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An Intelligent Quality Function Deployment (IQFD) for Manufacturing Process Environment

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Abstract

This research work provides methodology for development of intelligent quality function deployment (IQFD) application in the manufacturing process environment. The paper is composed of the background of QFD, related research work review, and points for developing in manufacturing environment. Then, it describes the needs of development on intelligent QFD due to uncertainty on the available human experts in product development and expansion, so we overcome the lack of the human availability and achieving an expert environment that can predicate the quality of the assuming product with respect of customer demand, so that it can provide system for retrieving design and manufacturing data . The paper applied the proposed methodology on the case study of the air cooler manufacturing process. IQFD was developed in Microsoft Excel environment with the matlab R 2006 language.

Keywords: Quality function deployment; Voices of customer; neural network

1. Introduction

The quality function deployment is widely spreading into the world because of its outstanding usefulness. Basically, Quality Function Deployment (QFD) is aimed to fulfil customer's expectation of the product or service. QFD has been used by many companies because of the following three basic reasons (1) To save design time and development time (2) To focus on the satisfaction of customer (3) To improve communication at all levels of the organization.

Based on these three basic reasons, the research expansion of the traditional QFD can be analyzed into three branches. For the first reason, the QFD can be implemented effectively for developing the new product design by pointing the linkage between design stages through manufacturing environment. However, the traditional QFD is quite weak in implementing the modification of the existing product due to lack of human experts. In real application of QFD, the human experts are needed to provide the relationship on each matrix of QFD implementation. But, the life of the human expert, sometimes, could not last long enough with the product development. In addition, the human expert who is involved in the initial development of QFD might not stay long enough with the company. In those cases, the company that used QFD efficiently met the problem of the lacking of human experts or historical product design development. Therefore, it is necessary to keep track of the product development history to shorten the product and design development.

For the second reason, many researchers are currently focused on the development of many approaches, and some are known as ‘voice of customers’ [1-2] for prioritizing customer needs. At that point, Cohen [3] also stated in his QFD book that it is necessary to prioritize customer needs based on market analysis. He compared between prioritization matrix method and analytical hierarchy process method, and also provided advantages and disadvantages of each method. Despite its invaluable contribution to the field of product manufacturing and design, it does have its feebleness. First, QFD has neglected to take into consideration the priority among customer requirements.

Some customer attributes may be felt, or actually are, having greater or lower priority than others. QFD does not prioritize the attributes in any of its procedures. Consequently, inconsistency in the result would be inevitable. Fortunately, Saaty [4] has done a research in using Analytical Hierarchy Process (AHP) in prioritizing customer requirements in QFD. Second, conventional QFD procedures have embedded in itself a tendency for subjective valuation of the weight in the relational matrix of House of Quality (HOQ). This might cause bias in the outcome and vary the actual result.

For the third reason, QFD is well organized for improving the communication inside the organization if it is correctly implemented [1]. On the other hand, the improvement of the personal computer power and internet communication derive to develop computerized QFD [5] and decision support system of QFD [6]. Therefore, this research is focused on above three reasons and the implementation trends of QFD. It can be concluded that QFD needs to be computerized for better communication

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by using Internet facilities; the computerized QFD needs to possess the memory for remembering the past histories of the product development; QFD should be the decision support tool for making right decision.

Based on above conclusions, this research proposed to develop the intelligent QFD with the help of neural network (NN) facilities and implemented into the computerized environment.

2. Model Development

Basically, the QFD models can be classified into two categories: (1) four-matrix model and (2) matrix to matrix model (30 matrices) [7]. In this research, the four-matrix model is selected due to ease of implementation, and it suits for manufacturing environment. In product manufacturing, it can be analyzed as:

- The product matrix composed of the product attributes;
- The products components matrix
- The manufacturing processes matrix
- The production and control entities matrix

And the matrices details are shown in table 1.

For implementing QFD, it is necessary to have human experts for developing proper attributes, matrices, and links among developed matrices. For the new product development, it is not much difficult if all people tried to cooperate and shared information effectively. But, for modification of the existing product for meeting the changes of the customer's needs, the existing QFD will be met with difficulties of modifications and addition of new attributes or matrices because of lacking human persons who developed those QFD matrices initially. Therefore, it is necessary to keep in track the record of the changes and to map the expertise knowledge into the QFD development if possible. On the other hand, the NN research also developed very fast; and is efficient for mapping the human knowledge into computers. Thus, the research proposed to develop the IQFD by integrating traditional QFD and efficient mapping of the human knowledge into computers. Thus, the research proposed to develop the IQFD by integrating traditional QFD and NN technique. The framework of the model is shown in Figure1.

For implementation of QFD, a manufacturing environment for Air cooler production is selected. The prototype model initiated with generating customer expectations in the air cooler manufacturing. The model consists of four related matrices, which are product Part design Characteristics, Main product Components, manufacturing processes, and production and control entities as the last matrix. Each matrix is constructed in individual Excel worksheet.to capture the customer's needs effectively [1], we use the brainstorm group with interview to collect their needs.

2.1. Matrix I: Product Characteristics (Design Matrix)

This stage of QFD consists of the following information:

- Customer Requirements
  Product parts design characteristics
- The priorities of the customer requirements
- Relationship between the customer requirements and the product characteristics.

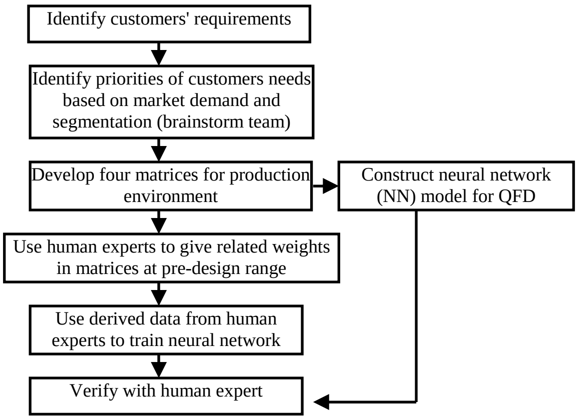

Figure 1 : the framework of IQFD model.

And the steps are:

1. The project did the market research for obtaining the customer requirements, and all the suggested customer requirements are listed out. They are related to the air cooler product characteristics in the matrix of HOQ, QFD's first and vital phase to product quality. The matrix of HOQ is shown in Table 2.
2. The team discussed the expertise available; and evaluated the priority of each requirement; numbers ranging from 9 to 1 are assigned to each requirement. Number 9 is assigned to the most preferable requirement, and the rest are assigned accordingly with decreasing preference. These priorities are shown in Table 1 as the importance column.
3. The product design characteristics that relate to those customer requirements are identified and placed along the top of the matrix. They are the product features of air cooler.
4. Then the impact of each product design characteristic on meeting those customers requirements based on the priority of requirement is quantified; and is so called the relationship values. The 9-point rating scale is used.
   9 = High impact on the requirement
   3 = medium
   1 = least impact
   The number in between indicates intermediate sense.
5. The importance or weight of each product design characteristics relating to the customer requirements is computed by summing the product between importance of customer requirement and the relationship value in the product design Characteristics matrix column. Matlab program facilitates the calculation in providing formulas to compute these weights. These values are shown in Table 1 as the Total row.
6. After the weights of product design Characteristics are computed. They are normalized by dividing them by the sum of all weights. They are shown as the Normalization row in Table 1.
7. Transferring the product design characteristics and their weights to the next matrix by placing the product design characteristics along the left of the next matrix and their weight next to it.

Table 1 : matrices contains.

Customer's requirements (CR)	Design requirements (DR)	Main and sub components	Processes and operations	Production and control attributes
Motor and water pump with long life	Size (a- small, b-medium, c-large).	Mechanical group (a- fan, b- fan cover, c- fan shaft, d-fan bushes).	Winding process.	Material entities.
Different size and shape	Shape (a- square, b- rectangular).	Electrical group (a- motor, b- water pump).	Coil finishing (varnish).	Electrical entities.
Low electricity consumption.	Weight (a- ordinary, b- medium, c- light).	Structure (a- frame, b- windows).	Manufacturing of motor body and water pump body.	Mechanical entities.
Quite and efficient working.	Brand name {the name of company} (a- acceptable, b- medium, c- very good).	Accessories (a- pulleys, b- belt, c- water distributor).	Manufacturing of shafts.	
Safety	Coil wire size.		Manufacturing of bushes.	
Light weight	Numbers of coil wire turns.		Join methods.	
Three fan speed	Assembly.		Plate cutting and forming.	
Low price	Rotating speed.		Manufacturing of accessories.	
Corrosion resistance	Warranty.			
	Durability (a- medium, b- high).			
	Manufacturing cost.			
	Power "electricity ".			
	Out put power "air ".			
	Metal type.			

Table 2 : Designen Matrix.

CR/DR	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	important
1	0	0	0	0	0	2	2	2	3	5	9	7	7	4	8	9	5	7	7	7	5	4	6
2	8	8	8	8	8	3	3	3	3	4	6	3	3	5	3	3	3	3	7	4	6	5	2
3	5	4	6	0	0	2	2	2	3	5	7	8	8	2	8	5	4	6	3	8	7	3	3
4	2	2	2	2	2	2	3	3	3	5	7	4	4	6	7	6	6	7	7	4	5	7	7
5	0	0	0	0	0	0	0	0	2	5	7	4	4	5	4	6	4	5	7	4	2	7	1
6	3	5	8	0	0	6	5	9	1	3	5	0	0	0	0	2	2	5	5	1	3	8	5
7	1	2	3	0	0	0	0	0	2	5	8	7	7	2	8	3	2	3	7	8	8	3	4
8	3	5	7	2	5	2	5	7	2	5	9	1	1	2	3	5	5	7	9	3	3	9	9
9	0	0	0	0	0	0	0	2	2	5	8	0	0	0	1	8	5	7	8	0	0	8	8
Total	91	120	163	48	75	86	115	134	112	213	345	141	141	113	198	254	197	276	274	170	174	296	3440
Normalization%	2.84	3.48	4.73	1.39	2.18	2.50	3.34	3.89	3.25	6.19	10.02	4.09	4.09	3.28	5.75	7.38	5.72	8.02	7.96	4.94	5.05	8.60	

Table 3 : Componant Matrix.

CR/Components	A	B	C	D	E	F	G	H	I	J	K	Impo.
1	4	4	1	1	1	0	9	9	2	3	1	2.84
2	4	4	2	2	1	0	9	9	4	3	2	3.48
3	4	4	3	3	2	0	9	9	6	4	2	4.73
4	4	3	1	0	1	0	9	9	0	2	5	1.39
5	4	3	1	0	1	0	9	9	0	2	5	2.18
6	2	2	1	0	0	0	4	2	1	0	0	2.5
7	3	3	1	0	0	0	6	3	1	0	0	3.34
8	5	5	2	0	1	0	9	6	3	0	0	3.89
9	3	3	1	1	1	1	2	2	1	0	0	3.25
10	3	3	1	2	3	3	2	2	1	0	0	6.19
11	5	5	3	5	9	9	5	5	3	2	1	10.02
12	0	0	0	0	7	7	0	0	0	0	0	4.09
13	0	0	0	0	7	7	0	0	0	0	0	4.09
14	2	2	2	2	2	1	3	1	1	0	3	3.28
15	6	1	2	2	7	0	0	0	9	6	0	5.75
16	0	0	1	1	7	7	7	8	1	2	0	7.38
17	0	0	1	1	3	2	4	4	1	1	0	5.72
18	1	1	2	2	5	5	7	7	3	2	1	8.02
19	2	3	3	4	8	7	9	9	4	2	1	7.96
20	0	0	0	0	9	7	0	0	1	0	0	4.94
21	1	0	0	0	9	0	0	0	5	1	0	5.05
22	3	5	7	7	1	1	9	9	7	0	0	8.6
Total	265.42	234.17	211.70	220.22	510.22	373.04	553.37	487.70	319.00	160.41	72.57	3406.30
Normalization%	7.79	6.87	6.21	6.46	14.98	10.95	16.24	14.32	9.36	4.69	2.13	

2.2. Matrix II: Product Components (Components Matrix)

Air cooler component consists of two levels, main component at the first level, and sub component at the second level.1. The project team breaks down the main and sub components, and places them along the top of Matrix II. It aims to determine the degree of impact that the product design characteristics have on main/sub components. 2. Determine relationship values between main/sub components and the product design characteristics. They are shown in Table 3. 3. The weight of each component is given and normalized similarly as previous. Finally, transferring the components matrix into matrix III. This is manipulated automatically by matlab program with its built-in function.

2.3. Matrix III: Processes Matrix

This matrix relates the components to its manufacturing processes (Table 4). The procedures are as follows: 1. from the air cooler, the air cooler processes are arranged at the top of the matrix. The objective is to determine the interrelationship between the manufacturing processes of the components and the parts components. This helps to identify where emphasis is to be placed on. Soon processes will be related to production and control entities at the last matrix. 2. Quantify the relationship values for each process. 3. The weight of all processes components is automatically calculated by matlab and normalization is done. 4. Transfer the process components and their weights to the next matrix.

2.4. Matrix IV: Production and Control

The matrix is presented as Table 5.

1. Identify the production and control entities with respect to the process components and arrange them at the top of this matrix.
2. Quantify the relationship values.
3. Matlabl formula calculates the weight of each production and control entities and their normalization values.

At this stage, the corresponding importance of production and control entities is known, so the team can decide on which production and control entities to pay more attention. As a result, it will lead the manufacturing team to concentrate on the right way that significantly reduces the time wasted on guessing. After developing the QFD matrices for air cooler, it is necessary to receive the expertise ideas of giving weights in the relationship among matrices. At that point, the NN is developed based on the QFD matrices structure. The integrated QFD model is shown in figure 2.

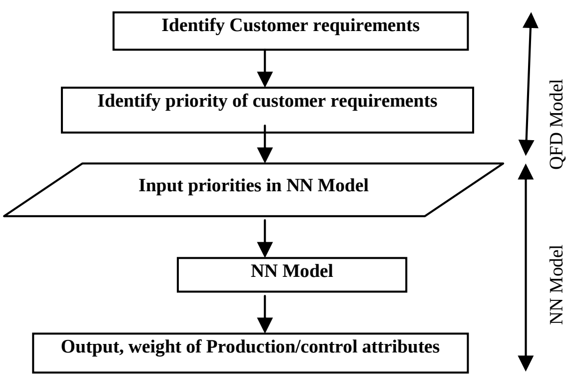

Figure 2: Integrated QFD model.

3. Neural Network Model Development

3.1. Constructing the Network

Conceptually, the network is constructed based on the input of customer requirements. Taking into account the priorities among the requisites, the network calculates within its inner layers of processing units; and generates the desired output as shown in Figure 3.

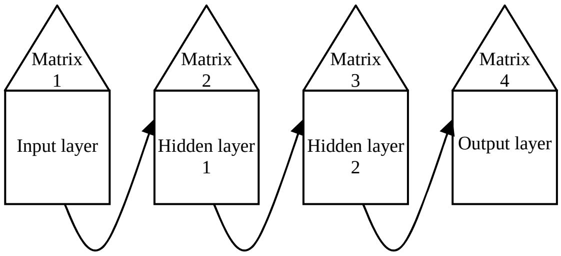

Figure 3 : Neural network construction with QFD.

Among the candidates of network architecture, the Multi-layer Perceptron (MLP) is chosen for its wide applicability and elementary structure. Then, assuming the simple nature of the problem, only one hidden layer is assigned to the MLP architecture. For simplicity and conformity to the 9-point rating scale, the end user needs are limited to only nine items. Relating to the number of customer requirements, the number of processing units (PE) is set to match the input channels of customer requirements. This will help to make the network to learn at the first trial, and thus reduce the number of training sessions required to produce a reliable network. The PE transfer function is of sigmoid curve. In more detail, a momentum type of learning rule is conducted throughout the training.

3.2. Generating Training Data Sets

The NN technique is used to overcome QFD weakness in subjective judgment of relationship values with the help of human expert. Initially, NN needs input of data sets to train the network. The training data sets are generated by QFD process in the following steps.

1. In the HOQ matrix, the priority for each customer requirements is assigned on a 9-point rating scale.
2. The relationship values between customer requirements and product design characteristics is quantified based on the priority of the customer requirements.
3. After entering the priority and relationship values into the matrix of HOQ, matlab automatically gives the production and control entities weights in the last matrix's bottom row. This is done by the inter-linking of the matrices in matlab.
4. Switching to a different set of priority, the corresponding relationship values yields another set of assembly attribute weights. By repeating the procedures, the training data sets for NN are generated. It is required that each customer requirement priority yields only one set of relationship values.

3.3. Training the Network

Before the network can be used, it must be trained sufficiently good to serve the forecasting purpose. Data sets are needed for training purpose.

Table 4 : Process Matrix.

Components / Processes	A	B	C	D	E	F	G	H	Impo.
1	0	0	0	2	2	5	9	0	7.79
2	0	0	0	0	0	7	9	0	6.87
3	0	0	0	9	8	6	9	4	6.21
4	0	0	0	8	9	6	9	0	6.48
5	9	9	9	0	0	0	1	0	14.98
6	9	9	9	0	0	0	2	0	10.98
7	0	0	0	0	0	6	9	0	16.24
8	0	0	0	0	0	7	9	0	14.32
9	0	0	1	3	0	1	5	9	9.36
10	0	0	0	0	0	0	0	9	4.59
11	0	0	0	0	0	2	0	9	2.13
Total	233.64	233.64	243	151.39	123.58	374.48	604.93	169.56	2134.22
Normalization %	10.94	10.94	11.38	7.09	5.79	17.54	28.34	7.94	

Table 5: Production and Control Matrix.

Processes/Prod.&Cont. At.	A	B	C	Impo.
1	2	9	0	10.94
2	1	9	0	10.94
3	1	9	1	11.38
4	7	0	9	7.09
5	7	0	9	5.79
6	8	0	9	17.54
7	9	1	9	28.34
8	0	0	4	7.94
Total	529.74	327.68	571.98	1429.4
Normalization%	37.06	22.92	40.01	

At that point, we used the plus minus two level design approach of relationship values of the first matrix to generate the training data sets. Then, 60% of the training data set is used for training the NN, and it checks the possible mean square error on each train. The training approach used 100 epochs. After training NN with 60 % of the generated data set, the remaining 40% data set is used for validation of NN. The training result in terms of mean square error can be seen in Figure 4 and Figure 5 and Fig.6. Then, the final weight values are obtained from the training section for the three layers of the neural networking units; and then embedded into the network simulation environment table5, table6 and table7. In conclusion, the trained NN for air cooler is working without the human expert, and it can generate the reasonable relationship by varying the customer needs' weights. Due to the NN structure solely dependent on the QFD matrix. And these weights are shown in table 6, table 7 and table 8.

4. Conclusions and Further Development

The proposed IQFD method is implemented in the computerized environment by using matlab 2006 and Neural Solutions Software.

Table 6 : final weight for first unit.

"Final weights of the synaptic connections for the three layers of the neural network in unit one"

v1= [-1.4821 -0.8115 -0.4476 -0.9748 0.1549 -0.5914 0.3067 -0.4965 -0.1733;
-0.2379 0.0508 -0.0075 -0.0384 -0.0224 0.1537 -0.0065 0.1622 0.0753;
-0.0838 -0.0421 -0.0359 -0.0528 0.0058 0.0140 -0.1444 0.0626 0.0065;
0.0257 0.0229 -0.2078 0.0055 -0.0425 -0.1863 0.0612 0.0092 -0.0293;
-0.0184 -0.0959 -0.0144 0.1254 -0.0203 -0.0454 -0.1324 -0.0808 0.0083;
-0.0168 -0.0146 0.1393 -0.2520 -0.1513 -0.0652 -0.0662 -0.0461 0.0766;
-0.0117 0.0745 0.0652 0.0585 -0.1126 0.0103 -0.0146 -0.1406 0.2237;
0.0168 -0.0890 -0.0377 -0.1008 -0.0815 -0.0221 0.0248 -0.0375 0.0327;
-0.0501 0.0139 -0.0661 0.0944 0.0367 -0.0279 -0.0077 -0.0471 0.0863];

w1= [1.3900 0.3770 0.0067 0.0679 -0.1921 -0.0256 -0.0111 0.0838 -0.0210;
0.0555 0.0044 0.0997 0.0912 0.0541 -0.1499 0.0083 0.0795 0.0667;
0.1002 -0.0314 0.1216 -0.0172 0.0932 -0.0050 0.1578 -0.0785 -0.1393];

Z1= [-0.9935 -0.1351 -0.2680];

Table 7 final weight for second unit.

"Final weights of the synaptic connections for the three layers of the neural network in unit two"

v2= [2.0012 0.3303 0.3458 -0.3488 0.4689 0.0415 0.0204 -0.0657 0.1217;
-0.0673 0.0379 -0.0498 -0.0688 0.1736 -0.0447 -0.1228 -0.1003 0.0825;
-0.0149 -0.0330 -0.1119 0.1339 0.1937 0.1082 -0.0670 -0.0186 0.0231;
-0.2449 -0.0500 0.0808 -0.0909 0.1635 0.2373 0.1341 -0.1054 0.0672;
0.0473 -0.0036 0.0041 -0.0413 -0.1256 0.0229 0.0388 -0.0072 -0.0508;
0.0117 -0.0175 -0.0756 -0.0506 -0.0214 -0.0267 0.0393 0.0279 0.0856;
-0.0591 -0.0957 -0.0089 0.1620 -0.0199 0.0702 -0.1707 0.1373 0.0269;
-0.0655 0.1293 -0.2009 0.0081 0.0307 -0.0488 0.0228 0.0180 0.0625;
-0.1081 0.0441 0.1084 -0.1081 -0.0572 0.1862 0.0686 -0.0542 -0.1047];

w2= [-0.5607 0.0195 0.1321 0.1068 -0.0796 0.1416 0.4613 0.0860 0.2574;
0.0434 0.1274 0.1320 0.1789 -0.0406 -0.1374 0.0756 0.1482 -0.1209;
-0.1917 0.0639 -0.0909 0.0391 -0.1535 -0.0839 0.0376 0.0033 -0.0783];

Z2= [-0.4135 0.0314 -0.4407];

Table 8: final weight for third unit.

"Final weights of the synaptic connections for the three layers of the neural network in unit three"

v3= [	**1.7227**	**0.7087**	**0.2051**	**0.7215**	**-0.2017**	**0.2616**	**-0.1405**	**0.5181**	**-0.1038;**
	-0.0277	**0.0599**	**0.0580**	**0.0500**	**0.2690**	**0.1552**	**-0.0953**	**-0.0816**	**-0.0159;**
	-0.1294	**0.0147**	**0.0240**	**-0.0517**	**0.0290**	**0.1384**	**0.0778**	**0.2094**	**0.0871;**
	-0.0888	**-0.0101**	**-0.0351**	**-0.0559**	**-0.1423**	**-0.0758**	**-0.0006**	**0.0080**	**-0.0195;**
	-0.0987	**-0.2635**	**0.0892**	**-0.0753**	**0.0247**	**0.0443**	**0.0524**	**-0.0937**	**0.0075;**
	-0.0072	**0.0028**	**0.1578**	**0.0926**	**-0.1436**	**0.0911**	**0.1364**	**0.0636**	**-0.0527;**
	-0.2415	**-0.0876**	**-0.1108**	**-0.0249**	**0.0149**	**-0.1074**	**0.0482**	**0.1682**	**-0.0685;**
	-0.0694	**-0.0265**	**-0.0026**	**-0.0150**	**-0.1693**	**0.0202**	**-0.0787**	**0.0594**	**-0.0268;**
	-0.1391	**-0.0328**	**-0.1111**	**-0.1258**	**0.0719**	**0.0763**	**0.0752**	**0.0790**	**-0.1188];**
w3= [	**-1.4517**	**-0.3023**	**0.1727**	**0.1191**	**0.6450**	**0.2424**	**0.4894**	**0.2155**	**0.3843;**
	0.0102	**-0.0511**	**0.0179**	**0.0339**	**0.0599**	**-0.0335**	**-0.0953**	**-0.0579**	**0.0039;**
	-0.0041	**0.0249**	**-0.0037**	**-0.0131**	**-0.0086**	**-0.0322**	**0.0234**	**-0.0502**	**0.1541];**
Z3= [	**-1.0054**	**-0.1196**	**-0.1447**	**];**					

Based on the case study of the air cooler manufacturing, Figure 7 , Figure 8 and Figure 9 show how the changing in the customers requirements at the first matrix effect the manufacturing trend at the last matrix focusing on three basic entities, which are the material , electrical and mechanical specifications. It is quite difficult to add the new customer needs or to reduce the customer needs after or during the manufacturing stage (through the layout operations which are basically a design conditions). The proposed method of IQFD allows the design to retrieve data systemization during the manufacturing processes and/or pre stage design, and the proposed method working well, and thus, the project is extending to handle adding, removing, and changing the attributes of design characteristics or the customer needs for neural network, which means very wide product specifications. In addition, it will be applicable for multi manufacturing domains and entering the sensitivity analysis to justify the possible changing relating to the weights of needs.

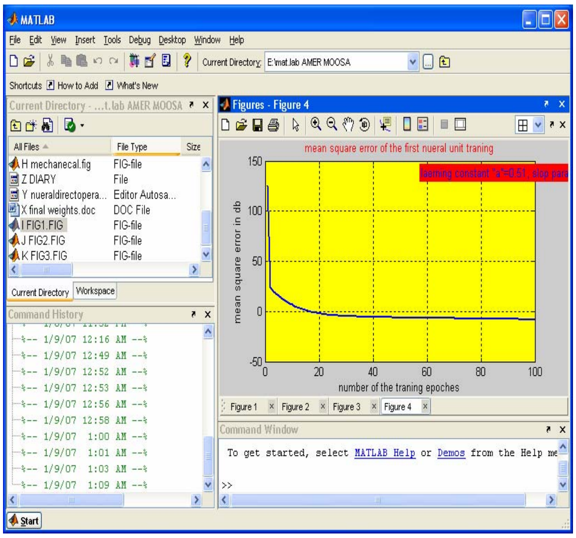

Figure 4: first unit error.

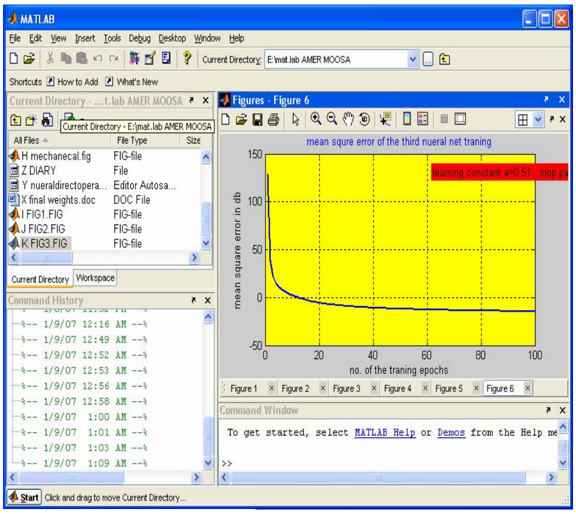

Figure 5: second unit error.

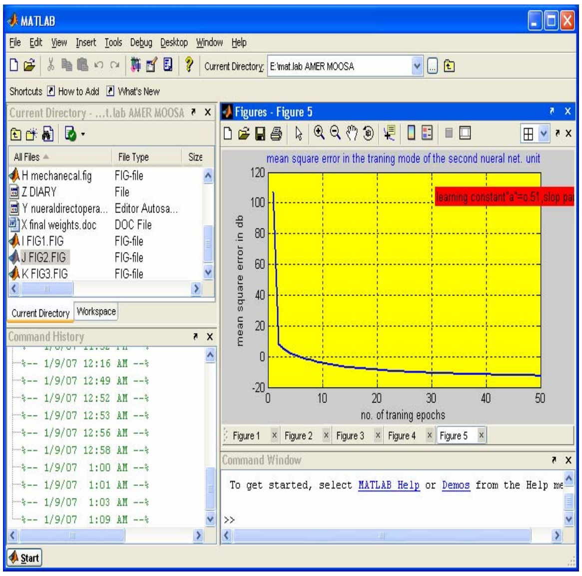

Figure 6: third unit error.

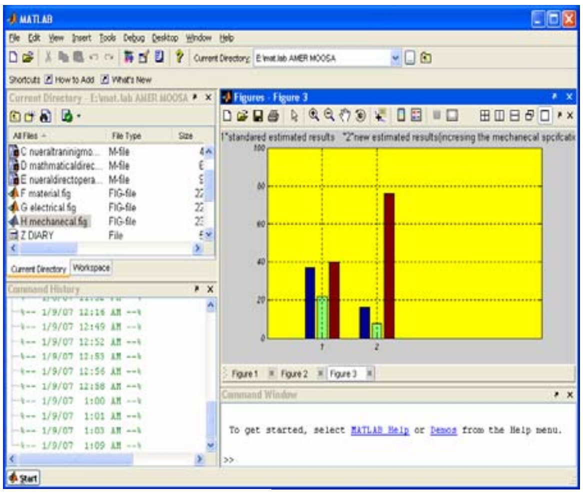

Figure 7: material properties.

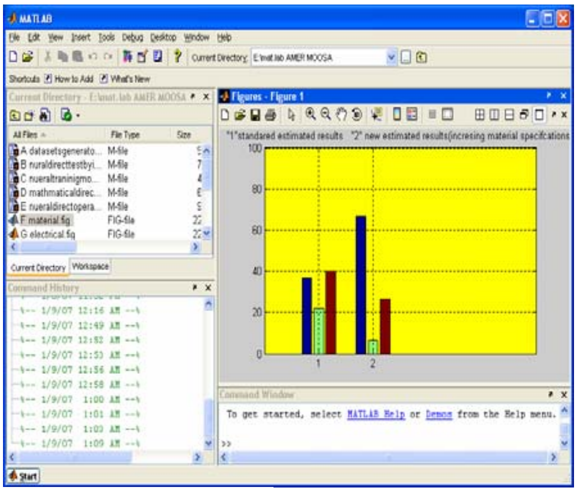

Figure 8 electrical properties.

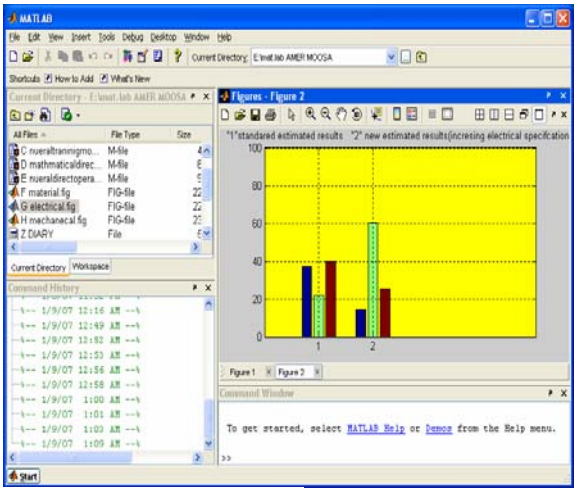

Figure 9 : mechanical properties.

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