CHAPTER 4

SUPPLY CHAIN DISRUPTION FOR FASTENER INDUSTRY

4.1 INTRODUCTION

Supply chain disruption can be defined as any occurrence which produces both negative consequences in regular supply chain operations and some degree of “confusion/disorder” within the supply chain. The primary focus of this section is to provide an overview of alternative classifications of different supply chain disruptions which might enable in development of more specific disruption management strategies (Vakharia and Yenipazarli 2008).

4.2 FASTENER MANUFACTURING

Fasteners are used to join two or more components. They are categorized into permanent and non-permanent fasteners. The non-permanent fasteners can be used for assembly purposes and can be removed during the repairing of the assembled components.

Fasteners like keys, rings, and pins can be used in shafts. Mostly, they don’t have threads in them. However, threaded fasteners like bolts, screws, nuts, setscrews, can be used for assembling and disassembling components and also a study can be used under non-permanent fastening. One
permanent fastener is rivet that can be used for assembly and it has to be damaged during disassembly.

Figure 4.1 Bolt and nut arrangement

Figure 4.1 presents the bolt and nut in position. Plate-1 and plate-2 are fastened by using a bolt and nut. The bolt has a cylindrical part with its head having facility to be handled by spanner/wrench/ allen keys. The number of sides on the bolt head is in general six sides. The other shapes of the head can be smooth, rounded head with no sides, and a circular head perpendicular to the axis of the bolt. Similarly, the nut has a height sufficient to be handled by using the spanner/wrench. The shape of the sides can be hexagonal, square, jam, slotted, and castle. The height of the nut is linked to the length and diameter of the bolt. The material of the bolt and nut is a mild steel. Also, the material of the bolt and nut can be of any material according to the specific application.
Figure 4.2  Screw in position

Figure 4.2 presents the screw in action. Plate-1 and plate-2 are fastened by using a screw. The screw has a cylindrical part with its head having facility to be handled by screw driver/ allen keys. The screw has a flat head/ slightly rounded head with one slot or many slots for driving the screw. The application of the screws can be in woods/ sheet metal/ machine cutting. A screw has a height sufficient to be handled by using the spanner/screw driver. The material of the screw can be any metal or non-metals.

Figure 4.3  Stud in position
Figure 4.3 presents the stud in position. Plate-1 and plate-2 are fastened by using a stud. Stud is a cylindrical rod with both the ends having threads. On one end, a nut can be fixed whereas the other end of the stud can be driven into two plates.

As per the figures 4.1-4.3, the common shape of the fasteners are cylindrical with head or without head and with the presence of slots and sides for handling them. The fasteners can be manufactured by using one machine with multiple tools or it can be manufactured by using many machines arranged in a specific layout.

Figure 4.4 presents the manufacturing stages of bolts and nuts. All the components go through the specified machines available in the factory. The time of manufacturing at each machine varies for different types of fasteners.

The time between the start and the finishing of a production process can remain constant if every resource is correctly working.

**Module 1:** Step 1 and step 2 are interrelated. They represent in placing an order of required material based on the inventory status. The received material is stored as an inventory.

**Module 2:** It shows the process sequences like (3) forming blanks, (4) sorting the blanks and storing into bins, (5) lubricating blanks, (6) heading the blanks, (7) threading the blanks external and internal, and (8) quality testing.

**Module 3:** It represents the maintenance department.
The dark blue double arrow indicates a) delay in purchase of material and non-availability of material in the inventory department, and b) sufficient facility is not available to rectify the problems in the machines. The green color double arrow indicates time slackness in not moving the in-process material from one machine to another machine within the stipulated time due to problems in shifting the in-process material. The number of parameters considered at each location is 3. Hence, the total number of features used for a pattern is $3 \times 10 = 30$. 

**Figure 4.4  Supply chain flow in manufacturing bolt and nut**
Table 4.1 presents the machine numbers in column 1, machine name and their operations in column 2, required raw materials in column 3 and required basic facilities in column four.

Data collected from the fastener industry are as follows:

**Table 4.1   Machines, raw materials, facilities in fastener industry**

<table>
<thead>
<tr>
<th>Machine number</th>
<th>Operations</th>
<th>Presence of required raw material / in-process material at each machine</th>
<th>Working conditions of the personnel / availability of other facilities supporting manufacturing at each machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receiving the bar stock–use fork lifts</td>
<td>Unfinished bar stock</td>
<td>Operator availability and fork lift machines</td>
</tr>
<tr>
<td>2</td>
<td>Store in the inventory department–use fork lifts</td>
<td>Specially finished blanks</td>
<td>Operator availability and stock handling facility</td>
</tr>
<tr>
<td>3</td>
<td>Cut into blanks–use sawing machine</td>
<td>Cutting blades</td>
<td>Operator availability, cleaning facility</td>
</tr>
<tr>
<td>4</td>
<td>Transfer to temporary bins–conveyor system</td>
<td>In process workpiece for combining the bar stock. It depends on application</td>
<td>Supervisor availability</td>
</tr>
<tr>
<td>5</td>
<td>Lubrication–apply lubricant using lubricant supply system</td>
<td>Additional lubricants and waste clothes</td>
<td>Lubricant transfer facility</td>
</tr>
<tr>
<td>6</td>
<td>Heat treatment–transfer the workpiece to heating chamber–use trolley</td>
<td>Handling accessories</td>
<td>Heating chamber handling personnel</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th></th>
<th>Heading the workpiece-heading machine</th>
<th>Different dyes for heading</th>
<th>Operator availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Special threading-threading machine</td>
<td>Different threading tools</td>
<td>Operator availability and coolant facility</td>
</tr>
<tr>
<td>9</td>
<td>Chamfering-chamfering tool head</td>
<td>Chamfering tool based on different chamfering angles</td>
<td>Operator availability and coolant facility</td>
</tr>
<tr>
<td>10</td>
<td>Testing-use calibrators</td>
<td>Measuring accessories</td>
<td>Operator availability</td>
</tr>
</tbody>
</table>

### 4.2.1 Data Collection From Fastener Industry

Data collection on the manufacturing sequence is adopted in the fastener industries. The manufacturing sequence is presented at different stages. Different stages of developing data to analyze the presence of SCD are given in the schematic diagram (Figure 4.5).

1) Define the manufacturing process

2) Define the required amount of raw materials, man power, time required for completion of the customers’ orders

3) Define the design of the product, sequence of manufacturing, reliability of the working facility, power cut, absenteeism of the laborer, shortage of laborers and other possible unexpected factors

4) Define the extra number of days required to complete the orders inspite of various uncontrolled factors

**Figure 4.5 Factors considered for generating training and testing data sets**
The sequence of steps in the schematic diagram is explained below:

i) Manufacturing sequence is designed based on the customers’ orders, the various manufacturing elements, which lead to the final product,

ii) Depending on the volume of production, the various quantities of raw materials, and any subcontracts, to be given with lead time for receipt of materials should be considered,

iii) The working conditions of the existing machines used for manufacturing is obtained from the maintenance department. Different factors are taken into account.
   a) The type of support adopted, the reliability of the various components,
   b) The maintainability of the time taken to make the components work and the location where the components are to be serviced,
   c) The availability of the spare parts for replacing the components, and,
   d) Any reconditioning process and the time required for certain costly components are considered,

iv) Provisions for overcoming power cuts are considered, and,

v) Creating healthy working environment for the workers and motivate them to finish the jobs in time so that extra days and overtime payments are reduced.
Table 4.2 presents data collected from the fastener industry

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<th>M/C No.</th>
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Table 4.3 Testing data collected from fastener industry

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Figure 4.6  working status of machines in fastener industry

Figure 4.7 presents a plot showing the details of the working status of various machines in the fastener industry. The x-axis shows the machine numbers and the y-axis shows the percentage of working conditions as per the data collected. In the plot, blue colour is not visible as there is no break down in the machines. The orange colour indicates the machines under working condition but with some trouble in the machines. The grey colour indicates that the machines are working as expected. Machine 5 and 6 had some trouble and but it was working. All the machines worked to 75% as expected.
Figure 4.7 Status of inprocess material availability in Fastener industry

Figure 4.8 presents a plot showing the details of the inprocess material availability at various machines in the fastener industry. The x-axis shows the machine numbers and the y-axis shows the percentage of inprocess material availability as per the data collected. In the plot, blue colour is not visible as there was no lack of in process material availability. The orange colour indicates the minimum in process material availability at each machines. The green colour indicates that the in process material was available as expected. Inprocess material was available to a minimum of 78% as expected.
Figure 4.8 presents a plot showing the details of the working facility available for various machines in the fastener industry. The x-axis shows the machine numbers and the y-axis shows the percentage of working facility available as per the data collected. In the plot, blue colour is not visible as there were no lack of working facility availability. The orange colour indicates the minimum working facility available for each machines. The dark violet colour indicates that the working facility was available to a minimum of 78%.

Figure 4.9 presents a plot showing the supply chain status in the fastener data. The x-axis shows the training and the testing pattern numbers and the y-axis shows the percentage of supply chain status as per the data collected. In the plot, blue colour is not visible and it is the representation of the presence of information < 0.5 in the data. The orange colour indicates the presence of information 0.5 to 0.7 in the data. This indicates about no SCD but with some difficulties present. The grey colour indicates presence of information >0.7 in the data. This indicates no SCD and is without any disruption.
4.2.2 Fixing Target Values For Training The Fastener Data

Figure 3.11 presents the target value allotted for 1000 patterns of the fastener data. A value of 0 is allotted if the number of coded values <0.7 is below 21/30 or else 0.9 is allotted. Each vertical line indicates the change in value from 0.9 to 0.5 and 0.5 to 0.9.
4.3 OBJECTIVE FUNCTION FOR SUPPLY CHAIN MANAGEMENT EVALUATION

Some of the points that have to be considered to minimize disturbance in the manufacturing environment are as follows:

i) What are the facilities available for each step in the production sequence?

ii) If there is a problem at any machine either due to mishandling of equipment or due to poor maintenance, then how much time it would take to rectify the problem?,

iii) What is the impact of the delay in manufacturing due to power failure / reduced maintenance / insufficient inventory / non-availability of the operator?, and,

iv) What are the existing arrangements available in the factory to maintain smooth manufacturing without any disruption?

Figure 4.10  Target values for fastener data
The objective functions are set of equations which inform the management about the manufacturing cost incurred for achieving the production target. The objective function is based on the minimum cost incurred in manufacturing products within the stipulated time. The production cost increases due to following situations:

i) Due to delay in receiving raw materials,

ii) Non-availability of minimum inventory,

iii) Machine breakdown, and in

iv) Not maintaining product quality and hence the product becomes a scrap.

Many types of parameters can be used to formulate minimum manufacturing cost equation. These parameters vary for different manufacturing companies. Cohen and Lee 1989, used deterministic and analytical model for objective functions. The function maximizes the total after-tax profit for manufacturing facilities constraints. The constraints are managerial constraints (resource and production) and logical consistency constraints (feasibility, availability, and demand limits). The outputs of the objective functions are finished products and subassemblies at the manufacturing facilities.

Different models using stochastic analysis were developed (Cohen and Lee. 1988) for the following situations:

i) **Material control:** It deals with economic aspects, such as bills of material, cost data, and production requirements,

ii) **Production control:** It, determines the production lot sizes and lead times for each product, given material response times, and,
iii) **Finished goods:** It determines, the economic order size and quantity for each product by using cost data, fill rate objectives, production lead times, and demand data.

Different qualitative performance measures have been proposed earlier to achieve the required objective function:

i) Qualitative performance measures has no direct numerical measurement, and,

ii) Quantitative performance measures can be directly described based on cost.

**Cost minimization:** It is reduced in manufacturing environment as given by equation (4.1).

\[
\text{Manufacturing cost} = \alpha \left( \frac{1}{1 + \text{Machine idle time}} \right) + \left( \frac{1}{1 + \text{Over time}} \right) \tag{4.1}
\]

\[
\text{Machine idle time} = \begin{cases} 
0 & \text{cost is minimum} \\
> 0 & \text{cost increases}
\end{cases} \tag{4.2}
\]

\[
\text{Overtime} = \begin{cases} 
0 & \text{cost is minimum} \\
> 0 & \text{cost increases}
\end{cases} \tag{4.3}
\]

In equation (4.3), the overtime refers to the working time of the laborers which double the normal wages. This may be due to the intention of the workers to always work overtime and slow the average working speed during regular shift, and the manufacturing is not achieved by the workers of the machine numbers > 7 per day per shift due to breakdown of the machine numbers <=7 \{It means any of the machine numbers (n-1) which is under breakdown and will result in not machines (n) in not achieving the production target\}. Hence, only when the machines (n-1) are set right, then (n) can achieve the production target.

The production of fastener/ automobile/ paper is based on many manufacturing criteria. In the SCD prediction, inputs are derived from various
data recorded from the log book of the maintenance department. Figure 4.11 presents the different parameters considered for obtaining data from the log book.

Figure 4.11 Parameters used for creating the training and the testing datasets
Sample simulation data used for predicting SCD is given in Tables 4.2 and 4.3. It shows the working conditions of the machines as given by equation (4.4).

\[
\text{Machine working condition} = \begin{cases} 
0 & \text{not working} \\
1 & \text{working} 
\end{cases} 
\] (4.4)

In Tables 4.2 and 4.3 the machine working status can be expressed as given in equation (4.5)

\[
\text{Machine working on daily basis} = \begin{cases} 
& \leq 0.5 \quad \text{not suited for manufacturing, maintenance is required} \\
&> 0.5 \& < 1 \quad \text{performance of the machine is not good} \\
&= 1 \quad \text{machine working in good condition} 
\end{cases} 
\] (4.5)

If the job is on machine number 5 and table shows machine six as 0, then machine 6 has to be rectified/replaced. Also, if the job is half-finished in machine 5 and there is break down at machine 5, then table shows 0. In such case, the task cannot be completed on machine 5, and hence, machine 5 has to be rectified.

In Tables 4.2 and 4.3 the amount of material can be expressed as given in equation 4.6.

\[
\text{Amount of material available on daily basis} = \begin{cases} 
< 1 \quad \text{insufficient material} \\
= 1 \quad \text{sufficient material} 
\end{cases} 
\] (4.6)

In Tables 4.2 and 4.3 the values can be expressed as given in equation (4.7)
4.4 RESULT AND DISCUSSION

This implies the method of collecting data for training and testing the neuro-fuzzy algorithms. Fuzzy logic is employed to obtain Fuzzy inference system (FIS) by using the training data. In the training process of BPA/RBF/ESNN/CMAC algorithms, the adjustments of the membership functions, rules and defuzzification parameters of the FIS until correct mapping of the inputs with outputs in the fuzzy logic is carried out. In the testing process, the outputs of adaptive neuro-fuzzy inference system (ANFIS) are compared with already stored information in a template, and suitable corrective action is carried out to mitigate the SCD.

Table 4.4 shows the distributions of input patterns used for training and testing the neuro-fuzzy algorithms. The FIS/ BPA/ RBF/ ESNN/ CMAC is trained with 500 patterns of set-1 and is tested with 500 different patterns of set-2.

<table>
<thead>
<tr>
<th>Table 4.4 Patterns used for training and testing the algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I Class II All machines working (No SCD) 10% SCD 20% SCD</td>
</tr>
<tr>
<td>Training 300 50 50 100</td>
</tr>
<tr>
<td>Testing 300 50 50 100</td>
</tr>
<tr>
<td>Total 600 100 100 200</td>
</tr>
</tbody>
</table>
This chapter has presented a manufacturing information for fastener/ automobile/ paper. The working conditions of machines/ raw materials required at each machine/ facilities required at each machine are expressed in numerical values in the range of 0-1. These values are used for training and testing the neuro-fuzzy algorithms.

4.4.1 Training The FIS

4.4.1.1 Training the fastener data by using Tables 4.2

Figure 4.12 presents a fuzzy logic architecture for the fastener data. The fuzzy inference system (FIS) for fastener data is given below. Sugeno model has been used. The anding method used is ‘prod’. The ormethod used is ‘probor’. Also the implication method used is ‘prod, aggregatemethod used is ‘max’. Inorder to get the final output, weighted average methods are used in the defuzzification process.

![Fuzzy logic designer using fuzzyLogicdesigner toolbox](image)

**Figure 4.12** Fuzzy logic designer using fuzzyLogicdesigner toolbox

name: 'sug301'
type: 'sugeno'
andMethod: 'prod'
orMethod: 'probor'
impMethod: 'prod'
aggMethod: 'max'
defuzzMethod: 'wtaver'
input: [1x30 struct]
output: [1x1 struct]
rule: [1x55 struct]

Figure 4.13  Membership function editor

Figure 4.13 presents membership function editor. It shows the ‘gaussmf’ and the range of values for the gaussmf as [0.01767 0.9]

Figure 4.14  Rule viewer for the fastener data

Figure 4.14 presents the rule viewer for fastener data. Each row shows one pattern. Each column shows the resultant operation of the membership function with the input data.
Figure 4.15  Rule Editor

Figure 4.15 presents the rule editor. The rules can be added or modified as per the requirements of the FIS outputs.

Figure 4.16 presents the computation time for different radial distance. The computation time is highest when the distance is 0.4 and the computation time is lowest when the distance is 0.1.
Figure 4.16  Computation time

Figure 4.17  Error of the FIS

Figure 4.17 presents the error in FIS to be minimum when the distance is 0.1 and the error is maximum when the distance is 0.1.
Figure 4.18 Deviations in the estimated output

Figure 4.18 presents the outputs of FIS when testing the patterns. Highest deviation occurs when the distance is 0.8. More deviations occur for at least 7 test patterns.
4.4.2 Testing The FIS

4.4.2.1 Testing the fastener data by using Tables 4.19

![Image]

**Figure 4.19** Test pattern outputs for the fastener industry data

Figure 4.19 presents the outputs of FIS for fastener production data. An average error of 0.2 is obtained for all the test patterns used to test the FIS.

4.4.3 Training On BPA For Adjusting FISParameters

4.4.3.1 Parameter analysis for convergence of BPA

The updation of weight W1 and W2 delta rule for is meant the updating of numerical values in the weight matrices representing input to hidden layer, and hidden to output layer. The speed of updation of weights depend on two controlling parameters as given below:
1) $\alpha$ is an accelerating factor (0 to 1)
2) $\eta$ is a learning factor (0 to 1)

![Graph](image1.png)

**Figure 4.20  Convergence versus number of nodes in the hidden layer**

The learning parameter $\eta = 1$. The stopping criteria is 0.01. The figure 4.20 presents the convergence for different number of nodes in the hidden layer. The convergence value slowly decreases when the hidden node increases from 2 to 7.

![Graph](image2.png)

**Figure 4.21  Convergence versus number of nodes in the hidden layer for different $\eta$ values**
Figure 4.21 shows the plots for different $\eta$ values and different number of nodes in the hidden layer. When the $\eta=1$, minimum number of iterations are required for six nodes in the hidden layer. As the $\eta$ value decreases the number of nodes in the hidden layer is other than six, and the convergence value increases.

![Graph showing convergence versus number of nodes in the hidden layer for different $\alpha$ values](image)

**Figure 4.22**  Convergence versus number of nodes in the hidden layer for different $\alpha$ values

Figure 4.22 presents the impact of $\alpha$ as an accelerating parameter in addition to learning factor during the training process of the BPA. It uses the difference between the previous(1) and previous(2) weight values and $\alpha$ provides a slightly increasing or decreasing values for achieving global convergence compared to the values provided by the learning factor. The optimal convergence value is obtained the $\alpha$ value is 0.5 and the number of nodes in the hidden layer is 6, then minimum iteration takes place.
To train the ANN, 32x5x1 topology is used. Only 1000 patterns have been considered for training purpose. The dataset has been separated as training and testing, datasets Training indicates the formation of final weights.

4.4.4 Training The BPA Using Fastener Production Data

Figure 4.23 Convergence curve for BPA on training the fastener data

Figure 4.23 shows the convergence curve for topology of 2 nodes to 25 nodes in the hidden layer with estimation of 90%. The network is trained to reach MSE of 0.01853. It is converged in 5 iterations. If the number of patterns is further increased from 1000 then the convergence iterations will increase. In addition, the convergence depends on the orthogonality of data presented for training. If the subsequent patterns are not orthogonal, the convergence would take a longer time or it may not converge.
4.4.5 Testing The BPA Performance

In the testing process, trained weights are used to process the test pattern inputs so as, to obtain outputs in the output layer of the BPA network. The obtained output is compared with the target output to identify the error of BPA learning process.

4.4.5.1 Testing the BPA using the fastener production data

![Graph showing BPA estimation using fastener production data](image)

**Figure 4.24**  BPA estimation using fastener production data

Figure 4.24 presents the outputs of BPA network during the testing process by using the fastener data. The number of nodes in the hidden layer is 2, 5, 10 and 20. When the number of nodes used are 10, and then the error between the obtained outputs and the target values are minimum as indicated by grey color line. The outputs of the network are not visible in the plot when the nodes in the hidden layer are 2 and 10. This is due to overlapping.
4.4.6    Performance of FIS By Using BPA Training

4.4.6.1    Testing the FIS by using the BPA trained weights and fastener production data

![Figure 4.25](image_url)  

**Figure 4.25   Performance of the FIS for the fastener data**

Figure 4.25 presents the outputs of FIS by using the BP for adjusting the FIS parameters. The target output, the actual output and the error are presented. The error of the FIS is shown on the secondary vertical axis. An error of 0.1 to 0.3 is present in the FIS trained by using the BPA
4.4.7 Performance of FIS By Using RBF Training

4.4.7.1 Testing the FIS using RBF trained weights and the fastener production data

Figure 4.26 Performance of the FIS for the fastener data

Figure 4.26 presents the outputs of FIS by employing the RBF for adjusting the FIS parameters. The target output, the actual output and the error are presented. The error of the FIS is shown on the secondary vertical axis. An error of 0.1 to 0.3 is present in FIS trained by using RBF.
4.4.8 Parameter Analysis for The ESNN

4.4.8.1 Number of reservoirs versus the error of the ESNN

![Graph](image)

**Figure 4.27** Error of ESNN for Different Number of Reservoirs

In Figure 4.27, the x-axis presents the number of reservoirs and the y-axis presents the error of ESNN. The error keeps fluctuating for different number of reservoirs in the hidden layer and it is minimum when the number of reservoir is 22.

4.4.9 Range of Weights For W Matrix

![Graph](image)

**Figure 4.28** Error of ESNN for different W values with reservoir=22
In figure 4.28, the x-axis presents the different random numbers and the y-axis shows error of ESNN for a reservoir =22. Minimum error is obtained when the random number is approximately 2.

### 4.4.10 Range of Weights For The $W_{ij}$ Matrix

![Graph showing error of ESNN for different $W_{ij}$ values with reservoir=22](graph)

**Figure 4.29** Error of ESNN for different $W_{ij}$ values with reservoir=22

In the figure 4.29, the x-axis presents the different random numbers and the y-axis shows error of the ESNN for a reservoir =22. Minimum error is obtained when the random number is approximately 0.5-0.6.
4.4.11 Range of Weights For The Reservoir Matrix

![Graph showing error between estimated and actual outputs for different reservoir weights]

**Figure 4.30** Error of ESNN for different reservoir matrix values with reservoir=22

In the figure 4.30, the x-axis presents the different random numbers and the y-axis shows error of ESNN for a reservoir =22. Minimum error is obtained when the random number is approximately 0.3.

4.4.12 Testing The ESNN By Using The Fastener Production Data

![Graph showing ESNN estimation using fastener production data]

**Figure 4.31** ESNN estimation using fastener production data
Figure 4.31 presents the outputs of ESNN network during the testing process by using the fastener production data. The number of reservoirs used in the hidden layer is 3, 5, 10, 15, 21 and 31. When the number of reservoir used is 10, the error between the obtained outputs and the target values are minimum as indicated by grey color line.

![Graph showing outputs of ESNN network](image)

**Figure 4.32 Performance of the FIS for the fastener data**

Figure 4.32 presents the outputs of FIS by using the ESNN for adjusting the FIS parameters. The target output, the actual output and the error are presented. The error of the FIS is shown on the secondary vertical axis. An error of 0.1 to 0.3 is present in the FIS trained by using ESNN.
4.4.13 Performance of FIS By Using CMAC Training

4.4.13.1 Testing the FIS by using CMAC trained weights and the fastenerProduction data

Figure 4.33 Performance of the FIS for the fastener data

Figure 4.33 presents the outputs of the FIS by using CMAC for adjusting the FIS parameters. The target output, the actual output and the error are presented. The error of FIS is shown on the secondary vertical axis. An average error of 0.05 is present in FIS trained by using ESNN.

4.5 SUMMARY

This chapter has provided the working aspects of fuzzy logic. It has given details about choosing membership functions and rule strengths. The presentation of data for training the fuzzy system and the outputs of the testing of the FIS are presented along with implementation of BPA for adjusting the parameters of the FIS. The training and the testing of the performance of the
BPA have been presented. The performances of the FIS with the BPA trained parameters are presented. The maximum error obtained is 0.32. This chapter has presented the implementation of RBF for adjusting the parameters of the FIS. The training and the testing of the performance of RBF have been presented. The performances of FIS with RBF trained parameters are presented. The maximum error obtained is 0.32 and it enables in implementation of ESNN for adjusting the parameters of the FIS. The training and the testing of the performance of the ESNN have been presented. The performances of FIS with the ESNN trained parameters are presented. The maximum error obtained is 0.32. The implementation of CMAC has helped in adjusting the parameters of the FIS. The training and the testing of the performance of the CMAC have been in presented. The performances of FIS with the CMAC trained parameters are presented. The maximum error obtained is 0.32. This is done for Fastener industry. In chapter 6 and 7, the implementation of same procedure is implemented for automobile and paper industry. Chapter 8 presents about the comparisons of the performance of BPA/RBF/ESNN/CMAC in adjusting parameters of the FIS.