Fuzzy Based Design for Third-Party Pipeline Failures in the Niger Delta Region of Nigeria

*[1]ARIAVIE, GO; EMETITIRI, RE; ONONEME, OE; OLOWU, ID

Mechanical Engineering Department, University of Benin, Benin City, Nigeria
ariaviefe@uniben.edu; 2348035615205

ABSTRACT: A Fuzzy based design for assessing failures of pipelines occasioned by third party in the Niger Delta Region of Nigeria has been proposed in this study. Twelve factors earlier identified by Ariavie et al (2010), were further grouped into four, viz : violence, desperation, misconduct and agricultural categories to allow for a less tedious rule base development. Each category has inputs (base inputs) plugged into it which is in turn plugged into another system (main engine). Based on this, the fuzzy model was designed, using MATLAB fuzzy toolbox to develop a hypothetical simulation which simply involves the feeding of randomly generated values between 0 and 1 to the controllers. The evaluation process of the first expert is presented and obtained for the four categories Risk values as 0.533, 0.509, 0.442 and 0.552 for violence, desperation, misconduct and agricultural respectively, with total risk value being 0.063. © JASEM

Introduction
Third-party pipeline failures are occasioned by interference of outside or external forces to the pipeline owners or pipeline itself due to encroachment into the right-of-way of pipelines (Ariavie et al, 2010, Ariavie et al 2011 and Ariavie and Ovuworie, 2012). Third-party risk affects the extent and possibility of harm or loss to humans and pipeline operators (in the form of personal injury or death, environmental degradation, property damage, loss or destruction of facilities). Consequently, it becomes imperative to design against pipeline failures that emanate from third-party activities, so as to eliminate or minimize them as much as possible.

Analysis procedures for third-party pipeline failures have so far been statistical in nature. However, requisite data are sparsely available in most developing countries, including Nigeria hindering mitigation actions that are essential for planning and enhanced decision making. Hence, an alternative that would require less mathematical formulation and rigor becomes imperative and therefore, fuzzy logic comes in handy (Novak et al, 1999). Due to its advantages and wide applicability, fuzzy logic method has gained much development and is discussed in detail as a subject in standard literature (Yager and Filer, 1994; Sivanandam, Sumathi and Deepa, 2001; Novak and Mockr, 1999). Fuzzy logic has become handy and it works well for addressing poorly characterized parameters and linguistic variables (Darbra *et al*., 2008).

MATERIALS AND METHOD
The twelve factors identified by Ariavie *et al.* (2010) as those that affect pipeline safety were adopted in this study. Because of tedious computations, the twelve factors were grouped into four (Table 1) categories allowing for a less tedious rule base development. Each category input (base input) is plugged into another system (main engine) as shown in Figure 1generating a single value at output (defuzzification), which is a fuzzy score assigned to that category. This score in turn is further plugged into the main fuzzy system which gives the risk evaluation value of the studied demographic region. The number of input variables and their associated membership functions determine the number of rules which oftentimes can reflect experiences of the human experts. Each rule reflects a non-linear relationship between independent variables (inputs) and dependent variables (outputs) of the process or system under consideration.

The identified steps taken in the design would include: 1. Identification of the input and output variables (the system's variables), 2. Determination of the ranges of input and output variables, 3. Determination of the membership functions for selected input and output variables, 4. Formation of the set of linguistic rules that represent the

Corresponding author Email: ariaviefe@uniben.edu;

relationships between the system variables, 5. Selection of the appropriate reasoning mechanism to

the formalization of the Fuzzy model (Mamdani inference technique), and; 6. Defuzzification.

**Table 1**: Category Arrangements of Hazardous Factors

Fishing and Farming Activities	Agricultural
Aging Pipeline, Company Operations, Government Neglect, Poor Engineering Construction.	Misconduct
Poverty, Get Rich Quick	Desperation
Revenge, Population Explosion, Militancy	Violence
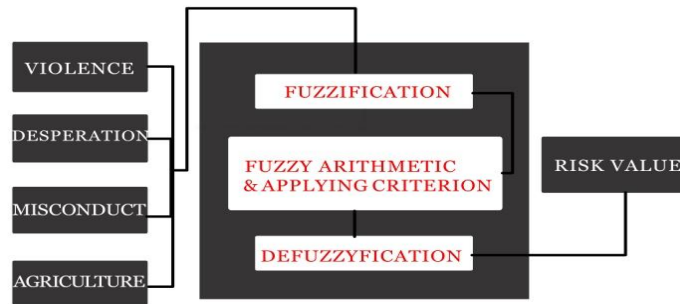
Fig 1: Category Input Layout for Total Risk Factor

Designs for Agricultural Risk Factors: Two factors of Farming and Fishing were combined as input data to give an output variable of Agriculture risk factor. The process of Fuzzification involves the assignment of membership function to the selected input as shown

in figure 2, using three steps grading system for the input variable and five for the output variable. The input and output is modeled with the adoption of the triangular membership function profile on a homogenous scale
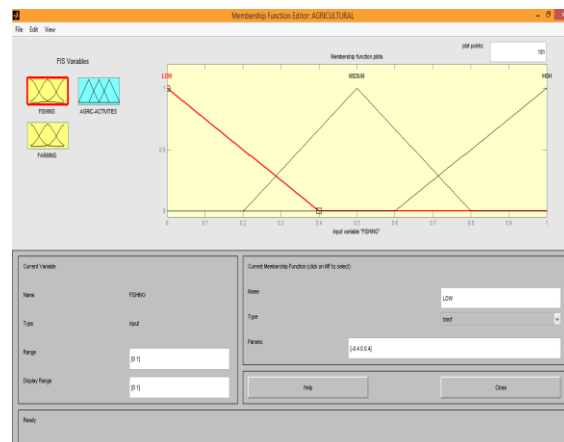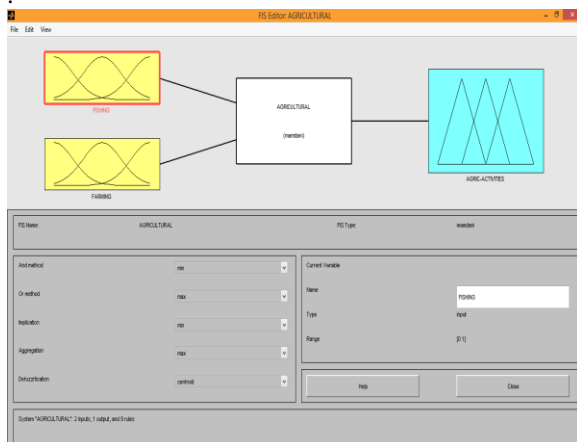
Fig 2: Agricultural Factor Sub Fuzzy System Process Diagram.

The figures above represents a 3 - grade system of ; Low, Medium and high with corresponding range values of (0-0.4, 0.2-0.8, and 0.6-1) and by defining

the if-then statement calibrated by expert knowledge and judgment, a total of 9 rules all displayed in Table 2 is obtained for agricultural risk estimates

Table 2: Rule Table for the Agricultural Risk Sub-Fuzzy Engine

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1	If	Farming	Is	Low	And	Fishing	Is	Low	Is	Agric risk	Is	Very low
2	If	Farming	Is	Low	And	Fishing	Is	Medium	Is	Agric risk	Is	Low
3	If	Farming	Is	Low	And	Fishing	Is	High	Is	Agric risk	Is	Medium
4	If	Farming	Is	Medium	And	Fishing	Is	Low	Is	Agric risk	Is	Low

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5	If	Farming	Is	Medium	And	Fishing	Is	Medium	Is	Agric risk	Is	Medium
6	If	Farming	Is	Medium	And	Fishing	Is	High	Is	Agric risk	Is	High
7	If	Farming	Is	High	And	Fishing	Is	Low	Is	Agric risk	Is	Medium
8	If	Farming	Is	High	And	Fishing	Is	Medium	Is	Agric risk	Is	High
9	If	Farming	Is	High	And	Fishing	Is	High	Is	Agric risk	Is	Very high

The next step defuzzifies the output membership plot by the center of gravity method yielding an output value based on expert input of the agricultural risk factor, and this is related with other category sub fuzzy engine outputs. This design process is continued for the remaining categories using the same input membership function profile. In Simulink of MATLAB, parameters and states are represented by blocks, while signals are represented by the lines that connect blocks. For each subsystem identified, two wo input signals for the Agricultural and Desperation Risk subsystem, five for the misconduct/attack subsystem and three for the violence risk subsystem and one output signals which represents the total risk.

The fourth step: Building the Simulink Block Diagram

This step is extensively the most consuming part of the design. It involves a careful selection of blocks with attributes enough to perform desired function. Careful thinking has been incorporated into designing this fuzzy Simulink system. Figure 4 is an adopted image of the Simulink model for Agricultural and Misconduct/Attack Risk Factors in Matlab.
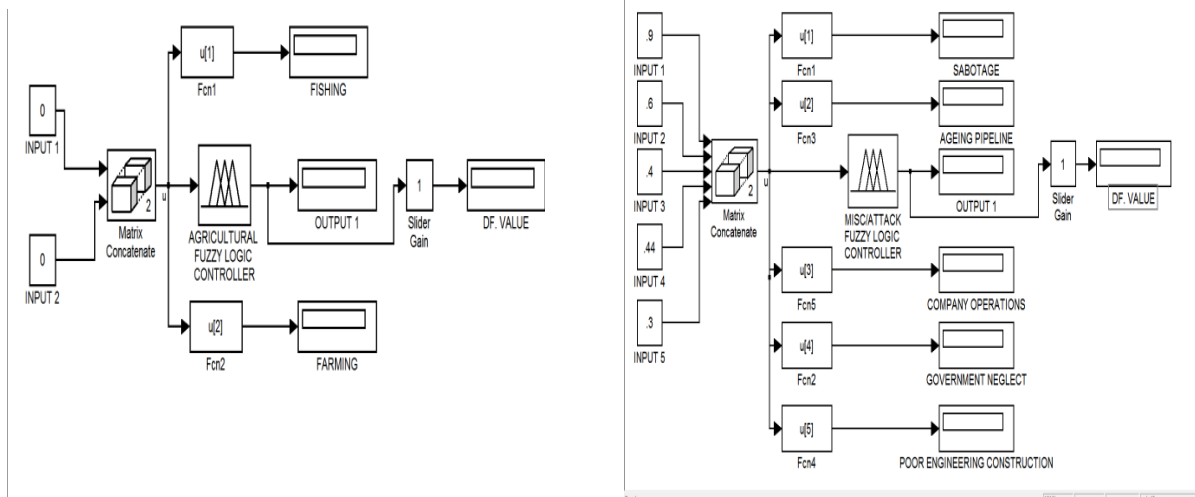
Fig 4: Working Simulink Model for Agricultural and Misconduct/Attack Risk Factors

The fifth step: Running the Simulation: After building the Simulink block diagram, next is to simulate the model and analyze the results. Simulink allows for defining interactive system inputs, simulate the model, and observe changes in behavior. This allows you to quickly evaluate your model.

The sixth step: Validating the Simulation Results: Finally, validate the model accurately and confirm that it represents the physical characteristics of the dynamic system.

With the completion of system design, the next step involves testing to determining whether the system is viable and can be trusted, but before the system is fed with various inputs, the mode of operation needs to be explained. The working process involves a manual feeding of values which are defined by experts opinions, these values can be obtained by utilizing the vivid flexibilities of questionnaires. The basic elements of the questionnaire should include the inputs and a way to pass judgment in relation to their effects on pipeline safety

A scale sample and question could be represented as follows

Question 1: Do you think human poverty has an effect on pipeline safety? Yes   No

If yes, to what extent do you think it affects pipeline safety? Mark the scale to record your opinion.

0 _____ 100

Low   Medium   High
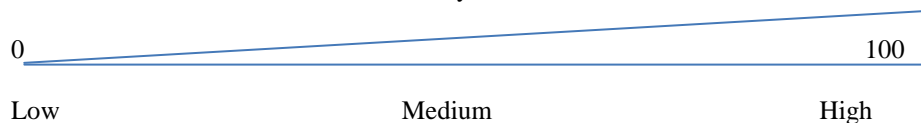
*¹ARIAVIE, GO; EMETITIRI, RE; ONONEME, RE; OLOWU, ID

This is the method by which expert opinion are obtained for a total of 12 inputs, the values are to be precisely read off the scale by measuring the length from the zero point position and interpolating to find the corresponding value with NO being of zero value.

The next step is that of evaluation, a process whence the already modeled system is fed with input in their converted form since the fuzzy scale has a support between 0 and 1 it is therefore necessary to convert the values obtained from percentage to decimal.

Hypothetical Simulation: For a comprehensive understanding of how the system works, an example is vital and for this reason a hypothetic simulation is provided.

The simulation simply involves the feeding of randomly generated values between 0 and 1 to the controllers and ascertaining the risk involved with each combination for these example, four data sets are created representing data inputs from hypothetical experts in its already converted form, this answers are listed in a Table 3

Table 3: Hypothetical Data for Simulation

Agricultural				
Data/input	Expert 1	Expert 2	Expert 3	Expert 4
Fishing	0.7	0	0	0.3
Farming activities	0.4	0.2	0.1	0.4
Misconduct/attack				
Data/input	Expert 1	Expert 2	Expert 3	Expert 4
Sabotage	0.5	0.8	0.75	0.9
Aging piprline	0.9	0.3	0.7	0.6
Company operation	0.7	0.45	0.88	0.65
Government neglect	0.2	0.5	0.62	0.9
Poor engineering	0.81	0.7	0.64	0.5
Construction				
Desperation				
Data/input	Expert 1	Expert 2	Expert 3	Expert 4
Poverty	0.43	0.8	0.7	0.65
Get rich quickly	0.89	0.4	0.5	0.65
Violence				
Data/input	Expert 1	Expert 2	Expert 3	Expert 4
Revenge	0.5	0.8	0	0.7
Population explosion	0.2	0.3	0.5	0.3
Militancy	0.8	0.7	0.7	0.5

With these generated values, evaluation is possible; simply by changing the value at the input nodes to the systems, the risk value can be ascertained. A detailed process on how the first expert data is evaluated will be discussed in the next section, only risk values for the other experts will be presented, bear in mind that they follow the same method of evaluation.

First stage of evaluation: Risk evaluation is carried out by the four models, effected by changing the inputs and running the simulation after which a single value is obtained at the output, each value obtained represents the risk of the factor on the pipelines.

Second stage of evaluation: This stage is almost similar to the first only that the values used here are from the subsystems simulated earlier, the four categories make up the input to this system, as shown in table 4 these category have the headings: Agricultural Risk, Misconduct/Attack Risk, Desperation Risk And Violence Risk.

The routine is re-run using these new values derived from the evaluation of expert 1 data set, and the results of all the experts are given in table 5

Table 4: Evaluated Opinion Result

AGRICULTURAL				
Data/Input	EXPERT 1	EXPERT 2	EXPERT 3	EXPERT 4
Fishing	0.7	0	0	0.3
Farming Activities	0.4	0.2	0.1	0.4
RISK	0.5879	0.1551	0.0800	0.4116
Misconduct/Attack				
Data/Input	EXPERT 1	EXPERT 2	EXPERT 3	EXPERT 4
Sabotage	0.5	0.8	0.75	0.9
Aging Piprline	0.9	0.3	0.7	0.6
Company Operation	0.7	0.45	0.88	0.65
Government neglect	0.2	0.5	0.62	0.9
Poor engineering	0.81	0.7	0.64	0.5
Construction				
RISK	0.5426	0.5574	0.7293	0.7204
Desperation				
Data/input	EXPERT 1	EXPERT 2	EXPERT 3	EXPERT 4
Poverty	0.43	0.8	0.7	0.65
Get rich quickly	0.89	0.4	0.5	0.65
Risk	0.75	0.7491	0.5879	0.5725
Violence				
Data/input	EXPERT 1	EXPERT 2	EXPERT 3	EXPERT 4
Revenge	0.5	0.8	0	0.7
Population explosion	0.2	0.3	0.5	0.3
Militancy	0.8	0.7	0.7	0.5
Risk	0.5	0.6188	0.3806	0.5

Table 5: Subsystem Output

DATA / INPUT	EXPERT 1	EXPERT 2	EXPERT 3	EXPERT 4
AGRICULTURAL RISK	0.5879	0.1551	0.0800	0.4116
MISC./ATTACK RISK	0.5426	0.5574	0.7293	0.7204
DESPERATION RISK	0.75	0.7491	0.5879	0.5725
VIOLENCE RISK	0.5	0.6188	0.3806	0.5
TOTAL RISK	0.533	0.509	0.442	0.522

## RESULT AND DISCUSSION

This section explains the method by which the various risks are combined. A proposed system is to find the mean value of the total risks to produce a single value, taking into consideration every experts opinion. This method would be used for the hypothetical simulation carried out. The mean value is computed for the above as follows using probabilistic theory of mutuality:

Expert1's opinion amounted to a risk value of 0.533; Expert2's opinion amounted to a risk value of 0.509

Expert3's opinion amounted to a risk value of 0.442; Expert4's opinion amounted to a risk value of 0.522
The total risk value for this hypothetical session =
$(0.533 \times 0.509 \times 0.442 \times 0.522) = 0.063$

This value obtained gives a sense of how risky an area is under the scope of assessment.
In order to use the developed model to assess the risk of pipelines failure, the different information and characteristics of the network pipelines can be collected and used as input data to the model. The output of the model is a number that represents the risk of failure of each pipeline and can be represented on a scale (0-10) as shown in figure 5.
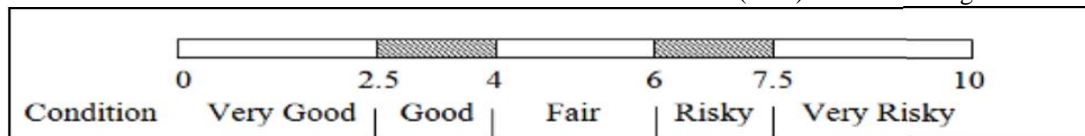
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Fig 5: Proposed Risk of Failure Scale (Fares et al, 2009)

For the assessment session above which yielded a value of 0.063 in the premise of 0 and 1, it is only logical to multiply this value by 10 to use this proposed scale.

Conclusion: In this paper, a fuzzy based design methodology has been proposed for evaluating the risk of oil transport pipelines due to third-party activities. Applicability of the proposed methodology has been tested on a real case in another field. Findings of the case study demonstrated that the proposed methodology can be easily applied by the professionals to quantify risk ratings. An advantage of the proposed methodology is that it will give investors a more rational basis on which to make decisions and it can prevent cost and schedule overruns. Forecasting the measure of risk of a pipeline can be made by any decision maker with the help of the fuzzy rating tool described in this paper, using Fuzzy Logic Toolbox and Simulink. Various risks that endanger complex systems have very difficult mechanisms of activation so precise mathematical modeling of the system is usually too complex for practical application. Fuzzy logic with its built-in toleration to imprecise data is an ideal tool for enhancing the effectiveness of pipeline risk analysis. It is also worth noting that fuzzy logic approach requires real experiences of experts and competent personnel to identify and collect needed data and to build a fuzzy system. However, subjective evaluation is limited especially when compared to other methods.

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