

Prediction and Analysis of Process Control using Artificial Neural Network

K.V. L. N. Murthy¹

Part-time Ph.D. Scholar in Department of Mechanical Engineering,
College of Engineering(A), Andhra University,
Visakhapatnam-3.

VVS Kesava Rao²

Part-time Ph.D. Scholar in Department of Mechanical Engineering,
College of Engineering(A), Andhra University,
Visakhapatnam-3.

Abstract:- Control charts that are used for monitoring the process and detecting the out-of-control signals are important tools for statistical process control. It is simple to estimate source(s) for out-of-control signals in the univariate process, whereas it is difficult to identify the source(s) in the multivariate processes. The reason is that these kinds of processes require monitoring and controlling of more than one quality characteristics simultaneously. Control charts are constructed using T^2 control chart and out of control signals are diagnosed through principal component analysis. In this section, artificial neural network model is proposed for prediction of source(s) for out-of-control signals. This model was implemented in an integrated steel plant for analysis of out of control signals, in production of hot metal process in the blast furnace.

Key words: T^2 control charts, univariate process

1.0 INTRODUCTION

Quality is one of the most important components for success in production. Some techniques have been developed for providing the desired quality. One of the most important techniques is quality control charts. These charts provide monitoring process and detect the source(s) of out-of-control signals. In multivariate processes, multivariate control charts are used for determining the out-of-control signals. The sources of out-of-control signals may also depend on a variable(s) and/or the relationship between variables. Control charts that detect the out-of-control signals are generally created with T^2 statistics. However, with this chart, it is accepted that there is interaction between variables. In this study, a multilayer neural network model has been established for eliminating disadvantages caused by separate evaluation of the variables. The proposed model is based on T^2 control charts, because there was relationship between variables.

If multiple variables, affecting the process, are monitored simultaneously, then multivariate quality control diagrams are used. Hotelling T^2 control diagram, developed by Hotelling based on arithmetic average. Although it is possible to evaluate the variables together and detect out-of-control signals in the process, it is not possible to determine the source(s) for these signals using this chart. Hence in previous chapter, monitoring of multiple

variables is made through T^2 a control chart and detection out-of-control signal in the process is done through principal component analysis with a case study of smelting process in the blast furnace of an integrated steel plant.

In this study, Multi Layer Perceptron (MLP) of Artificial Neural Network model has been proposed for prediction and analysis of out of control Signals caused by multiple variables. Six quality variables have been considered. Initially, data on the six variables is collected during one month period from blast furnace process randomly. These six variables are considered as inputs to the neural network. T^2 values of each observation and class of in control/out of control is considered as outputs to the neural network.

2.0 LITERATURE SURVEY

Gerardo Avendano and Gustavo Andrés Campos-Avendano (2017) [1] described the implementation of the control chart Hotelling's T^2 using real data obtained from the industry. It is concluded that the network has the ability to find out which variables have changed in the process when the Hotelling T^2 chart indicates that a change has occurred.

Igor Grešovnik et al. (2012) [2] developed and applied the framework based on artificial neural networks and an integrated optimization module to adjustment of process parameters in steel production. In the study, results of the model have been examined by experts from steel manufacturing industry, who confirmed that the trends exhibited in various parametric studies are consistent with expectations.

Edgar A. Ruelas-Santoyo et al. (2018) [3] described the application of wear pattern recognition system in carbon steel by employing multilayer perceptron in conjunction with digital image processing. In the study, the proposed system is compared with the human expert and an accuracy of 96.83% is obtained with less time and inspection cost

Owunna. I and A. E.Ikpe (2019) [4] adopted Artificial Neural Network modelling methodology for the TIG welding allowed extensive analysis of each input variables for predicting the best possible sets of output parameters, as well as optimizing the output data to obtain optimum values

Abhulimen and Achebo (2014) [5] investigated optimum properties in Tungsten inert gas weld of mild steel pipes using Artificial neural network prediction and optimization. The study revealed that ANN is successful to in predicting tensile and yield strength of TIG welded mild steel pipe joints .The results reported are in good agreement with other researchers

Tadeusz Wieczorek and Mirosław Kordos (2010) [6] presented neural network methodology for improving the efficiency of the steelmaking process by the measured data of the ladle heating furnace process (chemical compositions, temperature, etc.) to predict how much of particular additions should be added to the process. The authors felt that the results can probably be further improved if the selection of the activation functions in the hidden layer is performed during the training.

Boran and D.D. Diren (2017) [7] proposed model is to detect the source(s) for out-of-control signals without help of anexpert in the process, by using a multilayer neural network. This model was implemented with a case study, in furniture fasteners manufacturing. The authors concluded that with the proposed model, a large number of variables, affecting real processes can be analyzed together is possible.

Francisco Aparisi, José Sanz (2010) [8] designed neural networks to interpret the out-of-control signal of the MEWMA chart, and the percentage of correct classifications is studied for different cases. In this paper the percentage of correct classifications has been studied, obtaining similar results to the use of neural network for the Hotelling's T^2 control chart. In the study the authors developed software for Windows of very easy use, with the objective that the final user in industry can apply this method directly.

Shihua Luo Tianxin Chen and Ling Jian (2018) [9] developed composite model combining Principal Component Analysis (PCA) and Least Squares Support Vector Machine (LSSVM) is established to predict the furnace temperature. Also, in this paper, a new algorithm formed up by combining PCA and LSSVM is used to predict [Si] in Blast Furnace System.

Ishita Ghosh and Nilratan Chakraborty (2018) [10] predicted solidification defects during the continuous casting of steel alloy by employing a multilayer perceptron (MLP) based neural network model. The inputs to this neural model are the various important processing parameters such as Aluminum percent, carbon drop percent in steel production, iron oxide percent in the sand mold, carbon percent, sulphur percent, fraction solid percent and critical temperature. In the study, it has been observed that carbon drop percent during steel production and aluminum percent in the steel alloy have significant contribution in the formation of the shrinkage defect in steel alloy castings

Wei Li et al. (2016) [11], estimated the endpoint of the basic oxygen furnace (BOF) steel making process the endpoint carbon content and the endpoint temperature of BOF. The authors proposed integrated back propagation (BP) neural network and an improved particle swarm optimization (PSO) algorithm to optimize the prediction model

Seyed Taghi Akhavan Niaki and Babak Abbasi (2005) [12], proposed an artificial neural network based model to diagnose faults in out-of-control conditions and to help identify aberrant variables when Shewhart type multivariate control charts based on Hotelling's T^2 is used. The model was implemented with two numerical examples and one case study.

Dipak Laha et al. (2015) [13] made a study on Monitoring and control of the output yield of steel in a steel making. In the study, the authors considered data mining tools such as random forests (RF), ANN, dynamic evolving neuro-fuzzy inference system (DENFIS) and support vector regression (SVR) as competitive learning tools to verify the suitability of applications of these approaches.

McCulloch and Pitts, (1943) [14] introduced ANNs model. ANNs have received a great deal of attention as the theoretical foundations of building learning systems in the late 1950s and early 1960s.

Medhat H.A. Awadalla and M. Abdellatif Sadek (2012) [15] developed a spiking neural network architecture and used for control charts pattern recognition (CCPR). It has a good capability in data smoothing and generalization. The overall mean percentages of correct recognition of SNN-based recognizers were 98.61%.

Barghash, M.A. & Santarisi, N.S. (2004) [16] utilized artificial neural networks (ANN) for pattern recognition of the most common patterns which occur in quality control charts. The results of the study showed that the parameters such as minimum shift, shift range, population size and shift percentage, have significant effect on the performance of the ANN

Nimbale.S.M. and V. B. Ghute (2016) [17] developed neural network scheme for monitoring process mean. The performance of X chart, Tukey's chart and ANN model is evaluated by Average Run Length (ARL) using the simulation under normal and non-normal distributions. From the study, the authors concluded that ANN is effective when compared traditional X chart, in respect of ARL.

Stelios Psarakis (2011) discussed neural networks (NNs) [18] for the detection and determination of mean and/or variance shifts as well as in pattern recognition in the SPC charts. Furthermore the use of NNs in multivariate control charts is also addressed

Mohammad Reza Maleki and Amirhossein Amiri (2015) [19], proposed neural network-based methodology to detects separate mean, variance shifts and simultaneous changes in mean vector and covariance matrix of multivariate-attribute processes. The results of comparison showed that the proposed neural network-based method outperforms the T^2 control chart in most of the simultaneous shifts.

3.0 METHODOLOGY OF THE PROPOSED MODEL

The steps of proposed model are presented below:

Step 1: Collect the data on quality variables

A set of data containing 100 observations is collected for one month randomly. In each observation data on six quality characteristics (Hot metal Yield (Y), %S, %P, %Mn, %CO₂ and PM) of hot metal is collected for multivariate process control and diagnosis of critical characteristics for monitoring of smelting process.

Step 2: Develop the multivariate control chart

T² control chart is developed using Minitab 18 by considering the six quality characteristics of hot metal. The T² value of each observation is also calculated.

Step 3: Determine out-of-control signal for each observation

Out of control signals of each observation is identified from T² chart using upper control limit. T² value of each observation beyond upper control limits is considered as out- of –control. For each observation in-control/out-of-control class is designated.

For example, (1,1,1,1,1,1) means; Yield: in-control, %S-in-control, %P in –control, %Mn in-control, CO₂ in –control and PM-in-control. It is designated as one class.

(0,0,1,1,1,1) means; Yield: out-of-control, %S out-of-control, %P in –control, %Mn in-control, CO₂ in –control and PM-in-control. It is designated as another class.

Similarly various classes are assigned for each observation based on the out-of control of set of variables.

Step 4: Design multi layer perceptron neural network model

Multi layer preceptor neural network model id developed by considering six quality variables as inputs to

the input layer. Two output variables namely: T² value and class of in- control/out-of-control are considered as outputs of the output layer.

Step 5: Run the neural network model

MLP of Neural networks is implemented to the case study using SPSS 18 by considering independent variable (Inputs), dependent variables (Outputs), neural network architecture, and training parameters.

Step 6: Analyze the Results

The output of multilayer perceptron neural network model from SPSS 18 is analyzed for model summary, classification results, predicted values etc.

4.0 RESULTS AND DISCUSSION

Initially, the proposed model was implemented to hot metal production process, in an integrated steel plant with six quality variables for multivariate quality control through T² control chart using Minitab 18. Then, multilayer perceptron of neural network model is implemented using the results (T² values and class of in-control/out-of-control) obtained through multivariate quality control with SPSS18. Results of multivariate quality control through T² control chart and multilayer perceptron of neural network ore presented and discussed below.

4.1 Multivariate quality control through T² control chart

Data on Quality Variables

A set of data on Hot metal Yield (Y), %S, %P, %Mn, %CO₂ and PM containing 100 observations is presented below.

Table-1: Data on quality variables

S.No	Y	S	P	Mn	CO ₂	PM	S.No	Y	S	P	Mn	CO ₂
1	1.4915	0.0549	0.0922	0.0861	26.7662	17.6633	41	1.9994	0.0458	0.0849	0.0808	24.1524
2	1.8056	0.0427	0.0914	0.0835	24.2398	26.9744	42	1.7981	0.0523	0.0863	0.0842	24.9965
3	1.9274	0.0446	0.091	0.0858	25.3491	20.2104	43	1.5994	0.0523	0.0906	0.0845	26.0009
4	1.7945	0.049	0.0878	0.0823	24.9161	25.836	44	2.0372	0.0489	0.0844	0.0806	26.6394
5	1.5561	0.0527	0.0913	0.0853	24.6253	27.7104	45	1.7232	0.0501	0.0891	0.0831	25.2886
6	1.7356	0.0499	0.0888	0.083	25.227	20.904	46	1.3846	0.0575	0.0933	0.0877	27.2759
7	1.9134	0.0471	0.0858	0.0813	24.4236	25.1896	47	1.8082	0.0488	0.0874	0.0821	24.776
8	1.5641	0.0532	0.0912	0.085	26.2277	17.2387	48	1.9305	0.0459	0.0857	0.0812	25.403
9	1.6417	0.0515	0.0901	0.084	25.7379	18.8549	49	1.9196	0.0471	0.0858	0.0813	24.4222
10	1.5807	0.0502	0.091	0.0848	23.6426	16.252	50	1.8344	0.0484	0.0871	0.082	24.7095
11	2.1393	0.0513	0.0937	0.0837	25.5117	27.3977	51	1.6538	0.0513	0.0898	0.0838	25.65
12	1.7857	0.0492	0.0879	0.0824	24.9719	23.7013	52	1.8766	0.0476	0.0865	0.0816	24.5531
13	1.7932	0.0491	0.0878	0.0823	24.9337	24.7902	53	1.6926	0.0504	0.0893	0.0834	25.4447
14	1.5561	0.0534	0.0913	0.0853	26.3251	27.7104	54	1.8666	0.048	0.0867	0.0817	24.6036
15	1.7313	0.05	0.0889	0.083	25.2614	23.2693	55	1.3688	0.0484	0.0864	0.0834	24.0373
16	1.8474	0.0483	0.0871	0.0819	24.6842	15.7458	56	1.6506	0.0513	0.0899	0.0839	25.6952
17	1.4778	0.0552	0.0922	0.0863	26.8351	11.4382	57	1.2698	0.0591	0.0947	0.09	ГТТН
18	1.4047	0.0564	0.093	0.0871	27.2079	15.3513	58	1.5715	0.0473	0.0911	0.0849	Т.Т&Т
19	2.0074	0.0458	0.0849	0.0808	24.1382	24.794	59	1.7336	0.0499	0.0889	0.083	25.2506
20	1.5971	0.0416	0.0907	0.0845	25.3344	21.6647	60	1.9673	0.0463	0.0853	0.0809	24.2398
21	1.6842	0.0507	0.0894	0.0835	25.4848	25.2096	61	1.8094	0.0487	0.0873	0.0821	24.7718
22	1.8761	0.0476	0.0865	0.0816	24.5604	24.2119	62	1.7526	0.0491	0.0865	0.0815	26.0009
23	1.674	0.0509	0.0896	0.0836	25.5245	22.8109	63	1.469	0.0555	0.0924	0.0864	26.929
24	2.0813	0.0493	0.0835	0.0804	25.6507	18.7359	64	1.6518	0.0503	0.0899	0.0764	27.1744
25	1.5199	0.0545	0.0918	0.0858	26.6228	19.3311	65	1.7075	0.0481	0.0893	0.0833	23.9499
26	1.901	0.0472	0.086	0.0814	24.4664	23.1196	66	1.6275	0.0533	0.0919	0.0826	24.5074
27	1.4618	0.042	0.0925	0.0865	26.8953	22.0238	67	1.5919	0.0492	0.0866	0.0861	25.4447
28	1.5641	0.0492	0.0912	0.085	26.0749	17.2387	68	1.731	0.0452	0.0863	0.0808	25.4612

29	1.5345	0.054	0.0916	0.0855	26.48	22.945	69	1.5596	0.0533	0.0912	0.0851	26.2665
30	1.8422	0.0483	0.0871	0.0819	24.6982	16.0969	70	1.5994	0.0407	0.0906	0.0845	25.7672
31	1.394	0.0488	0.0906	0.085	26.3249	22.0178	71	1.6565	0.0513	0.0898	0.0838	25.6454
32	1.793	0.0497	0.0926	0.0839	24.6355	15.1697	72	1.5006	0.0548	0.0922	0.086	26.7342
33	1.7539	0.0497	0.0885	0.0829	25.1422	26.6364	73	1.8196	0.0486	0.0872	0.082	24.74
34	2.1428	0.0427	0.0827	0.0802	23.5048	23.0655	74	1.6981	0.0487	0.0927	0.0848	24.6982
35	1.3974	0.0567	0.0931	0.0873	27.2309	17.1195	75	2.0716	0.0516	0.0838	0.0805	26.3935
36	1.4633	0.046	0.0844	0.0832	24.7152	20.6069	76	1.6374	0.0463	0.0878	0.0852	23.8232
37	2.1892	0.0418	0.0818	0.0801	23.3724	20.7293	77	1.792	0.0491	0.0878	0.0823	24.9407
38	1.5966	0.0438	0.0907	0.0845	25.1704	15.8454	78	1.7105	0.0501	0.0892	0.0832	25.3491
39	1.5309	0.0488	0.0917	0.0855	25.178	22.8396	79	1.8254	0.0485	0.0872	0.082	24.7333
40	1.686	0.0495	0.0853	0.0819	26.48	18.5611	80	1.5194	0.0545	0.0919	0.0858	26.6287

Table-1: Data on quality variables (Contd..)

S.No	Y	S	P	Mn	CO 2	PM	S.No	Y	S	P	Mn	CO 2	PM
81	1.745	0.0499	0.0888	0.0829	25.2014	22.1462	135	1.7424	0.0507	0.0844	0.0805	23.4971	24.4837
82	2.0191	0.0489	0.0847	0.0807	23.8246	20.7982	136	2.1562	0.0426	0.0827	0.0801	23.4971	26.0082
83	1.5928	0.0466	0.0908	0.0845	24.5739	22.535	137	1.5678	0.0521	0.0911	0.0849	24.3921	22.7366
84	1.5715	0.053	0.0911	0.0849	26.1779	26.5707	138	1.7857	0.0535	0.0879	0.0824	25.3255	23.7013
85	2.0187	0.0457	0.0847	0.0807	24.0872	25.1585	139	1.7573	0.0427	0.0838	0.0823	25.2513	18.8454
86	1.7399	0.0499	0.0888	0.0829	25.2175	19.1465	140	1.7593	0.0495	0.0883	0.0827	25.0935	25.0756
87	1.995	0.0471	0.0849	0.0808	24.5232	26.2143	141	1.928	0.0489	0.0858	0.0812	25.1674	20.5101
88	1.5206	0.0469	0.0897	0.0873	24.9337	21.0024	142	1.7968	0.049	0.0878	0.0823	24.8841	23.6743
89	1.7774	0.0492	0.0881	0.0824	24.9965	23.4183	143	1.8666	0.0523	0.0867	0.0817	25.2744	17.9818
90	1.901	0.0518	0.086	0.0814	26.0316	23.1196	144	1.9305	0.0469	0.0857	0.0812	24.3775	25.4362
91	2.1332	0.0427	0.0828	0.0802	23.5285	20.9731	145	1.8844	0.0473	0.0862	0.0814	24.5074	25.6039
92	1.6739	0.0509	0.0896	0.0836	25.5443	26.1117	146	2.1306	0.0428	0.0829	0.0802	23.586	21.9935
93	2.0748	0.0445	0.0838	0.0805	23.8232	27.1298	147	2.0358	0.0453	0.0844	0.0806	24.0489	23.8234
94	1.7031	0.0503	0.0893	0.0833	25.4034	25.9908	148	2.0191	0.0457	0.0847	0.0807	24.0716	20.7982
95	1.5128	0.0499	0.087	0.0822	24.3491	24.4442	149	1.7634	0.0495	0.0883	0.0827	25.0762	22.3246
96	2.1149	0.0473	0.0835	0.0827	24.8706	17.908	150	1.9379	0.0468	0.0857	0.0812	24.3469	14.7679
97	2.0889	0.044	0.0833	0.0804	23.7181	19.358	151	1.5971	0.0524	0.0907	0.0845	26.0092	21.6647
98	1.6385	0.0515	0.0901	0.084	25.7646	24.4176	152	1.7539	0.0497	0.0886	0.0829	25.1438	22.8425
99	2.0798	0.0443	0.0837	0.0804	23.7846	22.9199	153	1.5717	0.0514	0.0869	0.0821	25.5443	19.7778
100	2.0599	0.0448	0.0839	0.0805	23.8993	27.2155	154	2.1254	0.0431	0.0829	0.0802	23.6	23.509
101	1.9409	0.0467	0.0857	0.0812	24.3394	26.1548	155	1.6895	0.0505	0.0894	0.0834	25.4612	22.9209
102	1.5309	0.054	0.0917	0.0855	26.5002	22.8396	156	1.313	0.0582	0.0942	0.0887	27.6172	22.1153
103	2.0599	0.0483	0.0839	0.0805	25.4312	27.2155	157	1.9928	0.0507	0.085	0.0808	27.5172	21.6071
104	2.0716	0.0446	0.0838	0.0805	23.8855	21.0998	158	1.5815	0.0529	0.091	0.0848	26.1635	27.1675
105	1.5191	0.0545	0.0919	0.0859	26.6345	26.2097	159	1.7977	0.0489	0.0878	0.0822	24.8706	18.2192
106	2.0403	0.0452	0.0843	0.0806	24.0219	26.4651	160	1.614	0.0522	0.0905	0.0843	25.9109	23.3491
107	1.5928	0.0526	0.0908	0.0845	26.0898	22.535	161	1.3634	0.0515	0.086	0.0814	24.0219	11.5413
108	1.6271	0.0519	0.0903	0.0842	25.8622	25.1169	162	1.4138	0.0564	0.093	0.0871	27.1744	14.9281
109	1.4915	0.0528	0.0922	0.0861	22.9634	17.6633	163	1.8583	0.0481	0.0868	0.0817	24.6355	23.7408
110	1.884	0.0493	0.0863	0.0815	26.0514	23.17	164	1.995	0.0458	0.0849	0.0808	24.1642	26.2143
111	1.7135	0.0483	0.0967	0.0821	24.2223	17.4587	165	2.0448	0.0451	0.084	0.0806	23.9494	18.9181
112	1.7584	0.0495	0.0884	0.0827	25.1024	19.3841	166	2.0207	0.0456	0.0846	0.0807	24.0701	26.5271
113	1.3219	0.058	0.0942	0.0883	27.5408	18.8045	167	1.5355	0.0539	0.0915	0.0855	26.4794	23.2795
114	1.7193	0.0501	0.0891	0.0831	25.3098	17.7366	168	1.2723	0.0589	0.0945	0.089	27.6356	16.1154
115	1.5327	0.054	0.0916	0.0855	26.487	18.3907	169	1.5464	0.0481	0.09	0.0879	23.8637	15.3259
116	1.9046	0.0443	0.0872	0.0817	23.5048	26.679	170	1.6108	0.0523	0.0905	0.0844	25.9367	25.6348
117	1.9575	0.0501	0.089	0.0837	24.5765	22.5143	171	1.5777	0.0426	0.0867	0.0805	25.7646	23.4897
118	1.7493	0.0488	0.0902	0.0813	24.3868	22.7569	172	1.7652	0.0494	0.0882	0.0826	25.0611	18.592
119	2.0185	0.0457	0.0848	0.0808	24.0971	23.3651	173	1.9028	0.0471	0.086	0.0814	24.4656	22.555
120	1.8272	0.0485	0.0872	0.082	24.7304	23.985	174	1.6029	0.0523	0.0906	0.0844	25.9687	18.8271
121	1.874	0.0529	0.0863	0.0847	25.1422	17.2462	175	2.1124	0.0433	0.083	0.0802	23.6162	18.1662
122	2.1945	0.0468	0.0871	0.0854	25.1506	22.1857	176	1.669	0.0457	0.0897	0.0837	26.8666	12.4178
123	1.7075	0.0502	0.0893	0.0833	25.3843	22.572	177	1.8474	0.0522	0.0871	0.0819	24.4325	15.7458
124	1.6649	0.0511	0.0897	0.0837	24.2636	23.1823	178	1.4121	0.0564	0.089	0.0827	26.7342	19.6577
125	1.5481	0.0537	0.0914	0.0854	26.4351	17.2562	179	1.5776	0.0519	0.0911	0.0849	24.538	22.0483
126	1.7938	0.054	0.0923	0.0815	27.1646	20.8569	180	2.0416	0.0451	0.0842	0.0806	23.9792	26.6844
127	1.8699	0.0477	0.0866	0.0816	24.5852	21.1865	181	1.4828	0.0545	0.0862	0.0824	25.2614	13.5488
128	1.6538	0.0517	0.0898	0.0838	25.1965	13.0942	182	1.4373	0.056	0.0927	0.0869	27.137	18.1476
129	1.5966	0.0524	0.0907	0.0845	26.0095	15.8454	183	2.0372	0.0452	0.0844	0.0806	24.039	15.5775
130	1.5589	0.0533	0.0912	0.0852	26.2716	24.7173	184	1.5678	0.0531	0.0911	0.0849	26.1908	22.7366
131	1.7709	0.0484	0.0881	0.0825	25.8656	21.2082	185	1.4618	0.0557	0.0925	0.0865	26.9845	22.0238
132	1.4894	0.055	0.0922	0.0861	26.772	21.989	186	1.4772	0.0552	0.0922	0.0863	26.8387	20.168
133	1.5191	0.0484	0.0919	0.0859	25.7913	26.2097	187	1.6811	0.0541	0.0867	0.08	23.7655	26.5459
134	1.472	0.0554	0.0923	0.0864	26.8826	10.8692	188	2.077	0.0443	0.0838	0.0804	23.7929	20.0468

Table-1: Data on quality variables (Contd..)

S.No	Y	S	P	Mn	CO 2	PM	S.No	Y	S	P	Mn	CO 2	PM
189	1.7989	0.0502	0.0876	0.0839	26.1635	14.6393	243	1.6276	0.0519	0.0903	0.0842	25.8598	22.865
190	1.5189	0.0546	0.0919	0.0859	26.6455	22.2332	244	1.7075	0.0548	0.0902	0.0806	25.6952	21.6118
191	1.8106	0.0487	0.0873	0.0821	24.7683	26.3628	245	1.943	0.0467	0.0857	0.0812	24.339	26.9357
192	1.8709	0.0477	0.0866	0.0816	24.5765	17.2731	246	1.7473	0.0498	0.0888	0.0829	25.1725	22.8612
193	2.1254	0.0519	0.0829	0.0802	26.6377	23.509	247	1.5355	0.0518	0.0915	0.0855	24.0591	23.2795
194	2.0074	0.0547	0.0849	0.0808	25.9107	24.794	248	1.8037	0.0488	0.0874	0.0821	24.7996	21.1308
195	1.4203	0.0562	0.093	0.087	27.1646	24.381	249	1.6382	0.0509	0.0948	0.0848	23.5285	20.6977
196	1.884	0.0474	0.0863	0.0815	24.5131	23.17	250	1.5484	0.0536	0.0914	0.0854	26.4166	16.5496
197	1.6565	0.0488	0.0898	0.0838	23.689	20.5873	251	2.1306	0.0499	0.0829	0.0802	25.2822	21.9935
198	1.4772	0.0493	0.0922	0.0863	25.8245	20.168	252	2.0813	0.0443	0.0835	0.0804	23.7546	18.7359
199	1.6467	0.0514	0.09	0.0839	25.7213	21.7651	253	1.5189	0.049	0.0919	0.0859	25.2236	22.2332
200	1.5481	0.0541	0.0914	0.0854	24.7139	17.2562	254	1.9897	0.046	0.085	0.0809	24.2223	20.043
201	1.9291	0.0469	0.0857	0.0812	24.3868	22.9829	255	1.7709	0.0493	0.0881	0.0825	25.0268	21.2082
202	1.5302	0.0541	0.0917	0.0856	26.5449	18.5001	256	2.1036	0.0434	0.0831	0.0802	23.6479	22.6864
203	1.9546	0.0497	0.0853	0.0833	25.7213	25.9535	257	1.9379	0.0446	0.0857	0.0812	27.7734	14.7679
204	1.5807	0.0529	0.091	0.0848	26.1647	16.252	258	1.732	0.0499	0.0889	0.083	25.2513	15.3479
205	1.6842	0.0454	0.0894	0.0835	24.5708	25.2096	259	1.5566	0.0533	0.0913	0.0853	26.3249	17.4542
206	1.8441	0.0477	0.0879	0.0837	26.5449	17.0859	260	1.833	0.0484	0.0872	0.082	24.7152	25.7512
207	1.6815	0.0507	0.0895	0.0835	25.5117	15.0795	261	2.2203	0.0411	0.0811	0.0801	23.2822	15.1375
208	2.1744	0.0452	0.0897	0.0837	25.9367	17.3112	262	1.787	0.0504	0.0882	0.083	25.2175	24.4946
209	2.0379	0.0452	0.0843	0.0806	24.0373	22.9044	263	1.6649	0.0512	0.0897	0.0837	25.6071	23.1823
210	1.7945	0.0508	0.0878	0.0823	24.6629	25.836	264	1.6995	0.0445	0.0904	0.083	26.6287	22.9649
211	1.7356	0.0485	0.0888	0.083	25.2467	20.904	265	1.9028	0.0479	0.086	0.0814	25.768	22.555
212	1.4674	0.0505	0.0831	0.0836	24.7718	26.1788	266	1.8601	0.0481	0.0868	0.0817	24.6273	26.4369
213	1.5631	0.0533	0.0912	0.0851	26.2318	18.9892	267	1.8546	0.0482	0.087	0.0818	24.6572	24.9651
214	1.6128	0.0499	0.0868	0.0818	24.0489	22.7546	268	1.4231	0.0562	0.093	0.087	27.1577	13.5973
215	1.944	0.05	0.0914	0.0862	24.776	24.3503	269	1.8551	0.0481	0.0869	0.0817	24.6515	25.5753
216	1.6406	0.0515	0.0901	0.084	25.7433	20.3064	270	1.7214	0.0501	0.0891	0.0831	25.3033	20.7909
217	1.5899	0.0526	0.0908	0.0846	26.1104	25.7896	271	1.5663	0.0531	0.0911	0.0849	26.2078	25.3239
218	1.9928	0.046	0.085	0.0808	24.2223	21.6071	272	1.4697	0.0555	0.0924	0.0864	26.9282	11.0376
219	1.5683	0.0489	0.0845	0.0816	25.3906	17.1566	273	1.5833	0.0528	0.0909	0.0847	26.1543	24.3146
220	1.6776	0.0508	0.0896	0.0836	25.5216	22.9236	274	1.5043	0.0548	0.0921	0.086	26.7054	24.6675
221	1.928	0.0469	0.0858	0.0812	24.3894	20.5101	275	1.5827	0.0528	0.0909	0.0847	26.1556	23.4246
222	1.8687	0.0477	0.0866	0.0816	24.5975	25.2462	276	1.7349	0.0499	0.0888	0.083	25.2367	18.5003
223	2.0802	0.0443	0.0836	0.0804	23.7655	23.3256	277	1.4497	0.0558	0.0927	0.0866	27.0808	13.3057
224	2.0729	0.0446	0.0838	0.0805	23.8637	24.1629	278	1.8805	0.0476	0.0864	0.0815	24.5329	18.114
225	1.7519	0.0497	0.0887	0.0829	25.1506	15.0428	279	1.6882	0.0505	0.0894	0.0835	25.4659	24.6686
226	2.0187	0.0576	0.0847	0.0807	24.2159	25.1585	280	1.5218	0.0544	0.0918	0.0857	26.6085	18.3717
227	1.9351	0.0468	0.0857	0.0812	24.3491	22.1453	281	1.9861	0.0462	0.0852	0.0809	24.2288	24.4741
228	1.5776	0.053	0.0911	0.0849	26.1737	22.0483	282	1.8898	0.0472	0.0861	0.0814	24.4864	25.3094
229	1.6602	0.0453	0.0871	0.0818	24.5531	26.2917	283	1.6614	0.0512	0.0897	0.0837	25.6154	20.6674
230	2.0207	0.0537	0.0846	0.0807	24.8011	26.5271	284	1.6003	0.0523	0.0906	0.0844	25.9896	22.1824
231	2.0052	0.0562	0.0827	0.081	24.7996	23.4319	285	1.5277	0.0541	0.0917	0.0856	26.5532	24.2823
232	1.7059	0.0502	0.0893	0.0833	25.3906	24.2477	286	1.462	0.0556	0.0924	0.0865	26.9662	18.6614
233	2.0263	0.0476	0.0896	0.0827	25.0762	26.8603	287	1.6941	0.0504	0.0893	0.0834	25.4225	24.3083
234	2.2487	0.0409	0.0808	0.08	23.0936	22.4112	288	1.5818	0.0528	0.091	0.0847	26.1571	14.2614
235	1.8605	0.048	0.0868	0.0817	24.6248	25.4641	293	2.1692	0.0425	0.0826	0.0801	23.465	21.8556
236	1.7298	0.05	0.089	0.083	25.2637	24.8036	294	1.7839	0.0492	0.088	0.0824	24.9794	25.0456
237	1.5314	0.054	0.0917	0.0855	26.4927	24.9941	295	1.8407	0.0484	0.0871	0.0819	24.7004	22.5337
238	1.669	0.051	0.0897	0.0837	25.5796	12.4178	296	1.5931	0.0526	0.0907	0.0845	26.0383	ГГ.ГГ
239	1.5578	0.0533	0.0913	0.0852	26.3061	23.3831	297	1.403	0.0565	0.0931	0.0872	27.2239	14.5255
240	1.4373	0.0562	0.0927	0.0869	24.4998	18.1476	298	1.6521	0.0513	0.0899	0.0839	25.6849	16.3442
241	1.9045	0.0471	0.086	0.0814	24.4623	22.5556	299	1.806	0.0488	0.0874	0.0821	24.7792	23.1008
242	1.9134	0.0527	0.0858	0.0813	26.3884	25.1896	300	2.0586	0.0449	0.0839	0.0805	23.8999	25.0646

Table-1: Data on quality variables (Contd..)

S.No	Y	S	P	Mn	CO ₂	PM	S.No	Y	S	P	Mn	CO ₂	PM
301	1.705	0.045	0.085	0.084	24.174	12.094	311	1.929	0.047	0.086	0.081	24.387	22.983
302	1.778	0.053	0.086	0.083	25.206	19.827	312	1.804	0.049	0.087	0.082	24.8	21.131
303	1.895	0.05	0.086	0.085	25.571	25.802	313	1.42	0.056	0.093	0.087	27.165	24.381
304	1.816	0.053	0.087	0.082	24.796	22.882	314	1.535	0.054	0.092	0.085	26.48	22.945
305	1.831	0.052	0.087	0.084	25.765	15.741	315	1.763	0.049	0.088	0.083	25.076	22.325
306	1.855	0.05	0.085	0.084	24.521	21.324	316	1.877	0.048	0.087	0.082	24.553	24.456
307	1.886	0.054	0.085	0.084	24.797	20.171	317	2.036	0.045	0.084	0.081	24.049	23.823
308	1.581	0.054	0.084	0.086	25.396	14.507	318	1.732	0.05	0.089	0.083	25.251	15.348
309	1.829	0.049	0.087	0.084	24.753	17.822	319	2.133	0.043	0.083	0.08	23.528	20.973
310	1.957	0.046	0.089	0.083	25.447	23.947	320	1.674	0.051	0.09	0.084	25.544	26.112

Multivariate control chart

T^2 control chart is developed using Minitab 18 by considering data on the six quality characteristics of hot metal and is shown in Fig.1.

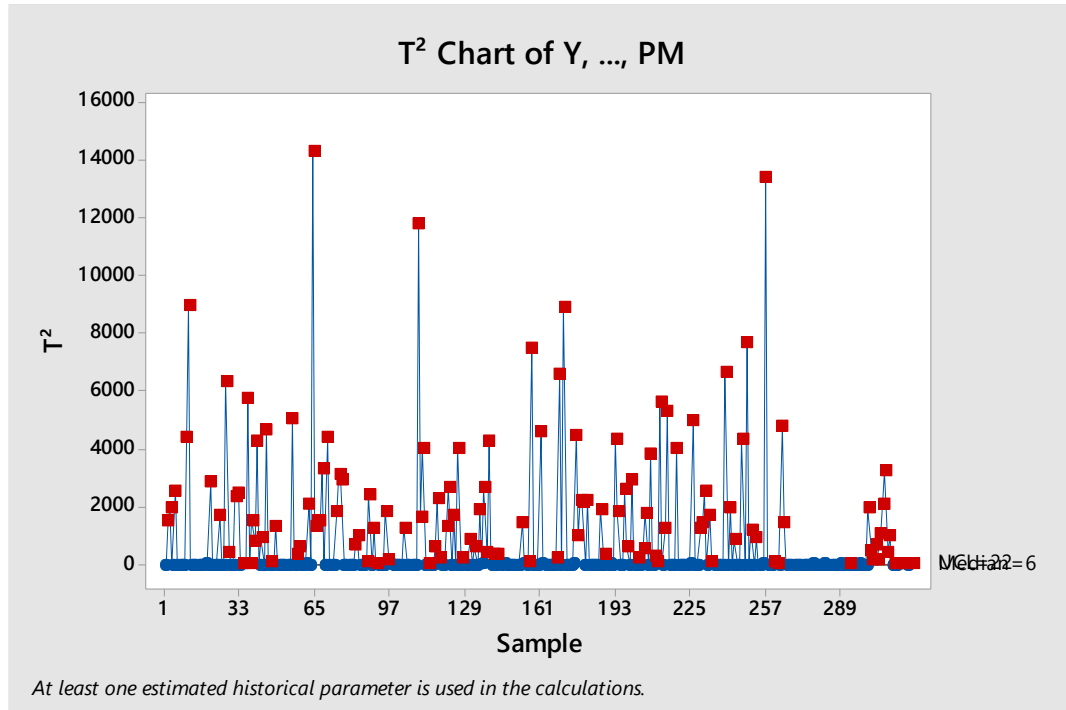


Fig. 1: T2 chart of Y, ..., PM

Out-of-control signal for each observation

Out of control signals of each observation is identified from T^2 chart using upper control limit. For each observation in-control/out-of-control class is identified and presented in Table-2.

Table-2: Out-of-control signals

S.No.	Y	S	P	Mn	CO ₃	PM	CLG	S.No.	Y	S	P	Mn	CO ₃	PM	CLG
1	1	1	1	1	1	1	1	51	1	1	1	1	1	1	1
2	0	0	0	0	0	0	3	52	1	1	1	1	1	1	1
3	0	0	0	0	0	0	3	53	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	54	1	1	1	1	1	1	1
5	0	0	0	0	0	0	3	55	0	0	0	0	0	0	3
6	1	1	1	1	1	1	1	56	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	57	1	0	1	0	0	0	2
8	1	1	1	1	1	1	1	58	0	0	0	0	0	0	3
9	1	1	1	1	1	1	1	59	1	1	1	1	1	1	1
10	0	0	0	0	0	0	3	60	1	1	1	1	1	1	1
11	0	0	0	0	0	1	11	61	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	62	0	0	0	0	0	0	3
13	1	1	1	1	1	1	1	63	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	64	0	0	0	0	0	0	3
15	1	1	1	1	1	1	1	65	0	0	0	0	0	0	3
16	1	1	1	1	1	1	1	66	0	0	0	0	0	0	3
17	1	1	1	1	1	1	1	67	0	0	0	0	0	0	3
18	1	1	1	1	1	1	1	68	0	0	0	0	0	0	3
19	1	1	1	1	1	1	1	69	1	1	1	1	1	1	1
20	0	0	0	0	0	0	3	70	0	0	0	0	0	0	3
21	1	1	1	1	1	1	1	71	1	1	1	1	1	1	1
22	1	1	1	1	1	1	1	72	1	1	1	1	1	1	1
23	1	1	1	1	1	1	1	73	1	1	1	1	1	1	1
24	0	0	0	0	0	1	11	74	0	0	0	0	0	1	11
25	1	1	1	1	1	1	1	75	0	0	0	0	0	1	11
26	1	1	1	1	1	1	1	76	0	0	0	0	0	1	11
27	0	0	0	0	0	0	3	77	1	1	1	1	1	1	1
28	0	0	0	0	0	0	3	78	1	1	1	1	1	1	1
29	1	1	1	1	1	1	1	79	1	1	1	1	1	1	1
30	1	1	1	1	1	1	1	80	1	1	1	1	1	1	1
31	0	0	0	0	0	0	3	81	1	1	1	1	1	1	1
32	0	0	0	0	0	1	11	82	0	0	0	0	0	0	3

33	1	1	1	1	1	1	1	83	0	0	1	0	0	1	12
34	1	1	1	1	1	1	1	84	1	1	1	1	1	1	1
35	1	1	1	1	1	1	1	85	1	1	1	1	1	1	1
36	0	0	0	0	0	0	1	11	86	1	1	1	1	1	1
37	0	0	1	0	1	1	9	87	1	1	1	0	0	1	13
38	0	0	0	0	0	0	3	88	0	0	0	0	0	1	11
39	0	0	1	0	0	1	10	89	1	1	1	1	1	1	1
40	0	0	0	0	0	0	3	90	1	0	0	0	0	1	14
41	1	1	1	1	1	1	1	91	1	1	1	1	1	1	1
42	0	0	0	0	0	0	3	92	1	1	1	1	1	1	1
43	1	1	1	1	1	1	1	93	1	1	1	1	1	1	1
44	0	0	0	0	0	0	3	94	1	1	1	1	1	1	1
45	1	1	1	1	1	1	1	95	0	0	0	0	0	0	3
46	1	0	1	0	0	0	2	96	0	0	0	0	0	1	11
47	1	1	1	1	1	1	1	97	1	1	1	1	1	1	1
48	0	0	0	0	0	0	3	98	1	1	1	1	1	1	1
49	1	1	1	1	1	1	1	99	1	1	1	1	1	1	1
50	1	1	1	1	1	1	1	100	1	1	1	1	1	1	1

Table-2: Out-of-control signals (Contd..)

S.No.	Y	S	P	Mn	CO ₂	PM	CLG	S.No.	Y	S	P	Mn	CO ₂	PM	CLG
101	1	1	1	1	1	1	1	151	1	1	1	1	1	1	1
102	1	1	1	1	1	1	1	152	1	1	1	1	1	1	1
103	1	0	0	0	0	1	14	153	0	0	0	0	0	1	11
104	1	1	1	1	1	1	1	154	1	1	1	1	1	1	1
105	1	1	1	1	1	1	1	155	1	1	1	1	1	1	1
106	1	1	1	1	1	1	1	156	1	0	1	0	0	0	2
107	1	1	1	1	1	1	1	157	0	0	0	0	0	0	3
108	1	1	1	1	1	1	1	158	1	1	1	1	1	1	1
109	0	0	0	0	0	0	3	159	1	1	1	1	1	1	1
110	0	0	0	0	0	0	3	160	1	1	1	1	1	1	1
111	1	1	1	1	1	1	1	161	0	0	0	0	0	1	11
112	1	1	1	1	1	1	1	162	1	1	1	1	1	1	1
113	1	0	1	0	0	1	15	163	1	1	1	1	1	1	1
114	1	1	1	1	1	1	1	164	1	1	1	1	1	1	1
115	1	1	1	1	1	1	1	165	1	1	1	1	1	1	1
116	0	0	0	0	0	1	11	166	1	1	1	1	1	1	1
117	0	0	0	0	0	0	3	167	1	1	1	1	1	1	1
118	0	0	0	0	0	1	11	168	1	0	0	0	0	1	14
119	1	1	1	1	1	1	1	169	0	0	0	0	0	0	3
120	1	1	1	1	1	1	1	170	1	1	1	1	1	1	1
121	0	0	0	0	0	0	3	171	0	0	0	0	0	0	3
122	0	0	0	0	0	1	11	172	1	1	1	1	1	1	1
123	1	1	1	1	1	1	1	173	1	1	1	1	1	1	1
124	0	0	0	0	0	0	3	174	1	1	1	1	1	1	1
125	1	1	1	1	1	1	1	175	1	1	1	1	1	1	1
126	0	0	0	0	0	0	3	176	0	0	0	0	0	0	3
127	1	1	1	1	1	1	1	177	0	0	0	0	0	0	3
128	0	0	0	0	0	0	3	178	0	0	0	0	0	1	11
129	1	1	1	1	1	1	1	179	0	0	0	0	0	0	3
130	1	1	1	1	1	1	1	180	1	1	1	1	1	1	1
131	0	0	0	0	0	0	3	181	0	1	0	0	1	0	5
132	1	1	1	1	1	1	1	182	1	1	1	1	1	1	1
133	0	0	0	0	1	0	4	183	1	1	1	1	1	1	1
134	1	1	1	1	1	1	1	184	1	1	1	1	1	1	1
135	0	0	0	0	0	0	3	185	1	1	1	1	1	1	1
136	1	1	1	1	1	1	1	186	1	1	1	1	1	1	1
137	0	0	0	0	0	0	3	187	0	0	0	0	0	0	3
138	0	0	0	0	0	0	3	188	1	1	1	1	1	1	1
139	0	0	0	0	0	0	3	189	0	0	0	0	0	0	3
140	1	1	1	1	1	1	1	190	1	1	1	1	1	1	1
141	1	0	0	0	0	1	14	191	1	1	1	1	1	1	1
142	1	1	1	1	1	1	1	192	1	1	1	1	1	1	1
143	0	0	0	0	1	1	16	193	0	0	0	0	0	1	11
144	1	1	1	1	1	1	1	194	0	0	0	0	0	0	3
145	1	1	1	1	1	1	1	195	1	1	1	1	1	1	1
146	1	1	1	1	1	1	1	196	1	1	1	1	1	1	1
147	1	1	1	1	1	1	1	197	0	0	0	0	0	0	3
148	1	1	1	1	1	1	1	198	0	0	0	0	0	0	3
149	1	1	1	1	1	1	1	199	1	1	1	1	1	1	1
150	1	1	1	1	1	1	1	200	0	0	0	0	0	0	3

Table-2: Out-of-control signals (Contd..)

S.No.	Y	S	P	Mn	CO ₃	PM	CLG	S.No.	Y	S	P	Mn	CO ₃	PM	CLG
201	1	1	1	1	1	1	1	286	1	1	1	1	1	1	1
202	1	1	1	1	1	1	1	287	1	1	1	1	1	1	1
203	0	1	1	0	0	0	6	288	1	1	1	1	1	1	1
204	1	1	1	1	1	1	1	289	1	1	1	1	1	1	1
205	0	0	0	0	0	0	3	290	1	1	1	1	1	1	1
206	0	0	0	0	0	0	3	291	1	1	1	1	1	1	1
207	1	1	1	1	1	1	1	292	1	1	1	1	1	1	1
208	0	0	0	0	0	0	3	293	1	1	0	0	0	1	19
209	1	1	1	1	1	1	1	294	1	1	1	1	1	1	1
210	0	0	0	0	0	0	3	295	1	1	1	1	1	1	1
211	0	0	1	0	0	0	7	236	1	1	1	1	1	1	1
212	0	0	0	0	0	0	3	237	1	1	1	1	1	1	1
213	1	1	1	1	1	1	1	238	1	1	1	1	1	1	1
214	0	0	0	0	0	0	3	239	1	1	1	1	1	1	1
215	0	0	0	0	0	0	3	240	0	0	0	0	0	0	3
216	1	1	1	1	1	1	1	241	1	1	1	1	1	1	1
217	1	1	1	1	1	1	1	242	1	0	0	0	0	1	14
218	1	1	1	1	1	1	1	243	1	1	1	1	1	1	1
219	0	0	0	0	0	0	3	244	0	0	0	0	0	1	11
220	1	1	1	1	1	1	1	245	1	1	1	1	1	1	1
221	1	1	1	1	1	1	1	246	1	1	1	1	1	1	1
222	1	1	1	1	1	1	1	247	0	0	0	0	0	0	3
223	1	1	1	1	1	1	1	248	1	1	1	1	1	1	1
224	1	1	1	1	1	1	1	249	0	0	0	0	0	0	3
225	1	1	1	1	1	1	1	250	1	1	1	1	1	1	1
226	0	0	0	0	0	0	3	251	0	0	1	0	0	1	12
227	1	1	1	1	1	1	1	252	1	1	1	1	1	1	1
228	1	1	1	1	1	1	1	253	0	1	0	0	0	1	18
229	0	0	0	0	0	0	3	254	1	1	1	1	1	1	1
230	0	0	0	0	0	0	3	255	1	1	1	1	1	1	1
231	0	0	0	0	0	0	3	256	1	1	1	1	1	1	1
232	1	1	1	1	1	1	1	257	0	0	0	0	0	0	3
233	0	0	0	0	0	1	11	258	1	1	1	1	1	1	1
234	0	1	1	0	0	1	17	259	1	1	1	1	1	1	1
235	1	1	1	1	1	1	1	260	1	1	1	1	1	1	1
271	1	1	1	1	1	1	1	261	0	0	0	0	1	0	4
272	1	1	1	1	1	1	1	262	0	0	0	0	0	1	11
273	1	1	1	1	1	1	1	263	1	1	1	1	1	1	1
274	1	1	1	1	1	1	1	264	0	0	0	0	0	0	3
275	1	1	1	1	1	1	1	265	0	0	0	0	0	0	3
276	1	1	1	1	1	1	1	266	1	1	1	1	1	1	1
277	1	1	1	1	1	1	1	267	1	1	1	1	1	1	1
278	1	1	1	1	1	1	1	268	1	1	1	1	1	1	1
279	1	1	1	1	1	1	1	269	1	1	1	1	1	1	1
280	1	1	1	1	1	1	1	270	1	1	1	1	1	1	1
281	1	1	1	1	1	1	1	296	1	1	1	1	1	1	1
282	1	1	1	1	1	1	1	297	1	1	1	1	1	1	1
283	1	1	1	1	1	1	1	298	1	1	1	1	1	1	1
284	1	1	1	1	1	1	1	299	1	1	1	1	1	1	1
285	1	1	1	1	1	1	1	300	1	1	1	1	1	1	1

Table-2: Out-of-control signals (Contd..)

S.No.	Y	S	P	Mn	CO ₃	PM	CLG	S.No.	Y	S	P	Mn	CO ₃	PM	CLG
301	0	0	0	0	0	1	11	311	1	1	1	1	1	1	1
302	0	0	0	0	0	0	3	312	0	1	0	1	1	1	21
303	0	0	1	0	0	0	8	313	1	1	1	1	1	1	1
304	0	0	0	0	0	0	3	314	0	1	0	0	0	1	18
305	0	0	1	1	0	1	20	315	1	1	1	1	1	1	1
306	1	0	0	0	0	1	14	316	0	0	0	0	0	1	11
307	0	0	0	0	0	0	3	317	1	1	1	1	1	1	1
308	0	0	0	0	0	0	3	318	1	1	1	1	1	1	1
309	0	0	0	0	0	0	3	319	1	1	1	1	1	1	1
310	0	0	0	0	0	0	3	320	0	0	0	0	0	1	11

Note: 1-in-control signal; 0- out-of-control signal

Note: CLG groups, 1: All variables in control; 2: S,Mn, CO₂ and PM are out of control; 3: Y,S,P, Mn, CO₂ and PM out of control; 4: Y,S,P, Mn and PM out of control; 5: Y,P,Mn and CO₂ out of control; 6: Y, Mn,CO₂ and PM out of control; 7: Y,S, Mn, CO₂ and PM out of control; 8: Y,S, Mn, CO₂ and PM out of control; 9: Y,S and Mn out of control; 10: Y,S Mn and CO₂ out of control; 11: Y,S,P, Mn, and CO₂ out of control; 12: Y,S Mn and CO₂ out of control; 13: Mn and CO₂ out of control; 14: S, P, Mn and CO₂ out of control; 15: S, Mn and CO₂ out of control; 16: Y, S, P and Mn out of control; 17: Y, Mn and CO₂ out of control; 18: Y, P, Mn and CO₂ out of control; 19: P, Mn and CO₂ out of control; 20: Y, S and CO₂ out of control; 21: Y and P out of control;

Table-3: Testing data set

S.No.	Y	S	P	Mn	CO ₂	PM
321	1.705	0.045	0.085	0.084	24.174	12.094
322	1.778	0.053	0.086	0.083	25.206	19.827
323	1.895	0.05	0.086	0.085	25.571	25.802
324	1.816	0.053	0.087	0.082	24.796	22.882
325	1.831	0.052	0.087	0.084	25.765	15.741
326	1.855	0.05	0.085	0.084	24.521	21.324
327	1.886	0.054	0.085	0.084	24.797	20.171
328	1.581	0.054	0.084	0.086	25.396	14.507
329	1.829	0.049	0.087	0.084	24.753	17.822
330	1.957	0.046	0.089	0.083	25.447	23.947
331	1.929	0.047	0.086	0.081	24.387	22.983
332	1.804	0.049	0.087	0.082	24.8	21.131
333	1.42	0.056	0.093	0.087	27.165	24.381
334	1.535	0.054	0.092	0.085	26.48	22.945
335	1.763	0.049	0.088	0.083	25.076	22.325
336	1.877	0.048	0.087	0.082	24.553	24.456
337	2.036	0.045	0.084	0.081	24.049	23.823
338	1.732	0.05	0.089	0.083	25.251	15.348
339	2.133	0.043	0.083	0.08	23.528	20.973
340	1.674	0.051	0.09	0.084	25.544	26.112

4.2 Multi layer perceptron of neural network model

MLP of Neural networks is implemented to the case study using data on six quality characteristics' of observations as independent variables and class out of control obtained are as dependent variables through neural networks module of SPSS 18.

Results of neural network analysis are presented in the following sect following outputs of neural network analysis are presented and discussed below.

MLP Network Information

- Number of inputs = Six (Quality Parameters).
- Number of output units = 1(Class of Out of Control)
- Maximum number of hidden units = 10
- Training dataset = 94.1% of the sample
- Testing dataset = 5.9% of the sample.
- Type of training = Batch training
- Optimizing Algorithm = scaled conjugated method
- Training options, Initial $\lambda = 0.0000005$

Case Processing Summary

Table-4 gives information about the datasets used to build the ANN model. From the table it is observed that the training dataset contains in 94.1% of the sample and testing dataset contains 5.9% of the sample.

Table-4: Case processing summary

Case Processing Summary			
		N	Percent
Sample	Training	320	94.1%
	Testing	20	5.9%
Valid		340	100.0%
Excluded		0	
Total		340	

Network Information

The Table-5 shows network information. In the Table-5, the number of neurons in every layer and one independent variable (out of control class) denoted as cluster number (CLG). Automatic architecture selection chose 10 nodes for the hidden

layer, while the output layer had 18 units to code the dependent variable. For the hidden layer the activation function was the hyperbolic tangent, while for the output layer also the softmax function is used.

Table-5: Network information

Input Layer	Factors	1	Y
		2	S
		3	P
		4	Mn
		5	CO2
		6	PM
	Number of Units		1110
Hidden Layer(s)	Number of Hidden Layers		1
	Number of Units in Hidden Layer		20
	Activation Function		Hyperbolic tangent
Output Layer	Dependent Variables	1	CLG
	Number of Units		21
	Activation Function		Softmax
	Error Function		Cross-entropy

Model Summary

The model summary is shown in Table-6.

Table-6: Model Summary

Training	Cross Entropy Error	0.268
	Percent Incorrect Predictions	0.0%
	Stopping Rule Used	Training error ratio criterion (.001) achieved
Testing	Cross Entropy Error	0.039
	Percent Incorrect Predictions	0.0%

Table-6 provides information related to the results of training and testing sample. Cross entropy error is given for both training and testing sample since is the error function that network minimizes during the training phase. The small value (0.268) of this error indicates the power of the model to predict financial soundness in the training set. The cross entropy error (0.0398) is also very less for the testing data set, meaning that the network model has not been over fitted to the training data. The result justifies the role of testing sample which is to prevent overtraining. From the results, it is observed that, there are no incorrect predictions based on training and testing sample.

Classification Summary

Table-7 displays classification for categorical dependent variable (financial soundness).

Table-7: Classification (Training Data Set)

Sample	Out of Control Class	Predicted																				%Correct	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		21
Training	1	198	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0%
	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0%
	3	0	0	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0%
	4	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0%
	5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0%
	6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0%
	7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0%
	8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0%
	9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	100.0%
	10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	100.0%
	11	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	100.0%
	12	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	100.0%
	13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	100.0%
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	100.0%
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	100.0%
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	100.0%
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	100.0%
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	100.0%
	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	100.0%
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	100.0%
	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	100.0%

Table-8: Classification (Testing Data Set)

Sample	Out of Control Class	Predicted																					%Correct
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
Testing	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100%
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	3	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100%
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	100%
	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	11	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	100%
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%
	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	100%
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	100%
	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	100%
	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	100%
	Overall Percent	30%	0%	30%	0%	0%	0%	0%	5%	0%	0%	15%	0%	0%	5%	0%	0%	0%	5%	0%	5%	5%	100%

As can be seen, the MLP network classification results, 100% out of control classes are correctly classified both in training and testing sample. Overall 100.0% of the training cases and testing cases were correctly classified.

Importance Analysis

Table-9 gives the impact of each independent variable in the ANN model in terms of relative and normalized importance.

Table-9: Independent variable importance values

Variable	Importance	Normalized Importance
Y	0.155	88.4%
S	0.172	98.1%
P	0.163	93.3%
Mn	0.169	96.5%
CO ₂	0.175	100.0%
PM	0.166	95.1%

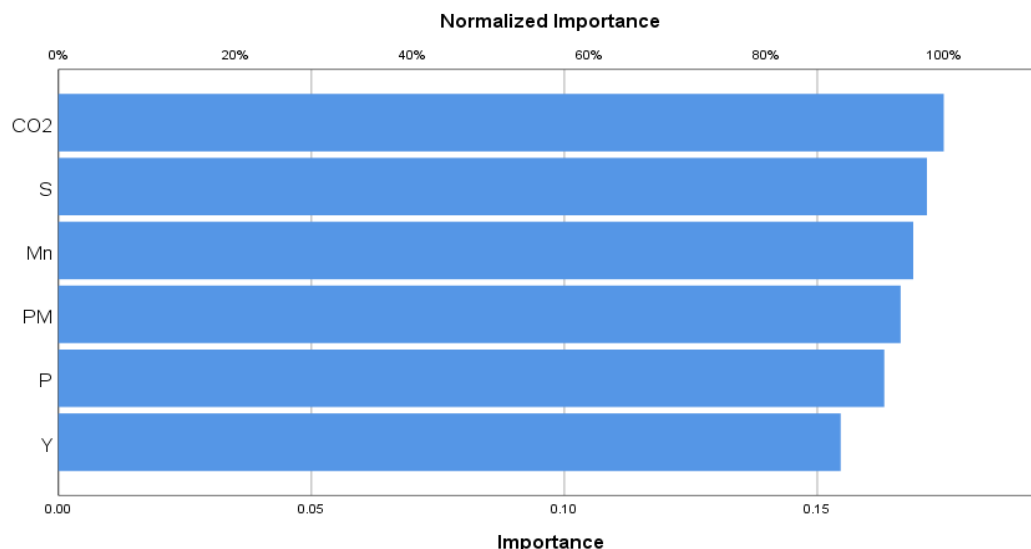


Fig. 2: Showing the normalized importance values

From the table, it is apparent that CO₂, and S are showing the high importance in classification of out-of-control signals since the relative importance of these variables are 0.175 and 0.172 respectively. Yield has the lowest effect

relatively on the classification of out-of control signals is obtained since the relative importance of the variable is 0.155. Fig.1 also depicts the importance of the variables,

i.e., how sensitive is the model is the change of each quality variables variable.

From the normalized importance values, it is observed that, highest weightage obtained with emission of CO₂ during smelting process in classifying the classes correctly. Artificial neural network models are increasingly used in scoring with varying success. According to some statisticians, although these new methods are interesting and sometimes more efficient than traditional statistical techniques, they are also less robust and less well founded. Furthermore, neural networks are unable to explain the results they provide. Finally, they are as black boxes with unknown operating rules.

5.0 CONCLUDING REMARKS

In this study, MLP model is proposed and is implemented to monitoring and control of smelting process of blast furnace of an integrated steel plant. This study presents a multilayer perceptron network model for out-of-control condition analysis in multivariate variable processes. In individual control chart method, every variable has its own control chart and variables are considered as independent. With the proposed model, a large number of variables, affecting real processes can be analyzed together. Hence, the loss of time and labor are eliminated. For these reasons, multilayer neural network is considered to be an effective tool for Prediction, analysis and control of complex processes.

6.0 FUTURE SCOPE OF STUDY

Future work will need to validate these findings in larger and more diverse samples, there is strong evidence that the proposed model can be used effectively to predict classification of out-of-control signals in respect of multiple variables, in particular to help the management to monitor the quality of hot metal. The method is a data driven method required experimentation to validate the results.

REFERENCES

- [1] Gerardo Avendano and Gustavo Andrés Campos-Avendano (2017), Application of a neural network to classify the out-of-control signal that gives the T² multivariate graph of Hotelling using data obtained in the industry, Proceedings of the International conference on Industrial Engineering and Operations Management Rabat, Morocco, April 11-13, 2017, pp.5682-5688
- [2] Igor Grešovnik, Tadej Kodelja, Robert Vertnik and Božidar Šarler (2012), Application of artificial neural networks to improve steel Production process, Proceedings of the IASTED International Conference(2012)June 25 - 27, 2012 Napoli, Italy, Artificial Intelligence and Soft Computing ASC, pp.249-255
- [3] Edgar A. Ruelas-Santoyo, José A. Vázquez-López, Javier Yañez-Mendiola, Roberto Baeza-Serrato, José A. Jimenez-García and Juan Sanchez-Márquez (2108), System for the recognition of wear patterns on microstructures of carbon steels using a multilayer perceptron, Ingeniería e Investigación vol. 38.No. 1,pp.113-120
- [4] Owunna.I and A. E.Ikpe (2019), Modelling and Prediction of the Mechanical Properties of Tig Welded Joint for AISI 4130 Low Carbon Steel Plates using Artificial Neural Network (ANN) Approach, Nigerian Journal of Technology (NIJOTECH), Vol. 38, No. 1, pp. 117 – 126
- [5] Abhulimen,I.U. and J.I. Achebo (2014), Application Of Artificial Neural Network In Predicting The Weld Quality of A Tungsten Inert Gas Welded Mild Steel Pipe Joint, International Journal of Scientific & Technology Research, Vol. 3, No. 1, pp.277-285
- [6] Tadeusz Wieczorek and Mirosław Kordos (2010), Neural Network-Based Prediction of Additives in the Steel Refinement Process, Computer Methods in Materials Science, Vol.10, N0.1, pp.1-9
- [7] Boran.S and D.D. Diren (2017), Analysis of Out of Control Signals in Multivariate Processes with Multilayer Neural Network, Special issue of the 3rd International Conference on Computational and Experimental Science and Engineering (ICCESSEN 2016), Vol.132.No.3-II,pp.1054-1057.
- [8] Francisco Aparisi, José Sanz (2010), Interpreting the Out-of-Control Signals of Multivariate Control Charts Employing Neural Networks, International Journal of Computer and Information Engineering, Vol.4,No.1, pp.24-28
- [9] Shihua Luo Tianxin Chen and Ling Jian (2018), Using Principal Component Analysis and Least Squares Support Vector Machine to Predict the Silicon Content in Blast Furnace System, IJOE – Vol. 14, No. 4, pp.149-162
- [10] Ishita Ghosh and Nilratan Chakraborty (2018), An Artificial Neural Network Model for the Comprehensive Study of the Solidification Defects During the Continuous Casting of Steel, Computer Communication & Collaboration, Vol. 6, No.1-2, pp.1-14
- [11] Wei Li , Xinchun Wang, Xusheng Wang, Hong Wang (2016), Endpoint Prediction of BOF Steelmaking based on BP Neural Network Combined with Improved PSO, Chemical Engineering Transactions, Vol.51, pp.475-480
- [12] Seyed Taghi Akhavan Niaki and Babak Abbasi (2005), Fault Diagnosis in Multivariate Control Charts Using Artificial Neural Networks, Quality and Reliability Engineering · December 2005 DOI: 10.1002/qre.689, pp.1-31
- [13] Dipak Laha , Ye Ren and P.N. Suganthan (2015), Modeling of steelmaking process with effective machine learning Techniques, Expert Systems with Applications, Vol. 42, No.2015, pp. 4687–4696
- [14] McCulloch, W. S., & Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. Bulletin of Mathematical Biophysics, Vol.5, pp.115-133.
- [15] Medhat H.A. Awadalla and M. Abdellatif Sadek (2012), Spiking neural network-based control chart pattern recognition, Alexandria Engineering Journal, Vol.51.pp.27-35
- [16] Barghash, M.A. & Santarisi, N.S.(2004), Journal of Intelligent Manufacturing, Vol.15, <https://doi.org/10.1023/B:JIMS.0000037713.74607.00>
- [17] Nimbale.S.M. and V. B. Ghute (2016) , A Neural Network based Individual Control Chart, International Journal of Engineering Research & Technology, Vol.5, No.5, pp.24-27
- [18] Stelios Psarakis (2011), The use of neural networks in statistical process control charts, Quality and Reliability Engineering , Vol.27, No.5, pp. 641-650
- [19] Mohammad Reza Maleki and Amirhossein Amiri (2015), Simultaneous Monitoring of Multivariate-Attribute Process Mean and Variability Using Artificial Neural Networks, Journal of Quality Engineering and Production Optimization Vol. 1, No. 1, pp. 43-54