API 581 RBI. At the latter, calculation from both methods was evaluated in terms to develop the inspection interval.

2. Methodology

In this paper fuzzy logic was used to determine the probability of failure. The consequence area was used from the RBI assessment because the consequence area for equipment was constant. Risk value was resulted from combining PoF and CA. At the latter, the calculated risk from both methods was compared. The risk was evaluated to determine inspection interval.

2.1. Problem Identifying
First identifying the problem about what, when, where, why and how the problem existed before doing the next step of the assessment. The objective is to give perspectives and directions to collect information that is needed.

2.2. Literature Study
References from established journals, articles, textbooks and standards are needed as supporting data to develop solutions and ideas in terms of proposing recommendations of the problem.

2.3. Collecting Data
Quantitative assessment needs data such as thickness, temperature, pressure, contents of the fluid, inspection report, and type of material construction. All of them are required to be able to do a full assessment in resulting in a reliable risk calculation.

2.4. Corrosion Rate and Remaining Life Assessment
The corrosion rate is a major factor in determining risk based on API 581 RBI. It used as input to determine the damage factor of equipment. Also, the corrosion rate can estimate the remaining life of the equipment.
2.5. **RBI Assessment**

RBI can determine inspection intervals. A RBI assessment determines risk by combining the probability and the consequence of equipment failure. When an owner/user chooses to conduct a RBI assessment, it shall include a systematic evaluation of both the probability of failure and the consequence of failure following API 580. API 581 details an RBI methodology that has all of the key elements defined in API 580.

2.6. **Fuzzy Methods**

Fuzzy logic can handle linguistic terms and numerical data which able to result a better decision. The objective of using fuzzy logic system is to overcome the uncertainty of the assessed component. In this paper, fuzzy method is using to calculate probability of failure.

3. **Results**

3.1. **RBI Assessment**

RBI assessment consists of two sections which are the calculation of the probability of failure and consequence area.
3.1.1. Probabilities of Failure
Calculation of probability of failure divided into two sections which are the determination of damage factors and management systems factors. API 581 has provided damage mechanisms and questionnaires for management systems factors. The calculation of POF is arranged in the equation.

\[
P_f(t) = g_{ff} \cdot f_{total} \cdot D_f(t) \cdot F_{MS}
\]

Where,
- \( P_f(t) \) is the probability of failure
- \( G_{ff} \) is generic failure frequency
- \( D_f(t) \) is the total damage factor
- \( F_{MS} \) is the value of calculated management systems factor

### Table 1. Summary of PoF Calculation

| No. Tag | Equipment       | Probability of Failure |
|---------|-----------------|------------------------|
|         |                 | Head | Shell    |
| 31-C-3  | Blow-Off Tank  | 4,E-07 | 4,E-07  |
| 31-C-8  | Blow-Off Tank  | 4,E-07 | 4,E-07  |
| 31-C-10 | CBD Tank       | 2,E-06 | 4,E-07  |
| 31-C-11 | Blow Off Tank  | 4,E-07 | 4,E-07  |
| 31-C-13 | Blow-Off Tank  | 4,E-07 | 4,E-07  |
| 31-C-14 | Blow-Off Tank  | 4,E-07 | 4,E-07  |
| 31-C-21 | CBD Tank       | 7,E-07 | 4,E-07  |
| 31-C-22 | CBD Tank       | 4,E-07 | 4,E-07  |

3.1.2. Consequence of Failure
The consequences of failure are analysed using different techniques on each category. API 581 provides 4 categories [7]:

a. Flammable and explosive consequence is calculated using event trees combined with computer modelling to determine various outcome of probabilities (pool fires, flash fire, vapour cloud explosions). Consequence areas can be determined based on personnel injuries and equipment damage due to explosion and thermal radiation.

b. Toxic consequence is calculated using computer modelling to determine radius of consequence area due to overexposure of personnel injury to toxic concentrations within vapour cloud. Where the fluid is flammable and toxic, if the release is ignited, the toxic consequence is minor (assuming toxics are consumed in the fire).

c. Non-flammable, non-toxic consequence are considered because can result in any serious consequences. Physical explosions and Boiling Liquid Expanding Vapour Explosions (BLEVE) considered as cause of serious personnel injuries and equipment damage.

d. Financial consequence calculated losses due to business interruption and costs associated with environmental releases. Business interruption is estimated from the result of flammable and non-flammable consequence area. Environmental consequence is determined directly from calculation of mass available for release or from release rate.
3.2. Fuzzy Methods
In these methods, fuzzy was used to determine the probability of failure from the qualitative assessment as the input to determine the level of damage mechanisms.

3.2.1. Qualitative Assessment
The targets for qualitative assessment are engineers who responsible and know the condition of the pressure vessels. There are 4 engineers in total. A questionnaire is provided through a google form. Several questions about engineers’ opinions due to the actual condition of the pressure vessels, including basic information of the engineers as input for the weighting scheme. The questionnaire contents were:
a. Respondent’s Job Title
b. Job Service Time
c. Respondent’s Educational Level
d. Respondent’s Age
e. Pressure Vessel Damage Mechanism

3.2.2. Weighting Scheme
Expert opinions are being assessed based on their position, experience, educational level and their age \(^8\). Table 3 explained the details. The final result of this section is the relative weighting score for each engineer.

\[
\text{Expert Weighting} = \frac{\text{Total Score } E_n}{\text{Total Score Overall}} \tag{2}
\]

Where,  
\(E_n\) is \(n^{th}\) expert opinions

\[\text{Table 3. Weighting factor value}\]

| No | Title     | Service Time | Edu. Level  | Age  | W. Score | W. Factor |
|----|-----------|--------------|-------------|------|----------|-----------|
| 1  | Lead Engineer | <5            | Bachelor    | <30  | 9        | 0.27273   |
| 2  | Engineer    | <5            | Bachelor    | <30  | 9        | 0.27273   |
| 3  | Inspector   | <5            | Bachelor    | <30  | 7        | 0.21212   |
| 4  | Engineer    | <5            | Bachelor    | <30  | 8        | 0.24242   |
|    | Total       |               |             |      | 33       | 1         |
3.2.3. Membership Functions
In this section, membership functions are formed using a default distribution of 4 types of probability level. Table 4 provides linguistic terms and their TFN coordinates. This membership function as a basic function to develop fuzzy value.

| Damage Mechanism      | Probabilities | TFN          |
|-----------------------|---------------|--------------|
| Low (L)               | Low (L)       | (0, 0, 0.33) |
| Medium (M)            | Medium (M)    | (0, 0.33, 0.67) |
| Medium High (MH)      | Medium High (MH) | (0.33, 0.67, 1) |
| High (H)              | High (H)      | (0.67, 1, 1)  |

![Figure 2. Membership Function Graphic](image)

3.2.4. Damage Mechanisms
Seven damage mechanisms are selected as the main focus in determining the probability of failure. These damage mechanisms are marked by experts to determine the grade of probability through qualitative assessment. The damage mechanisms are:

a. Thinning Damage
b. Boiler Water Corrosion
c. Thermal Fatigue
d. Soil Corrosion
e. Erosion Corrosion
f. Microbiologically Induced Corrosion
g. External Corrosion

Experts gave their assessment in determining the probability of failure based on their knowledge and record of the equipment’s operational procedure.

| Indicator                          | E1 | E2 | E3 | E4 |
|-----------------------------------|----|----|----|----|
| Thinning Damage                   | M  | M  | L  | H  |
| Boiler Water Corrosion            | MH | M  | L  | L  |
| Thermal Fatigue                   | L  | L  | L  | L  |
| Soil Corrosion                    | L  | L  | L  | M  |
| Erosion Corrosion                 | MH | L  | M  | H  |
| Microbiologically Induced Corrosion| L  | L  | M  | L  |
| External Corrosion                | MH | MH | L  | H  |
3.2.5. **Concordance Matrix**

Matrix was made by analysing the membership function. Intersection area and union area of “medium” and “medium-high” grade are measured. The method used in this section is an inter-rater reliability method. Inter-rater reliability is a method to measure the consistency of the implementation of a rating system. In other words, it is a level of agreement between rates which gives a score of how much similarity exists in the ratings.

The similarity is found in medium and medium-high grade. Therefore, it was assessed due to the intersection and union area. The results of the assessment were provided in Table 6 and Table 7.

| Qualitative | MH | M | M | MH |
|-------------|----|---|---|----|
| MH          | 1  | 0.25 | 0.25 | 1 |
| M           | 0.25 | 1  | 1  | 0.25 |
| M           | 0.25 | 1  | 1  | 0.25 |
| MH          | 1  | 0.25 | 0.25 | 1 |

| Qualitative | MH | M | M | MH |
|-------------|----|---|---|----|
| MH          | 1  | 1.75 | 1.75 | 1 |
| M           | 1.75 | 1  | 1  | 1.75 |
| M           | 1.75 | 1  | 1  | 1.75 |
| MH          | 1  | 1.75 | 1.75 | 1 |

After the values of intersection area and union area were obtained, concordance calculation was arranged using the equation (3).

\[
CM = \frac{IA}{UA}
\] (3)

Where,
- IA is value of intersection area
- UA is value of union area

| CM          | 0.143 | 0.143 | 1 |
|-------------|-------|-------|---|
| 0.143       | 1     | 1     | 0.143 |
| 0.143       | 1     | 1     | 0.143 |
| 1           | 0.143 | 0.143 | 1 |

3.2.6. **Relative Concordance**

The value in relative concordance is obtained from previous concordance matrix calculation with the power of two. The result was multiplied with the calculation of the amount of opinion then they were squared.

\[
RC_n = \sqrt{\frac{1}{n-1} \cdot \sum(CM)^2}
\] (4)
Where, 
\( n \) is total expert opinions 

Table 9. Relative concordance value

| Experts | \( RC_n \) |
|---------|-----------|
| 1       | 0.8248    |
| 2       | 0.8248    |
| 3       | 0.8248    |
| 4       | 0.8248    |

\( \sum RC = 3.2991 \)

3.2.7. Relative Grade of Concordance

The relative grade was calculated for each relative concordance by comparing the \( n \)th relative concordance with the total relative concordance using equation (5).

\[
RGC_n = \frac{RC_n}{\sum RC}
\]  
(5)

Where,

\( RGC_n \) is relative grade of concordance for \( n \)th expert

Table 10. Relative grade concordance value

| Experts | \( RGC_n \) |
|---------|-----------|
| 1       | 0.25      |
| 2       | 0.25      |
| 3       | 0.25      |
| 4       | 0.25      |

3.2.8. Consensus Coefficient of the Expert

The consensus coefficient is calculated for every expert. The expert's weighting scheme is combined with relative concordance.

\[
CCS_n = \frac{RGC_n \cdot EW}{\sum (RGC \cdot EW)}
\]  
(6)

Where,

\( EW \) is the calculated expert weighting

Table 11. Consensus coefficient of the each expert

| Experts | \( RGC_n \cdot EW \) | CCS_n |
|---------|---------------------|-------|
| 1       | 0.068               | 0.2727|
| 2       | 0.068               | 0.2727|
| 3       | 0.053               | 0.2121|
| 4       | 0.061               | 0.2424|

\( \sum (RGC \cdot EW) = 0.25 \)
3.2.9. Triangle Fuzzy Number
The consensus coefficient was used to determine new TFN coordinates by doing multiplication with the basic membership function of each linguistic terms. Then, all multiplication result summed up with another calculation from other experts in the same type of damage mechanisms.

\[ TFN_c = \sum(CCS_c \times n) \] (7)

Where,

\( n \) is the basic membership function of triangular fuzzy number

| Table 12. New TFN coordinate |
|-----------------------------|
| Indicator                  | Coordinate |
|                            | 1      | 2      | 3      |
| Thinning Damage            | 0.162  | 0.343  | 0.677  |
| Boiler Water Corrosion     | 0.091  | 0.343  | 0.677  |
| Thermal Fatigue            | 0.000  | 0.091  | 0.424  |
| Soil Corrosion             | 0.000  | 0.000  | 0.414  |
| Erosion Corrosion          | 0.253  | 0.414  | 0.747  |
| Microbiologically Induced Corrosion | 0.000  | 0.071  | 0.404  |
| External Corrosion         | 0.343  | 0.525  | 0.859  |

3.2.10. Fuzzy Inference System
The fuzzy inference system contains rules in determining the relation between two membership functions. In this case, damage mechanisms as input and probabilities as an output. This FIS is using an inline relationship. When damage mechanisms are low grade so does probabilities. There are total of 4 rules in this FIS using IF_ THEN logic.

1. If (Damage Mechanism is Low) then (Probabilities is Low) (1)
2. If (Damage Mechanism is Medium) then (Probabilities is Medium) (1)
3. If (Damage Mechanism is Medium_High) then (Probabilities is Medium_High) (1)
4. If (Damage Mechanism is High) then (Probabilities is High) (1)

Figure 3. Fuzzy Inference System in MATLAB

3.2.11. Fuzzification System
The result from multiplication between the consensus coefficient with the default membership function of each linguistic terms was used to determine the input in the damage mechanism section. The example can be seen in Figure 4.

Figure 4. Fuzzification System in MATLAB
### Table 13. Final PoF from Fuzzy Methods

| Indicator                          | Fuzzy Probabilities |
|------------------------------------|---------------------|
| Thinning Damage                    | 0.347               |
| Boiler Water Corrosion             | 0.347               |
| Thermal Fatigue                    | 0.239               |
| Soil Corrosion                     | 0.108               |
| Erosion Corrosion                  | 0.427               |
| Microbiologically Induced Corrosion| 0.219               |
| External Corrosion                 | 0.52                |
| Probabilities                      | 0.00015113          |

#### 3.3. Risk Calculation

Total calculated risk is obtained from calculated probability of failure and consequence area.

$$R(t) = P_f(t) \cdot CA$$  \hspace{1cm} (8)

Where,

- $P_f(t)$ is probability of failure, failure/year
- $CA$ is consequence of area, m$^2$

### Table 14. Result of Risk Calculation

| Equipment | Risk-RBI | Risk-fuzzy |
|-----------|----------|------------|
|           | Head     | Shell      |            |
| 31-C-3    | 3.7E-04  | 3.7E-04    | 0.136      |
| 31-C-8    | 2.9E-04  | 2.9E-04    | 0.105      |
| 31-C-10   | 1.4E-03  | 2.4E-04    | 0.086      |
| 31-C-11   | 2.0E-04  | 2.0E-04    | 0.075      |
| 31-C-13   | 2.9E-04  | 2.9E-04    | 0.105      |
| 31-C-14   | 3.0E-04  | 2.9E-04    | 0.105      |
| 31-C-21   | 3.8E-04  | 2.4E-04    | 0.086      |
| 31-C-22   | 3.7E-04  | 3.7E-04    | 0.136      |

#### 3.4. Inspection Interval

The inspection interval is an estimation of the inspection schedule. The calculated risk was compared with the risk target provided by the company.

### Table 15. Inspection Interval from Fuzzy Methods

| Equipment | Fuzzy-Risk | Risk Target (m²/Year) | Inspection Interval (Years) |
|-----------|------------|-----------------------|----------------------------|
| 31-C-3    | 0.13       | 0.5                   | 3.83                       |
| 31-C-8    | 0.1        | 0.5                   | 4.96                       |
| 31-C-10   | 0.08       | 0.5                   | 6.02                       |
| 31-C-11   | 0.07       | 0.5                   | 6.96                       |
| 31-C-13   | 0.1        | 0.5                   | 4.96                       |
| 31-C-14   | 0.1        | 0.5                   | 4.96                       |
| 31-C-21   | 0.08       | 0.5                   | 6.02                       |
| 31-C-22   | 0.13       | 0.5                   | 3.83                       |
4. Discussion

Fuzzy-PoFs were obtained on level $1.5 \times 10^{-4}$ for every equipment. The fluid between one equipment to others is the same, so it assumed that damage mechanisms for all the equipment are the same therefore qualitative assessment only done once. For instance, RBI-PoFs were relatively the same. The PoF was on the $10^{-7}$ level. If we compare both results, fuzzy-PoFs has a higher value. It was because RBI has a complex calculation process in determining PoF value. The result of the calculation was summarized in Table 17.

Interval inspection calculated with fuzzy was in range 3.67 years up to 6.96 years ahead. It was counted from the last inspection year. On the other hand, interval inspection calculated with API 581 RBI in the range 4 years up to 7 years. In practical conditions, RBI needs time to develop the program and formula for certain systems in a company. More complex a system, more time is needed. RBI assessors are developing and running their program and formula in 3 years in the company. Within 3 years, deterioration might occur in the system with no signs. Also, if an abnormal condition happened the personnel needs to re-assess the assets.

Figure 5 exposed two types of inspection intervals. There is an interval from RBI calculation and fuzzy methods. Mostly fuzzy logic resulted in lower interval inspection than RBI assessment. From this calculation, the fuzzy results can be used as an estimation for the local engineer's consideration to determine any inspection based on qualitative assessment. The resulting sensitivity could be increased with a more precision qualitative assessment of damage mechanisms.
Fuzzy logic is often used for mapping the level of certain factors such as probability, frequency of failure, and risk. So in this case, fuzzy logic used to obtain the probability of failure is considered correct and reliable enough. On the other hand, it is debatable when the method is used to determine the inspection interval because the maintenance strategy involved company budgeting. Therefore, this method is relatively hard implemented because not providing any further details. For further usage, fuzzy logic methods are properly used when there is no quantitative assessment has been done before or the latest condition of the system has not been assessed. The resulting accuracy in this fuzzy method can be still debatable because it is purely based on personnel opinions. For the method itself, fuzzy logic is possible to use because of its ability to transform the linguistic task into a numerical value. From this point, local engineers can conduct this assessment based on their knowledge and experience. Simple and quick is the correct word to describe this method. The consequences are highly educated and experienced personnel is needed in terms to have a reliable assessment. Also, the number of respondents shall be increased as the reason to have various opinions.

5. Conclusions
a. Experts’ opinions were transformed from linguistic tasks to a numerical value by using membership functions. Then, the numerical value was merged with the result of the concordance matrix. New triangular fuzzy numbers were obtained from the calculation. Lastly, new coordinates of TFN were input to the membership function in MATLAB software then the probability for each damage mechanism was obtained. POF was calculated by combining all probabilities number of damage mechanisms. The fuzzy-PoF is $1.5 \times 10^{-4}$ for all equipment.

b. Inspection intervals from RBI assessment were obtained through interpolation between calculated risk and risk target. In the fuzzy method calculated risk compared directly with company risk target. Inspection interval obtained by the fuzzy method mostly lower than the RBI inspection interval. Table 18 is the summary of inspection interval for both methods.

| Equipment | Type      | RBI (Years) | Fuzzy (Years) |
|-----------|-----------|-------------|---------------|
| 31-C-3    | Blow-Off  | 6,529       | 3,676         |
| 31-C-8    | Blow-Off  | 6,837       | 4,761         |
| 31-C-10   | CBD       | 5,300       | 5,781         |
| 31-C-11   | Blow-Off  | 7,129       | 6,681         |
| 31-C-13   | Blow-Off  | 6,837       | 4,761         |
| 31-C-14   | Blow-Off  | 4,768       | 4,761         |
| 31-C-21   | CBD       | 4,265       | 5,782         |
| 31-C-22   | CBD       | 4,283       | 3,678         |

Figure 5. Resulted inspection interval comparison
6. Recommendations

a. Qualitative assessment shall be conducted by responsible person or personnel who knows the actual conditions and has knowledge to do the assessment for looking up any deterioration occurred in the system. Respondents shall be collected as many as possible in terms to achieve accuracy and reliability of the assessment.

b. The qualitative assessment shall be conducted before quantitative assessment such as RBI. This fuzzy method is an alternative in case quantitative assessment take too long time or any sudden strategy shall be taken therefore any assessment shall be conducted as soon as possible. This method is able to be done by local engineers with basic knowledge of corrosion and other damage factors.

c. Research in determining fuzzy value for calculating risk shall be updated. Any modifications shall be applied. Hopefully, in the future the accuracy of fuzzy logic for qualitative assessment is accurate enough so any policies are right taken.

References

[1] Perumal, K. E., 2014. Corrosion Risk Analysis, Risk Based Inspection and a Case Study Concerning a Condensate Pipeline. Elsevier.
[2] Shishesaz, M. R., Bajestani, M. N., Hashemi, S. J. & Shekari, E., 2013. Comparison of API 510 pressure vessels inspection planning with API 581 risk-based inspection planning approaches. Elsevier.
[3] Selvik, J. T., Scharf, P. & Terje, A., 2011. An Extended Methodology For Risk Based Inspection Planning. Research Gate.
[4] American Petroleum Institute, 2016. API RP 580: Risk-Based Inspection. s.l.:American Petroleum Institute.
[5] Singh, M. & Pokhrel, M., 2017. A Fuzzy Logic-Possibilistic Methodology for Risk-Based Inspection (RBI) Planning of Oil and Gas Piping Subjected to Microbiologically Influenced Corrosion (MIC). International Journal of PR essure Vessels and Piping.
[6] Sa'idi, E., Anvaripour, B., Jaderi, F. & Nabhani, N., 2014. Fuzzy Risk Mdelling Process Operations in the Oil an Gas Refineries. Journal of Loss Prevention in the Process Industries.
[7] American Petroleum Institute, 2016. API 581: Risk-Based Inspection Technology. s.l.:American Petroleum Institute.
[8] Dong, Y., 2005. 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.
[9] Leal, G. L. N. & Naked, H. A., 2019. A Fuzzy Logic-Possibilistic Methodology to Analyze the Main Corrosion Damages Mechanisms in Pipes and Equipment Installed in an Oil and Gas Platform. International Journal of Science and Qualitative Analysis, pp. 15-23.
[10] R.T, L., 2011. Inter-rater Reliability. Dalam: D. J. C. B. Kreutzer J.S., penyunt. Encyclopedia of Clinical Neuropsychology. New york: Springer.