Research Article

APPROXIMATE, GENERALIZED FIELD DATA BASED MATHEMATICAL MODELING AND ANN SIMULATION OF PVC PIPE MANUFACTURING PROCESS

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ABSTRACT

PVC pipe extrusion with single screw extruder is the most widely used process among small and medium sized manufacturing industries in India. The increasing importance of plastic extrusion is gaining new dimensions in the present industrial age. This paper shows an idea about the methodology of formulation of field data based mathematical model for the dependent process parameters ($\Pi D1$), pipe dimensions ($\Pi D2$), pipe weight ($\Pi D3$) and productivity ($\Pi D4$) during PVC pipe manufacturing process. It helps to develop an approximate, generalized but reliable model for predicting and optimizing the critical process parameters which affects the quality, productivity of the process. This paper presents the procedure to analyze the impact of field parameters on the performance of PVC pipe manufacturing process. At the end of this work, the findings indicate that the topic under study is of good importance, as no such approach of formulation field data based mathematical models and simulation is adopted for small scale industries engaged in PVC pipe manufacturing.

KEYWORDS: Artificial neural network, field data based mathematical models, PVC pipe extrusion.

BACKGROUND

In present scenario of Indian manufacturing it is found that most of the small and medium scale manufacturer's in the field of manufacturing of PVC pipes are using non-standardized methods to produce PVC pipes. Some of these manufacturers are also located at the area of Maharashtra Industrial Development Corporation (MIDC) of rural regions as well as few at urban regions. It is observed through the field study that such manufacturer's do not seriously bothers about performance evaluation terms viz. quality, productivity, optimization, cycle time reduction and others. Such manufacturer's just wants to produce their PVC pipes and to sale it into the market at low costs. Because of the low cost, these pipes are seen in big demand of purchase by the poor, uneducated farmers and such other customer's. But after some use of such low quality pipes the customer's in said category felt unsatisfied with the problems viz. poor quality and poor performance of the pipes. To overcome these problems the methodology of formulation of field data based mathematical models is supposed to be found fit to produce the optimal type of quality pipes with optimal process parameters and at optimal productivity. For this purpose some small scale industries in these sectors are visited and the detailed study is performed regarding the entire operation of PVC pipe manufacturing process executed at their plants. It is studied that majority of total operation are executed manually and on the basis of trial-error approach. This needs to be focused and develop a mathematical relation which simulate the real input and output data.

Introduction to PVC pipe extrusion using single screw extruder

In the extrusion of plastics (figure 1), raw thermoplastic material in the form of small beads is gravity fed from a top mounted hopper into the barrel of the extruder. Additives such as colorants and UV inhibitors are often used and can be mixed into the main material prior to arriving at the hopper. The material enters through the feed throat (a funnel shaped opening near the rear of the barrel) and comes into contact with the screw. The rotating screw (at around 120 rpm) forces the plastic beads forward into the barrel which is heated to the desired melt temperature of the molten plastic (usually around 200°C). In most processes, a heating profile is set for the barrel in which three or more independently controlled heaters gradually increase the temperature of the barrel from the rear (where the plastic enters) to the front. In most extruders, cooling fans are present to keep the temperature below a set value if too much heat is generated. This extrusion process continues till the die. The die is an upright cylinder with a circular opening similar to a pipe die. The diameter can be a few centimeters to more than three meters across.

Figure 1: PVC pipe extrusion process

Approach of formulation of field data based mathematical model

To start let us assume that the observed phenomenon has four inputs A, B, C, and D. the responses are Y1 and Y2. It is intended to establish the mathematical relationships in much generalized form as under.

$$Y1 = K1 [(A)^{a1}, (B)^{b1}, (C)^{c1}, (D)^{d1}] \ldots\ldots\ldots\ldots (1)$$

$$Y2 = K2 [(A)^{a2}, (B)^{b2}, (C)^{c2}, (D)^{d2}] \ldots\ldots\ldots\ldots (2)$$

This is known as exponential form of the model. Assuming such a form, it is convenient to decide precisely the degree of influence of one input relative to other inputs on the response variable.[2] After having established this, one would be able to decide the inputs which have low influence on the response. Thus this aspect will crystallize the inputs which need attention from the point of view of improving the methods of performing the activity. This is the main purpose of formulation of FDBM for a process. Recalling equations (1) and (2) all needs to be done is to decide 5 unknown in this equation viz. k1, a1, b1, c1 and d1. For this purpose we need only 5 observations. Let us select observation number 1,23, 35, 41 and 48 (out of 50 valid sets of readings) then all this observations values of Y,A,B,C,D are known. As an example for observation 23, may be denoted as Y (23), A (23), B (23), C (23), D (23), then if we substitute these values in equation (1)

$$Y1 (23) = k1 [(A23)^{a1}, (B23)^{b1}, (C23)^{c1}, (D23)^{d1}] \ldots\ldots (3)$$

Taking log on both sides, following log linear relation can be obtained.

$$Log\ Y1 (23) = log\ k1 + a1\ log (A23) + b1\ log (B23) + c1\ log (C23) + d1\ log (D23) \ldots\ldots (4)$$

For observation number 1, 35, 41 and 48 similar equation can be formed. This gives a system set of 5 equations which can be put in matrix from as under

$$
\begin{pmatrix}
\text{Log Y1 (1)} \\
\text{Log Y1 (23)} \\
\text{Log Y1 (35)} \\
\text{Log Y1 (41)} \\
\text{Log Y1 (48)}
\end{pmatrix}
=
\begin{pmatrix}
1 & \log(A1) & \log(B1) & \log(C1) & \log(D1) \\
1 & \log(A23) & \log(B23) & \log(C23) & \log(D23) \\
1 & \log(A35) & \log(B35) & \log(C35) & \log(D35) \\
1 & \log(A41) & \log(B41) & \log(C41) & \log(D41) \\
1 & \log(A48) & \log(B48) & \log(C48) & \log(D48)
\end{pmatrix}
\begin{pmatrix}
\log k1 \\
a1 \\
b1 \\
c1 \\
d1
\end{pmatrix}
\dots (5)
$$

In equation (5) all quantities are known excepting logk1, a1, b1, c1, d1. It is recommended to use MATLAB software for this purpose for making this process of model formulation less cumbersome. If equation (5) is expressed as b=Ax, then to get elemental values in vector x MATLAb-7 allows an operator called 'left division'. In particular, the command x=A\b solves the matrix equation b=Ax. Thus, K1, a, b1, c1, and d1 can be found for one set of 5 readings from the total set of observation taken. Thus if 50 observation are taken then one will arrive at NCR combinations. Here 50C5 will be combination of 50 observations taken any 5 at a time. This will result in 2, 118, 760 possible combinations. Thus arithmetic average of these would probably be the most reliable values of k1, a1, b1, c1 and d1. After completing this laborious task the exact form of model will be obtained.

Formulation of field data based mathematical model

When one is studying any completely physical phenomenon but the phenomenon is very complex to the extent that it is not possible to formulate a logic based model correlating causes and effects of such a phenomenon, then one is required to go in for the field data based models.[1] In view of the dynamic nature of the context under investigation (which reveals complex phenomenon), it is decided that to formulate a field data based models for dependent process parameters (ΠD1), pipe dimensions (ΠD2), pipe weight (ΠD3) and productivity (ΠD4). These models are established adopting methodology of experimentation.[5] It is planned to collect the data by taking extensive observations in the process of PVC pipe extrusion process by actually visiting and PVC pipe manufacturing industries. The planning is carried out by using the classical plan of experimentation [6]. The response data is collected based on the entire generalized models. The approach adopted for formulating approximate, generalized field data based mathematical model suggested by Hilbert (1961) for any complex phenomenon involves following steps as (1) Identification of

independent and dependent variables or quantities. (2) Reduction of independent variables adopting dimensional analysis. (3) Formulation of the model.

Identification of variables and its dimensional analysis

Any physical quantity prevailing in the process under study is designated as process variable.[5] Process variables are categorized as: 1) Independent variables, 2) Dependent variables and. The following process variables are identified and they are grouped in dimensionless pi terms in table 1.

Table 1: Identification of variables and pi terms

Pi term	Code	Description of Pi terms	Pi term equation
Π1	C6	Acceleration due to gravity mm/s2	$\Pi1 = \dfrac{C6 \times C3 \times C2}{C5}$
	C3	Distance of electric motor from the extruder	
	C2	Mass or weight of the electric motor (kg)	
	C5	Torque on electric motor (N-mm)	
Π2	A12	Weight of extruder machine (kg)	$\Pi2 = \dfrac{A12}{A5} \times \dfrac{A1}{A2} \times \dfrac{A3}{A4}$ $\times \dfrac{A7}{A8} \times \dfrac{A6}{A9}$ $\times \dfrac{A10}{A11} \times \dfrac{A14}{A13}$
	A5	Hopper capacity (kg)	
	A1	Extruder machine length (mm)	
	A2	Extruder machine width (mm)	
	A3	Extruder machine height (mm)	
	A4	Barrel centerline from floor (mm)	
	A7	Screw outside diameter (mm)	
	A8	Screw inside diameter (mm)	
	A6	Hopper height (mm)	
	A9	Screw pitch (mm)	
	A10	Barrel length (mm)	
	A11	Barrel diameter (mm)	
	A14	Die length (mm)	
	A13	Die diameter or size (mm)	
Π3	W1	Resin wastage (kg)	$\Pi3 = \dfrac{W9}{W7} \times \dfrac{W7}{W8} \times \dfrac{W5}{W6}$ $\times \dfrac{W3}{W4} \times \dfrac{W1}{W2}$
	W2	Dust (kg)	
	W3	Filter (gm))	
	W4	Chemical wax (gm)	
	W5	TBLS powder (gm)	
	W6	Steric acid (gm)	
	W7	Wastage raw material size (mm)	
	W8	Powder size (mm)	
	W9	Filter material size (mm)	
ΠD1	D1	Screw speed (m/s)	
	D2	Melt viscosity (N-s/m2) or (kg/m-s)	
	D3	Melt density (kg/m3)	
	D4	Extruder pressure (kg/ms2)	
	D5	Die pressure (kg/ms2)	

	D6	Extruder temperature (0C)	$\Pi D1 = \dfrac{D4}{D1} \times \dfrac{D1}{D5} \times \dfrac{D2}{D3}$
	D7	Die temperature (0C)	
	D8	Pipe diameter or size (mm)	
	D9	Pipe wall thickness (mm)	
	D10	Pipe weight (kg)	$\times \dfrac{D3}{D2} \times \dfrac{D7}{D6}$
	D11	Processing time (sec)	
	D12	Productivity	
ΠD2	P1	Pipe diameter (mm)	$\Pi D2 = \dfrac{P1}{P2}$
	P2	Pipe wall thickness (mm)	
ΠD3	Y1	Pipe weight (kg)	$\Pi D3 = Y1$
	Y2	Processing time (sec)	
ΠD4	T2	Productivity	$\Pi D4 = \dfrac{Y1}{Y2} \times Y2/Y1$

Dimensional analysis is the best known and the most powerful technique of reducing the number of variables and making the experimental plan compact without loss of generality or control.[3] Dimensional analysis, basically, helps in deciding algebraic relationship amongst the various physical quantities encountered in the process.[4] Using Buckingham π theorem following dimensional equation is formed. Three independent pi terms (Π1, Π2, Π3,) and four dependent pi terms (ΠD1, ΠD2, ΠD3, ΠD4,) have been in the design of experimentation and are available for the model formulation. Independent Π terms = (Π1, Π2, Π3), Dependent Π terms = (ΠD1, ΠD2, ΠD3, ΠD4,). Each dependent Π is assumed to be function of the available independent Π terms,

For Process Parameters (ΠD1), ΠD1 = k1 x (Π1) ^{a1} x (Π2) ^{b1} x (Π3) ^{c1} ------------ (6)

For Pipe Dimensions (ΠD2), ΠD2 = K2 x (Π2) ^{a2} x (Π2) ^{b2} x (Π3) ^{c2} ------------ (7)

For Pipe Weight (ΠD3), ΠD3 = k3 x (Π3) ^{a3} x (Π3) ^{b3} x (Π3) ^{c3} ------------ (8)

For Productivity (ΠD4), ΠD4 = k4 x (Π4) ^{a4} x (Π4) ^{b4} x (Π4) ^{c4} ------------ (9)

By adopting the approach given above, the field data based mathematical models are formulated as given below

(1) $(\pi_{D1}) = 23.77935114 . \{(\pi_1)^{0.4389} . (\pi_2)^{-0.7474} . (\pi_3)^{0.4155}\}$

(2) $(\pi_{D2}) = 4.87E + 01 . \{(\pi_1)^{0.4416} . (\pi_2)^{-0.4445} . (\pi_3)^{0.1504}\}$

(3) $(\pi_{D3}) = 3.15E + 00 . \{(\pi_1)^{0.6958} . (\pi_2)^{-0.8655} . (\pi_3)^{0.5223}\}$

(4) $(\pi_{D4}) = 4.33E - 01 . \{(\pi_1)^{-0.0572} . (\pi_2)^{0.0948} . (\pi_3)^{-0.3847}\}$

Artificial Neural Network (ANN) based simulation

Artificial neural networks (ANN) can replicate numerous functions of human behavior,[6] which are formed by a predetermined number of layers with altered computing elements called neurons. In order to build a network, the neurons are interrelated. The crowd of connections determines the form and objectives of the ANN.[7] The processing capacity of the network is stored in the inter unit connection strengths, or weights, which are tuned in the learning process.
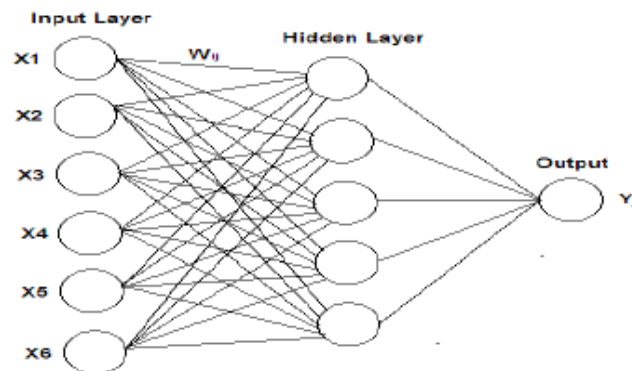

Figure 2: Basic structure of ANN 6/5/1 network

The various steps[7][8] followed in developing the algorithm to form ANN are: (1) The observed data from the experimentation is separated into two parts viz. input data or the data of independent pi terms and the output data or the data of dependent pi terms. The input data and output data are imported to the program respectively. (2) The input and output data is read by prestd function and appropriately sized. (3) In preprocessing step the input and output data is normalized using mean and standard deviation. (4) Looking at the pattern of the data, feed forward back propagation type neural network is chosen. (6) This network is then trained using the training data. The computation errors in the actual and target data are computed and then the network is simulated. In this work the main issue is to predict the future result. In such complex phenomenon involving non-linear system it is also planned to develop Artificial Neural Network (ANN). The output of this network can be evaluated by comparing it with observed data and the data calculated from the mathematical models. For development of ANN the designer has to recognize the inherent patterns.[9] Once this is accomplished training the network is mostly a fine-tuning process.[10] Following graphs shows the comparison and neural network predictions for all four models

For model 1: $(\pi_{D1}) = 23.77935114.\{(\pi_1)^{0.4389}.(\pi_2)^{-0.7474}.(\pi_3)^{0.4155}\}$
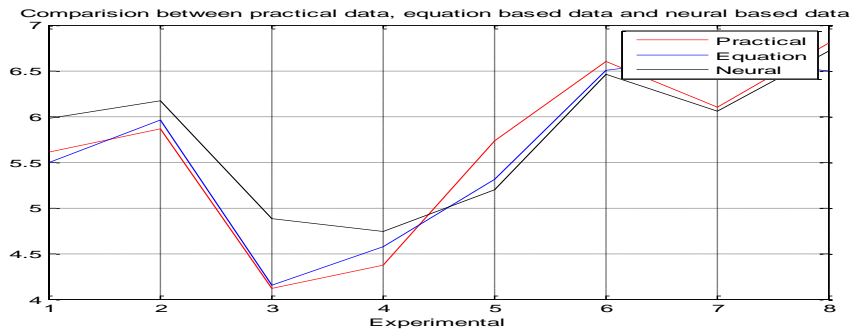
Figure 3: Comparison of results of experimental, model and ANN for model 1.
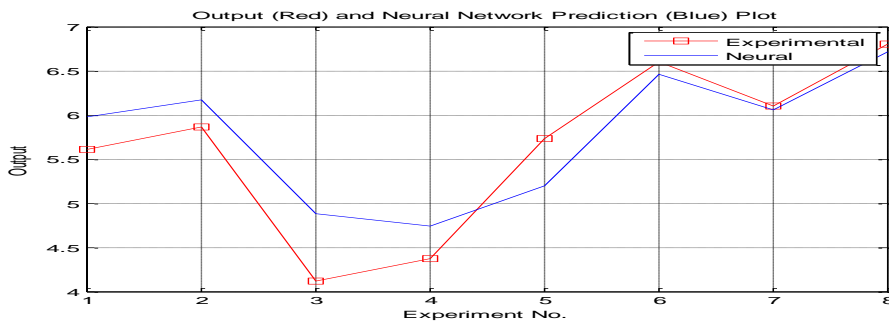

Figure 4: Neural network predictions for model 1.

For model 2: $(\pi_{D2}) = 4.87E + 01.\{(\pi_1)^{0.4416}.(\pi_2)^{-0.4445}.(\pi_3)^{0.1504}\}$
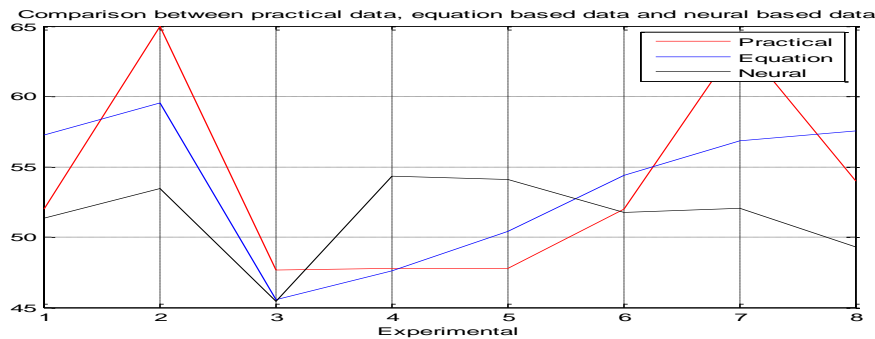

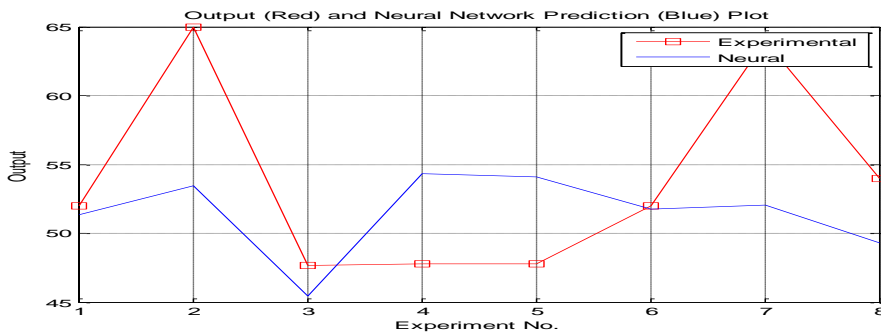**Figure 5: Comparison of results of experimental, model and ANN for model 2.**

Figure 6: Neural network predictions for model 2.

For model 3: $(\pi_{D3}) = 3.15E + 00.\{(\pi_1)^{0.6958}.(\pi_2)^{-0.8655}.(\pi_3)^{0.5223}\}$
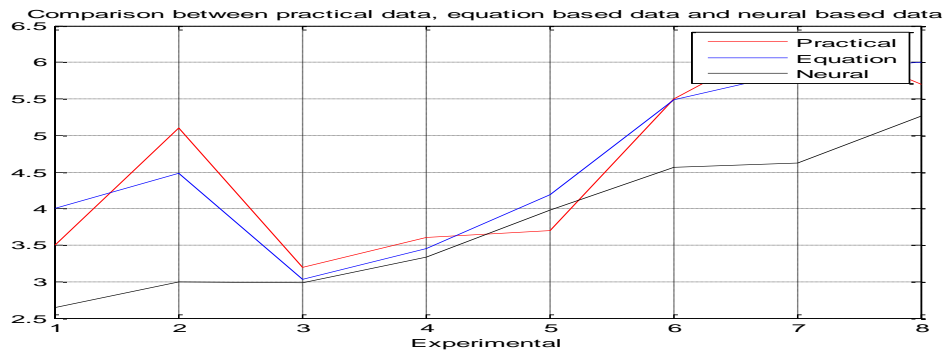

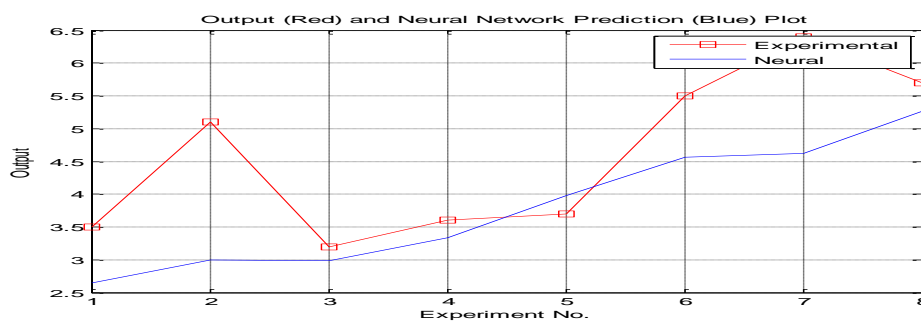**Figure 7: Comparison of results of experimental, model and ANN for model 3.**

Figure 8: Neural network predictions for model 3.

For model 4: $(\pi_{D4}) = 4.33E - 01.\{(\pi_1)^{-0.0572}.(\pi_2)^{0.0948}.(\pi_3)^{-0.3847}\}$
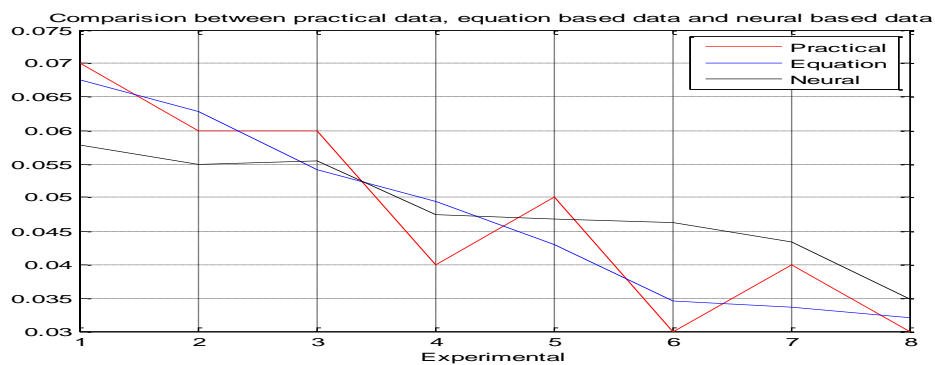

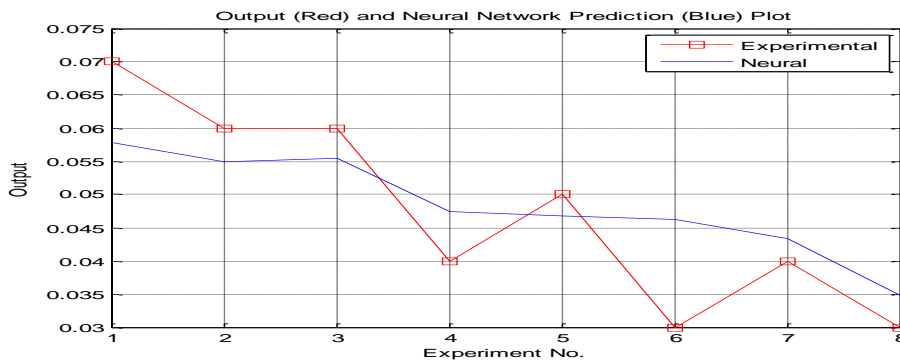**Figure 9: Comparison of results of experimental, model and ANN for model 4.**

Figure 10: Neural network predictions for model 4.

CONCLUSION

Most of the owners of small scale manufacturer's of PVC pipe manufacturing firms are not aware as to what extent the relationship exists between various inputs of PVC pipe manufacturing process. This can be achieved through formulation of field data based mathematical modeling. From the results it is seen that the mathematical models can be successfully used for the computation of dependent terms for a given set of independent terms. The mathematical model formulated is used to analyze the data and to establish relationship between different variables of PVC pipe manufacturing process. From ANN simulation modeling "Intensity of interaction of inputs on deciding Response "can be predicted which will help to control the variable for the desired results.

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