IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received October 8, 2020, accepted November 10, 2020, date of publication November 16, 2020,
date of current version November 27, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.3038061

Development of a Neuro-Fuzzy System for Assessing Information Management on the Shop Floor

EDMARA DOS SANTOS DRIGO[1,2], **JORGE LAUREANO MOYA RODRÍGUEZ**[1], **MARCELO EMBIRUÇU**[1], **AND SALVADOR ÁVILA FILHO**[1]

[1]Polytechnic Institute, Federal University of Bahia, Salvador 40210630, Brazil
[2]Federal Institute of Education, Science and Technology, Palmeira dos Índios 57608180, Brazil

Corresponding author: Edmara Dos Santos Drigo (edmarasd@gmail.com)

This work was supported in part by the Federal Agency for Support and Evaluation of Graduate Education (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, CAPES-BRAZIL), and in part by the National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq-BRAZIL) Productivity of Research Funds Processes 301811/2019-9.

ABSTRACT Communication problems are directly or indirectly related to the causes of industrial accidents. This may be associated with problems in information management at the operational level. Before evaluating information management on the shop floor, a documentary analysis was carried out in this study to identify problems in the communication among the causes of 5 accidents in the oil sector in Brazil. After documentary analysis, an adaptive neuro-fuzzy inference system (ANFIS) was developed to assess information management on the shop floor. A case study was developed with a sample of 120 respondents through the application of a survey. Managers, supervisors, and operators from a land-based oil production region participated in this study. The documentary analysis identified communication problems in 53% of the reports. The neuro-fuzzy model performed well, with the root mean square error (RMSE) being 0.229 in training and 0.296 in data verification. The results suggest that the ANFIS method can be successfully applied to establish a model of analysis of information management on the shop floor.

INDEX TERMS ANFIS, information management, internal communication, organizational communication, shop floor communication.

NOMENCLATURE

IF	Information Management
KM	Knowledge Management
ANFIS	Adaptive Neuro Fuzzy Inference System
RMSE	Root Mean Square Error
NAP	National Agency of Petroleum, Natural Gas and Biofuels
ICT	Information and Communication Technologies
IA	Information Acquisition
IS	Information Storage
ID	Information Distribution
SS83	Alpha Star Drilling Rig
SS69	West Eminence Drilling Rig
P-20	Oil Rig P-20
FPSO	Floating Production Storage and Offloading
CSM	Platform Ship City of São Mateus
OSMS	Operational Safety Management System
X, Y	Input Variables
F	Output Variable
$A_{1,2}, B_{1,2}$	Linguistic Variables
(Π)	Node
$W_{1,2}$	Impact of Rules
$\overline{W}_{1,2}$	Normalization output values
$F_{1,2}$	Degree of Activation of the Consequent
Σ	Sum
F	Output
N	Population Size
n	Sample Size
Z_{α}^{2}	Confidence Level
p	Success Probability
q	Probability of Failure
d	Maximum Error Allowed
FIS	Fuzzy Inference System

The associate editor coordinating the review of this manuscript and approving it for publication was Jenny Mahoney.

I. INTRODUCTION

In the oil industry, problems with communication procedures were among the causes of the most lethal catastrophe in offshore history. The explosion on the Piper Alpha platform culminated in 167 fatalities, with a loss of billions of dollars in the late 1980s [1], [2]. Evidence in investigating other accidents points to a not-so-different scenario, communication problems continue to be reported among the causes of incidents and accidents [3].

Communication problems compromise the safety of procedures, and the lack of information is a challenge for the management of the shop floor [4]. In accident investigation cases, the lack of information hinders the work of the experts, impairs organizational learning, and prevents the creation of barriers to deal with risks [5], [6]. Recent research reveals the interest of the academy in communication on the shop floor [7]–[17]. These studies have contributed to the discussion of the role of communication in the implementation of strategies, employee satisfaction with the organization, and collaborative relationships, highlighting the need for investment in human resources and technological resources.

The risk scenario in the operational sphere of the oil industry justifies the need for information management. Oil exploration and production activities involve risks of damage to human health, the environment, and material damage. Data made available by the NAP (National Agency of Petroleum, Natural Gas and Biofuels) show that in the period between the years 2014 and 2018, 17190 communications on incidents were recorded in Brazil, with 19 fatalities [18]. The benefits of efficient communication for the organization, as well as the risks that problems in the flow of information represent for operational security, are evident in the literature consulted [1]–[3], [5]–[16]. However, it is possible to perceive gaps when it comes to information management in the operational sphere.

This study presents a neuro-fuzzy model for evaluating information management on the shop floor from organizational actions for the acquisition, storage, and distribution of information. This study offers 3 relevant contributions: (i) the finding that communication problems are present among the causes of accidents from the analysis of institutional documents; (ii) the definition of organizational actions for information management in the operational sector; (iii) the definition of a specific model for evaluating information management in the operational sector.

For the development of ANFIS model, a documentary analysis was initially carried out to identify communication problems in the description of the causes of accidents, justifying the need to evaluate information management in the context of the shop floor. 83 reports of implementation of recommendations made available by the NAP were analyzed [19], these reports come from investigations of 5 accidents in the oil sector in Brazil, which occurred between the years 2013 and 2017. After documentary analysis, a neuro-fuzzy model was developed to assess information management on the shop floor, in a land-based oil production region in the Northeast of Brazil. The model considered three input variables: actions to acquire information; actions for storing information; and actions for the distribution of information. Data were collected using a Likert scale questionnaire applied to managers, supervisors and supervisors who work in the operational sphere.

The article is organized as follows: section II provides a theoretical framework, a documentary analysis to identify the communication problem among the cases of accidents in the oil sector, and presents the ANFIS; section III shows the method; and section V presents some conclusions, limitations, and recommendations for future research.

II. THEORETICAL FRAMEWORK

A. INFORMATION MANAGEMENT

Within organizations, information management is an attribution of knowledge management. Knowledge management is a multidisciplinary area that involves technological resources and human factors in order to support the acquisition (creation), storage, distribution and use of knowledge, aiming to ensure competitive advantage and innovation [20], [21].

The emphasis on human resources and their interaction with technologies are common points of three information management models: the ecological model for information management [22]; the procedural model of information management [23]; and the information management model [24]. In the three models, the focus is not only on technology but also on the way people create, share, understand and use information. Therefore, a good internal communication system may not be enough to guarantee good communication, as the attitudes and actions of interpersonal communication also define the success of this system [25].

The appreciation of communication on the shop floor can happen through the balance of investment in technological resources and investment in human resources [26], [27]. In the consulted literature, studies approach the problem of communication on the shop floor from a technological perspective and from a human perspective (subjective). In the search for technological solutions, decision support systems have been developed focusing on the needs of the shop floor operator [4], [16], [28]–[31]. From a subjective perspective, some studies have sought to understand how communication on the shop floor collaborates with the organization [32]–[37].

On the shop floor, the importance of human information management, considering its interaction with ICT (Information and Communication Technologies), is justified because of the participation of communication problems among causes of accidents, by the need for information to deal with risk situations and the influence of the quality of communication on the engagement and satisfaction of the worker with the organization [10], [38]–[40]. The discussion of accidents in the oil sector, such as the Piper Alpha in 1988, the Montara oil spill in 2009, the Deepwater Horizon accident in 2010, and the Gullfaks C accident in 2010, is fruitful for

TABLE 1. KM actions for information management on the shop floor.

Variable	Actions	References
Information acquisition	Internal communication training	[44, 45]
	Instruction on strategic communication in the operational routine	[8, 43, 46]
	Instruction on feedback between shifts	[8, 47]
	Instruction on discussion of written records	[48, 49]
	ICT training	[50]
	IT support for users	[51]
Information storage	Instruction on information needs	[23, 52-55]
	Instruction on the risk of the absence of information about the shift	[38, 56]
	Instruction on detailed routine recording	[56]
	Deployment of ICT appropriate for the specific user	[57, 58]
	Implementation of appropriate communication channels for the task	[56, 59-61]
	IT acceptance observation	[62-64]
Information distribution	Offer of spaces for socializing	[12, 65, 66]
	Instruction on interacting with official emails	[67]
	Guaranteed moments for communication with the supervisor	[25, 68-70]
	Guaranteed moments for operator-operator communication	[71]
	Discussion of observed risks and complex topics	[25, 67, 72, 73]
	Encouragement and acceptance of suggestions	[63]

exemplifying the participation of communication in the set of errors that led to accidents [2], [41], [42]. In the cases mentioned above, the reports cite communication failure, flawed decision-making, insufficient communication about changes in the project, missing or poor-quality information, obsolete and inefficient communication processes.

1) ACTIONS FOR INFORMATION MANAGEMENT ON THE SHOP FLOOR

According to [43], the communication problem is among the causes of industrial accidents, but it is not the specific focus of investigations and investments. In the literature, it is possible to notice the absence of action planning for the management of human information in the operational context. Based on the consulted studies, 18 organizational actions were defined here as essential for the management of information in the operational sphere. The actions are divided into three knowledge management processes: acquisition; storage; and distribution of information. Table 1 presents the Knowledge Management (KM) processes and a brief description of each referenced action.

The actions for acquiring information, in this case, are theoretical and practical institutional training to present the internal communication process and informational strategies [8], [43], [46]. In the internal communication process are the information flows, the practice of continuous feedback, and the use of ICT [8]. Despite institutional training, eventual doubts may arise in communication interaction, and in this situation, the worker must receive support from the IT team [49]–[51].

The actions for storing information are specific instructions on how the information should be recorded after the shift, and on how the ICTs implanted must be suitable for the type of activity and for the users. The worker needs to be instructed on what information to record about his or her operational routine at the end of the shift, about the consequences of the absence of this information, and about the definition of what quality the information is. [23], [38], [52]–[56]. The installed ICTs influence the quality of the records, as well as the other channels (technological or not), and for this reason, the systems and processes for communication must be planned and implemented considering the type of task and the users [56]–[61]. The acceptance of ICT by workers must be observed [62]–[64].

Actions for the distribution of information are opportunities for integration. Spaces for socialization can be understood as informal actions or institutional actions [12], [65], [66]. Integration with communication tools such as institutional email is important because it is a channel for downstream information [67]. The interaction before the shift with the supervisor is an opportunity to discuss the information needed to carry out the task and the risks involved or to offer suggestions [25], [63], [67]–[70], [72], [73]. Communication between operators is essential for discussing shift events, and for discussing written records [71].

B. COMMUNICATION AND ACCIDENTS IN OIL SECTOR

This section presents a documentary analysis to identify the communication problem in the description of the root cause of accidents in the oil sector. The documentary analysis was carried out in four stages.

The first stage is the definition of the documents to be analyzed. The research was carried out from authentic documents: 83 reports of implementation of recommendations from accident investigation provided by the NAP [19]. Accidents occurred between the years 2013 and 2017 in Brazil in 5 different facilities: (i) Alpha Star Drilling Rig (SS-83), (ii) West Eminence Drilling Rig (SS-69) and (iii) Oil Rig P-20, the three accidents in 2013; (iv) FPSO (Floating Production Storage and Offloading) Platform Ship

TABLE 2. Documentary analysis - Alpha Star Drilling Rig case (SS-83).

Report Date	Doc	Communication failure identified	Absence/need for KM action
Circular Letter 002/SSM/2015 07/04/2015 Updated in 09/08/2019	R01, 02 R04 R08	Absence of information to perform the procedure	Instruction on strategic communication Instruction on information needs Guaranteed interaction with the supervisor Ensuring interaction among operators
	R05	Lack of information control Outdated or nonexistent procedures	Instruction on information needs Instruction on the risk of lack of information Implementation of appropriate channels Guaranteed interaction with the supervisor Ensuring interaction among operators
	R06 R07	Insufficient scenario information	Instruction on information needs Instruction on the risk of lack of information Discussion of observed risks and complex topics

City of São Mateus (CSM) in 2015; and (v) Norbe VIII DrillShip in 2017. The second stage is the definition of concepts and terms to be analyzed in the documents. The documentary analysis aimed to identify diagnoses related to communication problems in the description of the root cause of the accidents.

The third stage is the interpretation of written documents. The possible causes were classified according to the requirements of the Operational Safety Management System (OSMS) [74]. The failures were related to the absence and/or need for actions to manage information on the shop floor, shown in Table 1. The fourth stage is the refutation or confirmation of the concepts and terms. The presence of communication failures among the causes of accidents is refuted or confirmed in the light of the interpretation made in the events explored.

The documentary analysis identified failures in the communication in the description of the root cause in 53% of the documents. Communication problems are explicitly described, presenting an unmanaged informational environment in all 5 accidents analyzed.

1) CASE 1: ALPHA STAR DRILLING RIG (SS-83)

The accident in case 1 occurred in 2013, and consisted of a collision between the top drive system and the lifting basket where the operator was located. In the collision, the operator was thrown against the drilling floor. The accident resulted in 1 fatality, and the cause mentioned in the reports was classified, according to the OSMS, as an inadequate operational procedure. Table 2 presents a summary of the analysis of case 1.

Communication problems were reported in 7 of the 8 documents analyzed about the accident at the Alpha Star Drilling Rig. The reports showed a scenario of changes with unrevised, not discussed, unmanaged and uncontrolled risks. According to the analyzed documents, the operator was not trained for the procedure, and the supervisor was absent at the time of the accident. The lack of standard communication to confirm the safe position to be observed for task execution and the lack of information about the scene prevented the control and management of the risks involved in the procedure.

2) CASE 2: WEST EMINENCE DRILLING RIG

The accident at West Eminence Drilling Rig occurred in 2013 and consisted of the breaking of the cable that held the operator while he was working at height. The accident resulted in 1 fatality and the cause pointed out in the reports was classified, according to the OSMS, as a failure in the participation of personnel and inadequate promotion of conditions for the participation of the workforce. Table 3 presents a summary of the analysis of case 2.

The absence of information to perform the procedure is present in the description of the root cause in the reports. The communication failure observed in the reporter's narrative stems from the absence of operators involved in the accident at the meeting before the shift. The absence of information in the discussion before the shift prevented the operator from receiving and discussing guidance about the procedure, about the oil well project, and about the risks involved in the activity.

3) CASE 3: OIL RIG P-20

The accident at Platform P-20 occurred in 2013 when a fire started in the area of chemical tanks. The accident resulted in material damage and plant closure for 4 months. The cause indicated was classified, according to the OSMS, as a failure in the procedure for inspection, testing, and maintenance. Table 4 presents the synthesis of the analysis of case 3.

Of all 7 reports observed, the communication problem was identified in the P-20_R1 report, the failure identified was the absence of information in the inspection records. Without information about the inspection process, it is not known whether the inspection was carried out, who performed it, or what problems were found. Another flaw in the written records is the absence of information on corrective notes: "inspection records were flawed and lacked important

TABLE 3. **Documentary analysis - West Eminence case (SS-69).**

Report Date	Doc	Communication failure identified	Absence/need for KM action
Circular Letter 002/SSM/2017 25/01/2017 Updated in 09/08/2019	R01, 02 R04-07	Absence of information to perform the procedure	Instruction on strategic communication Guaranteed interaction with the supervisor Ensuring interaction among operators

TABLE 4. **Documentary analysis - Oil Rig P-20 case.**

Report Date	Doc	Communication failure identified	Absence/need for KM action
Circular Letter 004/SSM/2018 17/08/2018 Updated in 09/08/2019	R01	Absence of information to perform the procedure	Instruction on strategic communication Instruction on information needs Instruction on the risk of lack of information Instruction on detailed routine recording Implementation of appropriate channels

information to enable traceability and verification of routine performance, such as the identification of the person responsible for carrying out the task, problems found and their location''. It was possible to observe flaws in the communication channel used to record the inspection, as it should require useful information for future consultations and for risk control.

4) CASE 4: FPSO PLATFORM SHIP CITY OF SÃO MATEUS

The accident at the FPSO Platform Ship City of São Mateus was an explosion that occurred in 2015 and resulted in 9 fatalities, 26 injuries and damage to the facility. The causes of the explosion were classified, according to the OSMS, as: change management not carried out; shift change; outdated documents; absence of the supervisory function; outdated / unavailable procedure; incomplete operational procedure and absence of clear instructions; information control failure; lack of clear instructions in the emergency response procedure; failure to identify accidental scenarios; and use of tools in an explosive atmosphere. Table 5 presents the synthesis of the analysis of case 4.

Communication problems are explicit in 52% of the reports available on the accident investigation on the FPSO Platform Ship City of São Mateus. The reports present an unmanaged informational scenario after organizational change. There was no document on change management, and instructions for performing procedures were incompatible with the context. The existing instructions were guidelines for carrying out the procedure before the change. There was no possibility of consultation, as the designs were out of date.

The reports showed problems with the information recorded during the shift change, and information discontinuity for a new supervisor, who had no experience in this function. The absence of instructions for procedures in an emergency situation contributed to the use of ''equipment or tools not suitable for use in an explosive atmosphere''. Analysis of documents shows a lack of information to make decisions in situations of danger.

5) CASE 5: NORBE VIII DRILLSHIP

The accident at the Norbe VIII was an explosion that occurred in 2017 and resulted in 3 fatalities. The cause of the explosion was classified, according to the OSMS, as an incomplete operational procedure. Table 6 presents a summary of the analysis of case 5.

The communication failures identified are the lack of information and guidelines necessary for the safe operation of the boiler. Although there were two official documents, the document that the operators consulted for the operation was limited to four laminated sheets on the wall. This document ''did not contain all the necessary guidelines for the safe operation of the boiler, in addition to not being a document controlled and approved by the operator'' (Norbe VIII_R02).

In view of the analyzed documents, it is possible to conclude that communication problems were present in 53% of the reports analyzed in this study. The result of the documentary analysis indicates the need for information management in the operational area, as well as the evaluation of this management.

6) SYNTHESIS OF DOCUMENTARY ANALYSIS OF THE FIVE ACCIDENTS

The documentary analysis confirmed the role of problems in communication among the causes of the five accidents analyzed, corroborating with [3], [39]. The communication failures identified corroborated with the results of [2], [41], [42].

The reports revealed the need to plan and execute actions to manage information on the shop floor. In the five accidents analyzed from the reports, there was a lack of information

TABLE 5. Documentary analysis - FPSO Platform Ship City of São Mateus Case.

Report Date	Doc	Communication failure identified	Absence/need for KM action
Circular Letter 004 / SSM / 2016 19/04/2016 Updated in 09/08/2019	R01-03 R06 R09, 10	Absence of information about changes	Instruction on strategic communication Implementation of appropriate channels Guaranteed interaction with the supervisor
	R04, 05	Outdated documentation	Instruction on strategic communication Implementation of appropriate channels
	R08	Absence of information recorded at the shift change	Instruction on feedback between shifts Instruction on discussion of written records Instruction on information needs Instruction on the risk of lack of information Guaranteed interaction with the supervisor Ensuring interaction among operators
	R13, 14	Discontinuity of information to a new supervisor	Guaranteed interaction with the supervisor
	R18	Lack of information control Outdated or nonexistent procedures	Implementation of appropriate channels
	R24-34 R50-52	Absence of information to perform the procedure	Instruction on strategic communication Implementation of appropriate channels Guaranteed interaction with the supervisor
	R37-39 R53	Insufficient scenario information	Instruction on information needs Instruction on the risk of lack of information

TABLE 6. Documentary analysis - Norbe VIII Drillship case.

Report Date	Doc	Communication failure identified	Absence/need for KM action
Circular Letter 92/2019/SSM 18/02/2019 Updated in 09/08/2019	R02	Absence of information to perform the procedure	Instruction on strategic communication Implementation of appropriate channels Guaranteed interaction with the supervisor

to perform the procedures. In the context of organizational change, there was an absence of information management after a change. Operators were unaware of the risks involved in performing the procedures, and the scenarios of risks.

C. ADAPTATIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS)

The ANFIS method was introduced by Jang in 1993 [75]. It consists of a fuzzy inference system trained by an artificial neural network. This hybrid tool overcomes shortcomings and takes advantage of both tools: fuzzy logic and artificial neural networks [76].

In the ANFIS architecture, the network is made up of processing units called ''nodes''. These nodes have specific functions gathered in each of the five layers. The system builds a network of realization of the If -Then rules. In the ANFIS architecture (Figure 1), the outputs from the previous layers serve as input for the next layer.

Figure 1 presents an ANFIS architecture with 2 input variables (X, Y) and 1 output variable (F). The first layer represents the fuzzification stage, each input node is an adaptive node, and the degree of adherence to the linguistic term is calculated based on the premise of each rule (A_1, A_2, B_1, B_2).

In the second layer, each node represents a rule (Π), and in this step, its trigger level is calculated, which determines the degree to which the consequent of the rule will be reached. The effect of each rule is represented by W_1 and W_2.

In the third layer, the normalized value of the degree of activation of each rule is calculated. Each node of this layer is labeled N. Normalization output values are represented in $\overline{W}_1$ and $\overline{W}_2$.

In the fourth layer, the output of each neuron is calculated by the normalized output of the previous layer ($\overline{W}_1$ e $\overline{W}_2$) and by the degree of activation of the consequent of the rule (F_1, F_2).

The fifth layer is composed of a single node (σ), where the general sum of the outputs of the received signals is calculated to obtain the precise output of the system (F). The model response is the weighted average of the consequences of the rules [77].

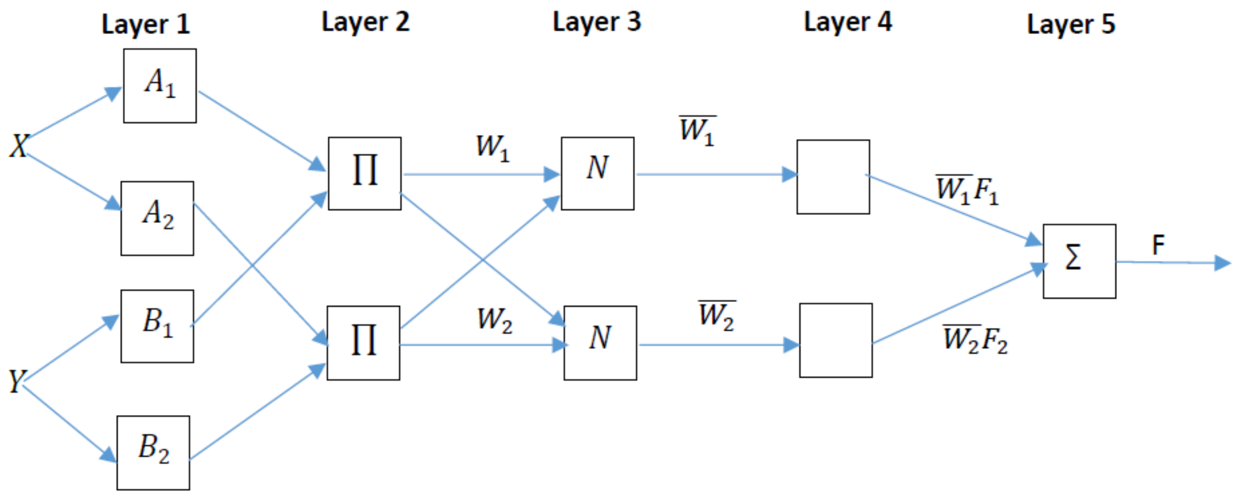

FIGURE 1. ANFIS architecture [76].

The ANFIS model has been used successfully in studies of different areas including economics, education, maritime industry, environmental engineering, as seen in the studies of [78]–[82]. Further details on the mechanism of the ANFIS can be found in the studies of [75], [76], [79], [83].

III. METHOD FOR DEVELOPMENT OF THE ANFIS MODEL FOR ASSESSING INFORMATION MANAGEMENT ON THE SHOP FLOOR

A. DEFINITION OF OBSERVED VARIABLES

The input variables observed in the model were 3 knowledge management processes: acquisition; storage; and distribution of information. For each input variable, 6 indicators were defined, which are knowledge management actions in each process. The variables and indicators are presented in Table 1.

B. DEVELOPMENT OF THE DATA COLLECTION INSTRUMENT AND ITS RELIABILITY AND SAMPLE SIZE DEFINITION

An instrument was developed to collect data from a 5-point Likert scale (1 to 5), with weights (1 to 5) for each indicator. The observed values were multiplied by the weight given to each indicator. The case study was carried out in a land-based oil production region in the Northeast of Brazil. To check the internal consistency of the scale, Cronbach's alpha coefficient was calculated. The instrument used for data collection and the data used in the modeling are available at [84]. The sample size was calculated by Equation 1, proposed by [85]:

$$n = \frac{N \cdot Z_{\alpha}^{2} \cdot p \cdot q}{d^{2}(N-1) + Z_{\alpha}^{2} \cdot p \cdot q} \qquad (1)$$

where n is the sample size, N is the size of the population (108), Z_{α}^{2} is the confidence level 95% (1.96 according to the normal distribution table), p is the probability of success or expected proportion (in this case 50% = 0.5), q is the probability of failure (1- p, in this case 1 - 0.5 = 0.5), and d is the maximum error allowed (0,03%). According to the result of Equation 1, 98 participants would be a sufficient sample. However, the responses of 120 participants were used as input data. The respondents were workers who operate on the shop floor in the positions of operator (92; 77%), supervisor (18; 15%) and manager (10; 8%). The profile is predominantly male, with 118 men and 2 women. Among the respondents 71% had completed high school education as the highest level of education.

To check the internal consistency of the scale and its reliability, Cronbach's alpha coefficient was calculated. The Alpha value must be positive, varying between 0 and 1. The result of calculating Cronbach's alpha coefficient was 0.89 which is therefore considered good on the scale presented by [86].

C. ANFIS PROCEDURE

The model was developed in the *Neuro-Fuzzy Designer* application in the Matlab® software in 4 stages: load data, Generate FIS, train FIS, and test FIS.

1) LOAD DATA

In the first stage, the values resulting from the treatment of the collected data were used as input data for the system. In order to achieve the valid predictions, data are randomly divided into training data with 70 percent, validation data with 15 percent, and testing data with remained 15 percent of data [87]. This division is the standard of the Matlab® and frequently used division ratios [87], [88]

2) GENERATE FIS

In the second stage, the grid partition method was used to generate the FIS. The Grid partition method was used to partition the inputs and outputs of the ANFIS. In this method, two steps are performed repeatedly until reaching the stopping criteria, such as error tolerance and the number of epochs.

First, the consequent parameters are adjusted by the ordinal least squares method, the antecedents being fixed. Then, the consequent parameters are adjusted by the decreasing gradient method, with the consequent fixed.

To generate the FIS, it is necessary to define the type of membership function of the input variables and the type of output variable. The RMSE values were used to determine the best membership function and epoch number in order to select the best fit model. Tests had been carried out with the types of membership functions available in the *Neuro-Fuzzy Designer*; therefore, the Input Membership function Gaussian combination type (*Gauss2mf*) presented the best result. The constant type output was used. Figure 2 presents the ANFIS structure defined.

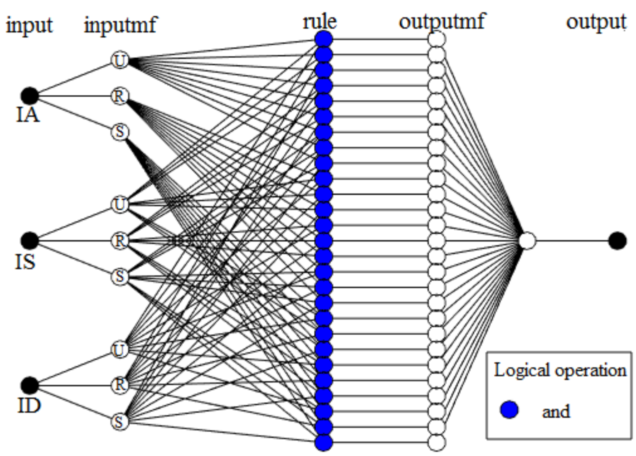

FIGURE 2. ANFIS structure.

The structure of the proposed model is composed of three input variables and 1 output variable. The application automatically created 27 rules "and".

3) TRAIN FIS

In this third stage, the inference system was trained with the hybrid optimization method, which consists of a combination of backpropagation methods (associated with estimates of the parameters of the input pertinence functions) and least squares (associated with estimates of the output parameters of the pertinence functions). The hybrid algorithm is highly efficient in training ANFIS systems [89].

The stopping training criteria defined were: error tolerance equals 10^{-7}, and number of epochs equals 100. As was done in choosing the type of membership function, RMSE values were used to the epoch number. After several tests, the number of epochs with the smallest RMSE was chosen.

Table 7 presents information from ANFIS after training the fuzzy inference system.

4) TEST FIS

In the fourth stage, tests of the fuzzy inference system were performed with training, test, and validation data.

TABLE 7. ANFIS information.

ANFIS Information	Data
Number of nodes	78
Number of linear parameters	27
Number of nonlinear parameters	36
Total number of parameters	63
Number of training data pairs	84
Number of checking data pairs	18
Number of fuzzy rules	27

D. DEFINITION OF FIS PROPERTIES

The fuzzy inference system (Figure 3) has 3 input variables which are: information acquisition (IA); information storage (IS); and information distribution (ID).

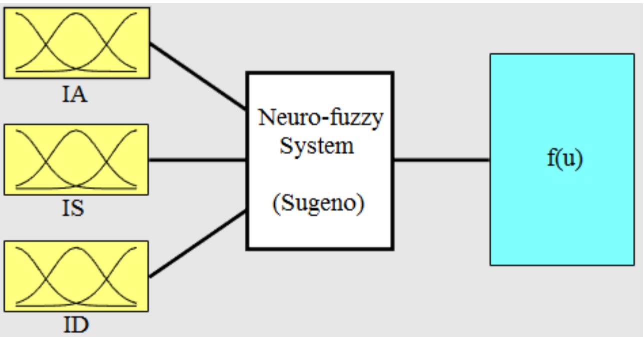

FIGURE 3. Fuzzy inference system.

The membership functions of the gauss2 type were classified as unsatisfactory, regular, and satisfactory in the three input variables. An example is shown in Figure 4.

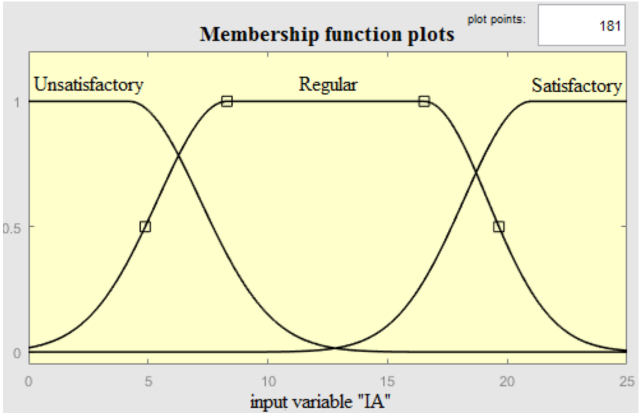

FIGURE 4. Membership function.

The *gauss2* function is the combination of two arguments and two parameters. The first argument determines the left shape of the curve and the second argument determines the right shape of the curve. Table 8 presents the parameters of the membership functions.

After the definitions presented in this section, the results of the model were analyzed and discussed.

TABLE 8. parameters of membership functions.

Input Variable	Linguistic Variable	Parameters (Gauss2mf)
IA	Unsatisfactory	[2.123 -3.75 2.984 4.188]
	Regular	[2.905 8.294 2.652 16.53]
	Satisfactory	[2.84 21.02 2.123 28.75]
IS	Unsatisfactory	[1.93 -1.136 1.843 5.626]
	Regular	[1.986 10.19 2.178 17.2]
	Satisfactory	[2.162 21.54 1.93 28.41]
ID	Unsatisfactory	[2.123 -3.75 3.068 4.29]
	Regular	[2.958 8.355 2.721 16.62]
	Satisfactory	[3.132 20.73 2.123 28.75]

IV. MODEL RESULTS AND DISCUSSION

When meeting the criteria defined for the ANFIS training stop, the RMSE obtained in training the data was 0.229, and 0.296 in the data checking (Figure 5).

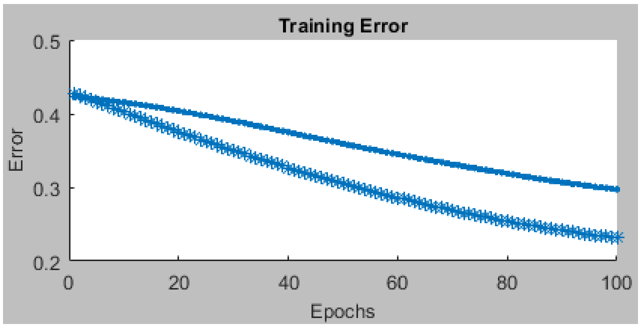

FIGURE 5. Training error.

RMSE was a measure used to evaluate the model's performance and to represent the distribution of errors, thus, less RMSE means less difference between the estimated values and the actual values [90], [91].

Predictive accuracy is improved with decrease in RMSE, the current model produced the smallest RMSE in the hundredth epoch, outperforming the other models in the additional tests performed.

In the *Neuro-Fuzzy Designer* application, the results of the model can be seen in the *Rule Viewer* and *Surface Viewer.*

Based on the *Rule Viewer* results, percentual errors were calculated considering the real values and the simulated values. The percentage errors observed in the variables Information acquisition, information storage and information distribution were 4%, 13% and 3%, respectively. The index for information management on the shop floor was present a percentage error of 5%, the overall accuracy achieved was 95%.

From the *Rule Viewer* results it is possible to carry out simulations to predict the impact that an increase or a decrease in the value of each input variable would cause in the information management index. The three input variables had a positive impact on the output index when their values were increased, up to their maximum values. Similarly, when the variables are decreased, down to their minimum values, there was a decrease in the output index.

In the simulation, when considering the maximum value of the variable IA, there was a positive impact of 16% on the information management index. Likewise, the information management index fell 10% with variable IA at its minimum value. When considering the maximum or the minimum value of the IS variable on the information management index, the positive and negative impact was 2%. When considering the maximum or the minimum value of the ID variable on the information management index, the positive and negative impact was 10%.

In the most positive scenario (the 3 input variables at their maximum value at the same time), information management on the shop floor would increase by 20% and reach an index of 76%. This index (76%) is the maximum value attributed to information management by respondents working on the shop floor. Therefore, even in the best scenario, the results indicate the need to carry out effective actions, such as the actions observed in the indicators of this model, for the management of information in the operational sector of the oil production region where the study was applied.

In the worst case scenario, the information management index would fall by 19% and reach 37%. This information is useful for visualizing the need to plan and execute actions to manage information on the shop floor, and consequently maintain operational security.

Based on the *Surface Viewer* results it was possible to confirm that the three input variables were relevant for determining the value at the output of the model. Figures 6, 7, and 8 show the influence of input variables on the output index.

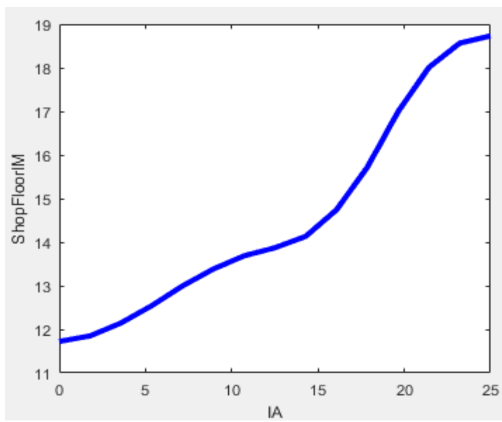

FIGURE 6. Impact of the IA input variable on the output variable.

The relationships between variables and their impact on information management on the shop floor can be observed through three surface graphics generated by the system. Figure 9 shows one of them, where the output variable is information management on the shop floor and the two input variables are: information acquisition; and distribution of information.

Figure 9 shows that the information acquisition input variable was more relevant in determining the output value than the information distribution input variable. The analysis of the other graphs, together with this one, shows that the inputs influence the output more strongly in the following order: information acquisition and distribution. Actions to store

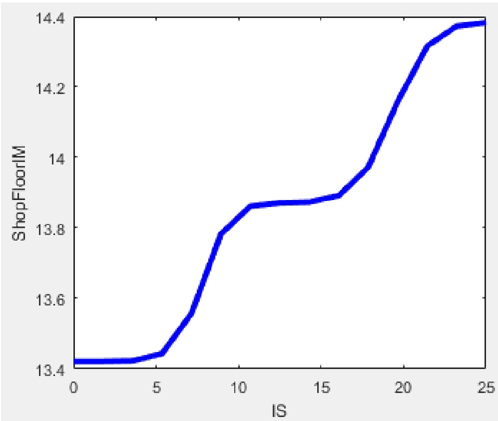

FIGURE 7. Impact of the IS input variable on the output variable.

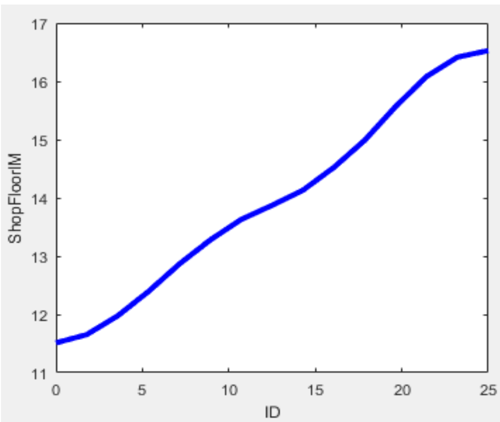

FIGURE 8. Impact of the ID input variable on the output variable.

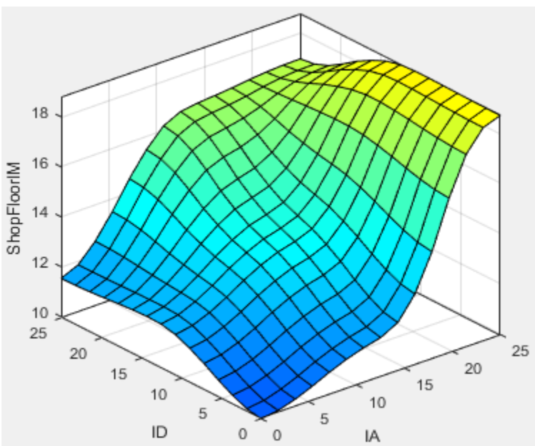

FIGURE 9. Relationship between two of the three input variables with the output variable.

information had a low impact on the information management index.

This result corroborates [22]–[24] regarding the need for the team responsible for information management to know its human resources, facilitate the information acquisition process, create channels and procedures for its systematization and create conditions for its sharing. The actions defined based on the consulted literature (Table 1) considered the need to observe investment in human resources and in the interaction of man with ICT.

The neuro-fuzzy model applied to the oil production region showed that the execution of actions in the information acquisition, storage, and distribution processes influence the information management index in the operational sector. Therefore, information management on the shop floor improves as more (and better) actions are taken to acquire, store and distribute information.

V. CONCLUSION

In this study, a documentary analysis was carried out in order to identify communication problems among the causes of 5 accidents in the oil sector. After documentary analysis, a neuro-fuzzy model was developed to assess information management on the shop floor in a land-based oil production region in the Northeast of Brazil. The model considered three input variables: actions for acquiring information; actions for storing information; and actions for the distribution of information.

From a theoretical point of view, the documentary analysis has contributed to the literature by confirming the participation of problems in communication among the causes of accidents in the oil sector. Previous studies have analyzed the causes of accidents in the sector; however, they did do so with a focus on communication problems. The actions identified in the literature for information management in the information acquisition, storage, and distribution processes were relevant indicators for document analysis and for the neuro-fuzzy model development.

The data for the development of the modeling were collected in an oil production region through an instrument based on a 5-point Likert scale. The instrument showed high reliability and internal consistency by calculating Cronbach's alpha. The errors obtained in the training steps and the test of the fuzzy inference system indicated the good performance and adjustment of the model.

From a practical point of view, the model result showed that the index for information management can increase by 20% if actions to improve communication on the shop floor were carried out. This study identified 18 practical actions that can be implemented for information management. The results of ANFIS model show the need for (re) planning, execution, and monitoring of practical actions for information management on the shop floor. Actions for storing information had a very low impact on the information management index. The simulations shown in the results of this study need to be discussed within the organization.

It is important to note that this study presented 2 limitations: the ANFIS model was developed for the operational sphere of goods-producing industries in the extractive area (i), and the application process or use of the information acquired during the task was not included as an input variable (ii).

(i) The definition of the model (including the variables observed and the development of the instrument for data collection) was discussed within the operational sphere of goods-producing industries in the extractive area. For the goods-producing industry in terms of equipment, for the intermediate goods industry or for the consumer goods industry, adaptations would be necessary after recognizing the context of the operational routine and the relevant variables. The study does not include service nor retail companies.

(ii) Most information and knowledge management models are made up of 4 processes: acquisition; storage; distribution; and use of information. A limitation of this study is the non-inclusion of the application process or use of the information acquired during the task as an input variable. Assessing the use of information is complex, and would depend on the prior existence of actions for the acquisition, storage, and distribution of information. This research would require the implementation of training and communicative practices, access to ICT systems, access to records, conducting interviews, and monitoring the operational routine for a period of time for observation. As an extension of this study, a recommendation is to develop applied research to analyze the process of using the information acquired after executing the actions for managing information on the shop floor defined in this study.

As an extension of this study, for a future work, a recommendation is to develop applied research to analyze the process of using the information acquired after executing the actions for managing information on the shop floor defined in this study.

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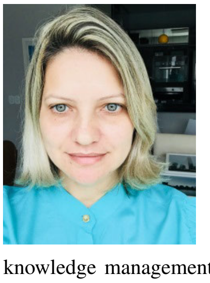


EDMARA DOS SANTOS DRIGO was born in Bandeirantes, Brazil, in 1979. She received the master's degree in industrial engineering from the Federal University of Bahia, Salvador, in 2016, where she is currently pursuing the Ph.D. degree in industrial engineering.

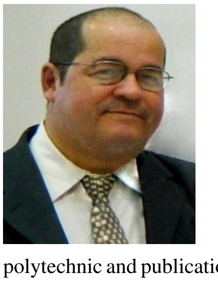
Since 2010, she has been a Professor with the Federal Institute of Education, Science and Technologies of Alagoas, AL, Brazil. She works in research on organizational communication, knowledge management, and human information management in the risk industry.

JORGE LAUREANO MOYA RODRÍGUEZ was born in Cuba. He received the Ph.D. degree in Projeto de Máquinas from the Universidad Central Marta Abreu de Las Villas, UCLV, Cuba, in 1994. He completed three postdoctorates in engineering with the Catholic University of Leuven, Belgium, in 2005, and the Universidad de Oviedo, Spain, in 2008 and 2011, respectively.

He is currently teaching and researching at the Federal University of Bahia. He participates in several projects in universities in Brazil and other countries in the field of mechanical engineering and also participates in multidisciplinary research in industrial engineering.

MARCELO EMBIRUÇU was born in Brazil. He received the master's degree in chemical engineering from the Federal University of Rio de Janeiro in 1993, and the Ph.D. degree in chemical engineering from the Federal University of Rio de Janeiro in 1998.

He was the Dean of Research, Creation and Innovation at the Federal University of Bahia, where he has been a Professor since 1994, and has been a Full Professor since June 2014. He has experience in the areas of industrial engineering, chemical engineering, and control engineering, with an emphasis on sustainable development of processes and products, acting mainly on the following themes: modeling and identification, control of processes and systems, optimization, and polymerization. He is currently teaching and researching at the Federal University of Bahia.



SALVADOR ÁVILA FILHO was born in Salvador, Brazil. He received the master's degree in environmental management and technology in the production process from the Federal University of Bahia, Salvador, in 2004 and 2001, respectively, and the Ph.D. degree in chemical engineering from the Federal University of Rio de Janeiro, Rio de Janeiro, in 2010.

He is currently teaching and researching at the Federal University of Bahia. His research at the polytechnic and publications involve issues such as human aspects of process control, operation production systems, operational reliability, worker profiles in character and personality to human errors, skills to reduce process losses, management and techniques for risk control, human and organizational factors for accident avoidance, and diagnosis of human factors to increase reliability.