Modeling the woven fabric density by using multiple linear regression and feed forward back propagation artificial neural networks

N. Haleem* and A. Rehman**
*Faculty of engineering and technology, National Textile University, Faisalabad, Pakistan
** Department of Textile Chemistry, National Textile University, Faisalabad, Pakistan

Abstract— **Fabric density plays a vital role in deciding various technical aspects of the fabric processing as well as serviceability parameters of the end product. Comfort properties of the garments along with its mechanical behavior and performance parameters are also directly related to weight per unit area of the fabric. In specific cases the buyer demands for a particular fabric density depending on end use of the product. In order to precisely model and simulate the mechanical and thermal behavior of the woven fabric and optimizing the weaving process by varying significant input variables it is quite necessary to accurately predict the value of fabric density. A large number of process and material based variables were initially selected to predict the weight per unit area of the woven fabric and most significant ones on the basis of Pearson's correlation analysis were sorted for designing regression equation and artificial neural network model. Feed forward back propagation artificial neural network with optimized parameters was utilized for predicting the woven fabric density by means of potential influencing variables i.e. warp and weft count, end and picks per inch, material type, cover factor and float length. A systematic approach was designed for weaving almost 72 samples of fabric in order to train the network and design the regression equation while 20 samples were woven for validating the accuracy of the equation and performance of the neural model. The predicted results of both models were found quite promising and encouraging. A comparative study between regression model and artificial neural network was also carried out on the basis of cumulative percent error between the actual and predicted values of the woven fabric density.**

Key words: Fabric density, regression analysis, artificial neural network, sensitivity analysis

I. Introduction

Fabric density is generally defined in terms of grams per square meter (GSM) of the fabric in weaving industry. Fabric is considered denser if its weight is relatively more in a unit area of the fabric. It is normally measured by cutting the fabric swatch of standard dimensions and weighing it in calibrated scale. Fabric density is an important parameter as in weaving and knitting mills buyer provides certain GSM specifications as per their requirement and possible variation may lead to rejection. [1] The selection of machinery setup for chemical treatment of fabric solely depends on mechanical properties of fabric which is determined by GSM and possible chemical consumption for fabric processing is also dependent on it. [2] In garments industry the sewing thread pretension is affected by fabric weight per unit area. High pretension is required for fabric having higher GSM for better seam performance [3]. Significance of GSM in finishing industry is also considerable. Permeability of heat, smoke, CO and CO_2 mainly depend on fabric weight which is considered important while designing fire retardant and water repellent fabric [4]. The significant serviceability parameters that are affected by fabric GSM are thermal and tactile comfort. Tactile properties relate to mechanical behavior of fabric i.e. compression, stretching, bending, shearing and extensibility while thermal properties refers to heat resistance, water vapor transmission and air permeability. The variation in fabric GSM creates significant direct or indirect changes in these parameters. [5]

In order to have better control of the fabric weaving process and justifying customer demand the modeling of fabric density can be a major contribution in this area. The prediction of fabric density before actually weaving the fabric can serve as a logical support for decision making while deciding various machine and process settings and ultimately the optimization of parameters leads the weaving process to improved quality assurance levels resulting in less rejections. In statistics regression analysis is a well known modeling technique that has been successfully applied in different areas of textile industry for predictability of end product parameters. [6-11] Regression modeling works on determining the relationship between response variables and predictors of a particular system and their effect on each other. Certain observations of a system are presented to statistical tool for development of a regression equation which is further validated by presenting the unseen observations. Regression equations models the system with acceptable accuracy level but the only limitation associated with it is its pure linear nature which fails to model any possible non linear relationship among the variables. [12] To accurately simulate the non linear behavior of variables artificial neural networks are used for improved predictability.

In recent decades artificial neural networks (ANN) have found promising applications in textile industry ranging from prediction of fiber parameters to the performance of end product. [13-16] ANN is extensively applied to model the non linear systems because of their ability to learn from presented data called training of a neural network. A well trained and optimized network is then applied to unseen data of the same system and predicted values are retained as outputs. Neural networks are often referred as 'black boxes' because the predicted results are not justifiable by some mathematical relationship and neural models are unable to explain the way it calculated the results. Neural network architecture consists of artificial neurons which are arranged in parallel layers in between the input and output layer. During the training process the weights between the neuron connections are adjusted in a particular way and optimized until a minimum error stage is reached. ANN has been classified in several branches but the class which found maximum application for predictability purposes is feed forward back propagation artificial neural networks in textile industry.

In this study two models had been designed and compared for accurate prediction of fabric density by selective input parameters based on correlation analysis related to material and process. First model was designed using regression in form of an equation that was based on statistical techniques while second model was designed through artificial neural networks which were based on artificial intelligence techniques. Regression analysis and ANN were applied on a data set of 92 fabric samples for predicting the fabric density among which 72 samples were utilized for training of the network while 20 samples were separated for validating the network. Various machine and process related parameters were initially selected as input variables but extensive analysis that is discussed further suggested a few variables that significantly affected the fabric density. Proposed variables were warp and weft counts, ends and picks per inch, cover factor, material density and fabric construction (which was designated by float length of the fabric). The modeling was carried out by using these variables as the input parameters.

II. MATERIALS AND METHODS

Selection of different levels of materials, counts, float length, end and picks density for construction of the fabric sample was quite diversified. Materials involved were Cotton, Polyester, Lycra, Tencel, Wool and their blends. The data was required in numerical form for modeling purposes, so materials were quantified on the basis of their specific density as it was directly related to the density of the woven fabric. Fabric samples were woven on Tsudakuma ZAX air jet loom. The counts were selected from coarser to finer class and threads density was also taken from loose to tight weave involving intermediate levels. Total fabric samples weaved were 92 which were classified in four different sets of 23 samples on the basis of their construction. The constructions used were 1/1, 2/1, 3/1 and 4/1 while their quantification was carried out by considering the float length of the weaves i.e. 1, 2, 3 and 4 respectively.

Fabric samples from each set were further divided into two classes. 18 samples from each set of 23 were utilized for training purposes of neural networks and deriving the regression equation while 5 samples were reserved for validating the performance and predictability of both models. Hence a total of 72 samples were involved in training while 20 were involved in validation of the results.

Fabric samples were woven and then tested for measurement of weight per unit area through standard procedure. The standard method of fabric density measurement for woven fabrics is ASTM D 3776.

In case of ends and picks determination, ASTM standard method D3775 was used for measurement of both parameters. A standard magnifying glass was placed over a smooth surface of sample and number of end and picks were measured subjectively by skilled laboratory staff.

Warp and weft cover factors were determined by fabric specifications by using the following equation

$$\text{Total Cover Factor (CF)} = [(W1+W2) - (W1*W2)] / 28$$

Where W1 and W2 represent individual warp and weft cover factors respectively.

III. VARIABLE SELECTION AND MULTIPLE LINEAR REGRESSION

A large number of process and material based variations along with the ambient conditions of the weaving shed can potentially affect the density of woven fabric. Multiple variables were selected from the process and material backgrounds and analyzed by the statistical tool for finding the most significant ones. Minitab 15 was used for performing the Pearson correlation analysis on the given data and it was found that ends per inch (EPI), picks per inch (PPI), warp count (Wp Ct), weft count (Wt Ct), float length (FL), total cover factor of warp and weft yarns (CF) and density of the input material (Dm) contributed the major share in fabric density and these parameters exhibited higher Pearson correlation values with the out put parameter.

The regression equation that was derived from the variables selected by Pearson correlation analysis is as follows

$$\text{GSM} = -91 + 2.16\text{FL} - 0.736\text{EPI} - 1.33\text{PPI} - 0.35\text{Wp Ct} + 0.165\text{Wt Ct} + 9.96\text{CF} + 76\text{Dm} \quad (1)$$

Table 1. Subset of training data set used for making regression equation as well as for training ANN1

Float Length	EPI	PPI	Warp count	Weft Count	Total Cover factor	Material density	GSM
1	55	55	20	20	25.04	1.4524	146
1	76	68	30	30	26.29	1.52	130
1	110	60	40	40	26.88	1.468	116
2	100	52	16	14	38.9	1.4625	275
2	130	100	40	40	36.37	1.4524	156
2	165	89	100	100	44.22	1.52	222
3	85	56	12	16	40.7	1.52	333
3	132	70	30	30	39.75	1.468	209
3	195	102	40	40	46.96	1.52	204
4	150	74	30	16	45.64	1.50752	254
4	203	115	60	40	44.39	1.4992	165
4	170	110	60	60	36.15	1.52	129

The statistical tool showed accuracy level of the regression equation through R-square value in terms of percentage. In this particular case of modeling fabric density the R-square value was found to be 93.8% which was having a quite acceptable level of data fitting.

IV. Artificial Neural Network

The model designed by MLR (multiple linear regression) was purely based on linear relationships among the variables it was necessary to model the given set of data by means of some non linear modeling technique like artificial neural networks in order to simulate the possibility of non linear relation ship existence in the variables. The improvement in the predictability of model could conclude the non linear relation ship of the variables with each other. Matlab R2010a with neural network toolbox was used to design ANN 1 for modeling fabric density and its architecture is shown in Fig 1.

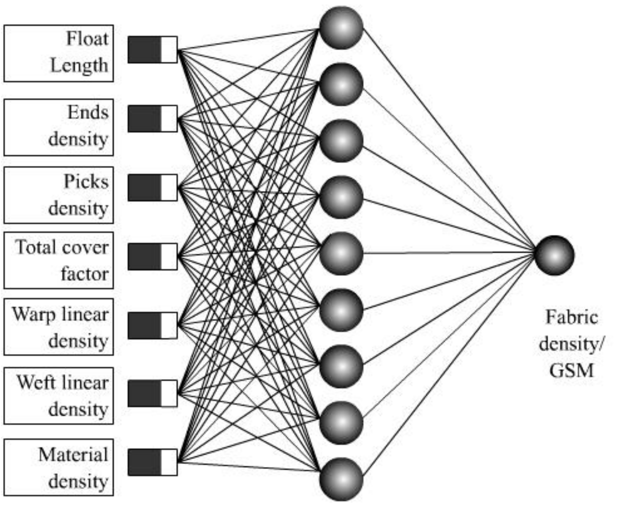

Figure 1. ANN 1 neural network model for woven fabric density

It contained seven input variables that were selected by means of correlation analysis, one hidden layer which contained nine neurons while fabric density was selected at the output end of the neural network. The number of hidden neurons was selected by hit and trial method and hidden neurons which tend to produce least mean square error were considered to be the optimized number of neurons for a particular model.

The network was trained with 72 observations, among which 70% were taken for training, 15% for validation and 15% for testing by the artificial neural network toolbox. Some prominent observations of data which is used for training the model and designing the equation is shown in table 1. There was a large choice available to train the network with different training functions each was logically based on a particular training algorithm. The default choice of training function is generally 'trainlm' which uses Levenberg–Marquardt algorithm for training the neural network. ANN 1 was trained with the same function and a relatively low mean square error was observed while the performance function was set to 'mse' which work on improving the performance of network by reduction of mean square error .

V. Results and Discussion

Two models based on multiple linear regression and artificial neural network were designed for predicting the woven fabric GSM. A data set of 72 samples is utilized to develop the regression equation for statistical modeling and to train the ANN1. The mean prediction error for the regression equation was found to be 5.42% which is relatively more than training error of 3.721% of the neural network ANN1. The comparison of this error safely concludes that neural network model is more able non linear mean of modeling the relationship of variables. A separate data set of 20 samples was saved for validating both of the models. The presentation of data to the statistical and neural models yielded mean error of

3.838% for regression model and 2.489% for neural model. The prediction error was improved in case of ANN1 which means that neural model has relatively better predictability of woven fabric GSM as compared to statistical tool and this reduction of error is related to the ability of neural model to better non linear fitting of data. The prediction and training errors are shown in table 2.

Table 2 Comparison of mean absolute errors of training and validation of data in statistical and neural model

Parameter	Training data		Validation data	
	Regression	ANN1	Regression	ANN1
Mean absolute error %	5.472%	3.721%	3.838%	2.489%

The sensitivity analysis of input variables with fabric density was carried out for both statistical and neural models. Sensitivity analysis is done by setting all variables to the average values except one that is varied from lowest to highest level in all available steps of values. This analysis yields the contribution of each parameter with the response variable i.e. fabric density in terms of percentage. This tool is used for finding the effect of certain variables on the response variable. The sensitivity analysis of statistical model depicted that total cover factor is the most significant parameter contributing to 55% while warp per inch and weft per inch contribute 20% and 17% respectively.

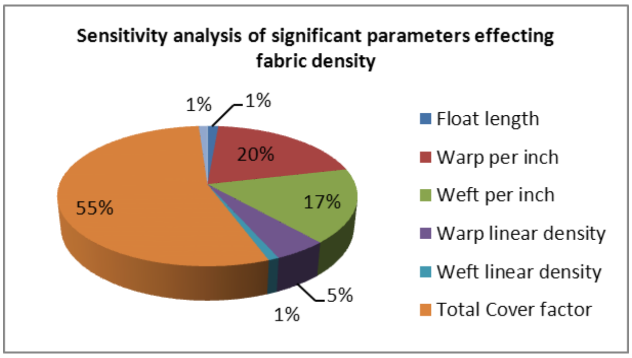

Figure 2. Sensitivity analysis of input variables in statistical model

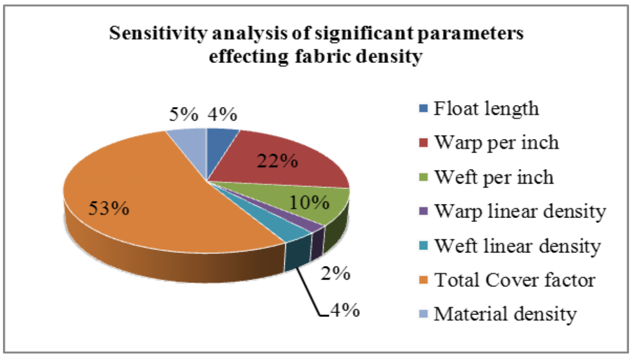

Figure 3. Sensitivity analysis of input variables in neural mode

The remaining factors have trivial contribution while the sensitivity analysis of neural model yields that the vital input variable is total cover factor of the fabric that contributes almost 53% while warp per inch contributes up to 22%. The remaining factors have minor contributions relatively. The reason for major contribution of total cover factor in fabric density lies in the fact that it is a cumulative representative of warp and weft per inch and linear densities. Hence it is safely concluded that the fabric density can be accurately modeled by selecting the significant input variables and utilizing the statistical and neural modeling approaches. However neural modeling is proved to be having better ability of representation of the nonlinear relationships of the variables.

ACKNOWLEDGMENT

We are thankful to Dr. Tanveer Hussain, associate professor and Dean of quality assurance department of National Textile University Faisalabad for sparing his time to provide worthy guidance in carrying out research work and technical writing.

VI. REFERENCES

[1] A.K.M. Masud, A. A. Khalid and F. Abedin, "Quality control by information technology in RMG," *Int. J. Quality and Innovation*, vol. 1, no. 1, pp. 53-64, 2009.

[2] "Dyeing Machinery," *dyespigments.com*,[online]. Available: http://www.dyespigments.com/machinery.html, [Accessed: April 29, 2010].

[3] A. N. Sai Krishnan and L. Ashok Kumar, "Design of sewing thread tension measuring device," *Indian Journal of fibre & Textile Research Journal*,vol. 35, pp. 65-67, March 2010.

[4] T. M. Kotresh, R. Indushekar, M. S. Subbulakshmi, S. N. Vijayalakshmi, A. S.Krishna Prasad, A. K. Agrawal, "Evaluation of Commercial Flame Retardant Polyester Curtain Fabrics in the cone calorimeter," *Journal of Industrial Textiles*,vol. 36, no. 1, July 2006.

[5] B.K. Behara, "COMFORT AND HANDLE BEHAVIOUR OF LINEN-BLENDED," *AUTEX Research Journal*, vol. 7, no.1, pp. 33-47, March 2007.

[6] A. A. Gharehaghaji, M. Shanbeh and M. Palhang, "Analysis of Two Modeling Methodologies for Predicting the Tensile Properties of Cotton-covered Nylon Core Yarns,"*Textile Research Journal*, vol. 77, no. 8, pp. 565-571, August 2007.

[7] Chi Leung Hui and Sau Fun Ng, “Predicting Seam Performance of Commercial Woven Fabrics Using Multiple Logarithm Regression and Artificial Neural Networks,” *Textile Research Journal*, vol.79, no. 18, pp. 1649-1657, December 2009

[8] J. K. C. Lam and R. Postle, “Stepwise regression studies on fabric mechanical blocks in wool/wool blend fabrics,” *Journal of textile institute*, Vol. 98, no. 2, pp. 163 – 168, 2006.

[9] K.P.S. Cheng and H.L.I. Lam, “Evaluating and Comparing the Physical Properties of Spliced Yarns by Regression and Neural Network Techniques,” *Textile Research Journal*, vol. 73, no. 2, pp.161-164, Feb. 2003.

[10] Luo Cheng and David L. Adams, “Yarn Strength Prediction Using Neural Networks Part I: Fiber Properties and Yarn Strength Relationship,” *Textile Research Journal*, vol. 65, no. 9, pp. 495-500, Sep. 1995.

[11] R.L.N. Iyengar and A.K. Gupta, “Some Functions Involving Fiber Properties for Estimating Yarn Tenacity,” *Textile Research Journal*, vol. 44, no. 7, pp. 492-494, July 1974.

[12] "Linear regression Model," *camo.com*, [online] Available: http://www.camo.com/rt/Resources/linear_regression_model.html, [Accessed: June 25, 2010]

[13] W. J. Jasper and E. T. Kovacs, “Using Neural Networks and NIR Spectrophotometry to Identify Fibers,” *Textile Research Journal*, vol. 64, no. 8, pp. 444-448, August 1994.

[14] M. C. Ramesh, R. Rajamanickam and S. Jayaraman, “The Prediction of Yarn Tensile Properties by Using Artificial Neural Networks,” *Journal of textile institute*, vol. 86, no.3, pp. 459 – 469, 1995.

[15] D. Bhattacharjee and V.K. Kothari , “A Neural Network System for Prediction of Thermal Resistance of Textile Fabrics,” *Textile Research Journal* , vol. 77, no. 1, pp. 4-12, 2007.

[16] C. Hui, “A new approach for prediction of sewing performance of fabrics in apparel manufacturing using artificial neural networks,” *Journal of the Textile Institute* , vol. 96, no. 6, pp. 401-405, 2005.