CHAPTER V

FORECASTING OF NEW ISSUED BANKNOTES USING WIDROW-HOFF ALGORITHM

5.1 Introduction

This chapter includes the experimentation of forecasting the new issued banknotes using Widrow-Hoff algorithm. The experimentation here concerns adjusting parameters such as weight, bias, number of epoch, and learning rate of the network in order to obtain minimum sum-squared error (SSE) of training data while data selection is made based on its original regression analysis approach. However GDP growths (%) is chosen instead of GDPs at current prices (millions of baht) because saving deposit rates (%) may be dominated during training period.

5.2 Experimental Conditions

5.2.1 Training Data

Training data contains 48 input data having GDP growth rates and saving deposit rates and 48 output data which are issued banknotes from 1989 to 1992. The input data which are GDP growth rates and saving deposit rates are shown in Table 5.1 and 5.2 respectively. The outputs, the values of monthly issued banknotes are shown in Table 5.3.

1. GDP Growth Rates (%)† January 1989 - December 1992

Table 5.1 - GDP Growth Rates (1989-1992)

Yr./Month	1	2	3	4	5	6	7	8	9	10	11	12
1989	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
1990	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6
1991	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
1992	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1

2. Saving Deposit Rates (%)† January 1989 - December 1992

Table 5.2 - Saving Deposit Rates (1989-1992)

Yr./Mth.	1	2	3	4	5	6	7	8	9	10	11	12
1989	7.13	7.13	7.13	7.13	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25
1990	7.25	7.25	7.25	9.00	9.00	9.00	9.00	9.00	9.00	9.00	10.00	11.00
1991	11.00	10.75	10.25	9.00	9.00	9.00	10.50	9.00	9.00	9.00	9.00	8.50
1992	8.00	7.50	6.50	6.00	6.00	6.50	6.50	6.50	6.50	6.50	6.50	6.25

3. Values of monthly issued banknotes (millions of baht)†:

January 1989 - December 1992

Table 5.3 - Values of Issued Banknotes (1989-1992)

Month/Year	1989	1990	1991	1992
1	22,492.0	28,304.0	22,923.8	41,970.9
2	18,403.9	15,104.5	32,412.9	22,419.5
3	17,721.8	20,598.6	22,272.9	27,447.9
4	16,475.0	21,308.2	24,362.3	30,036.0
5	16,937.1	19,088.5	22,835.2	25,660.9
6	18,844.0	20,750.5	22,441.9	25,558.0
7	16,302.6	21,656.4	23,428.7	27,223.5
8	17,777.6	24,743.8	24,986.0	30,710.3
9	16,930.8	21,262.9	25,687.3	28,582.2
10	17,775.5	21,968.6	28,092.0	30,128.0
11	19,547.6	24,069.1	26,704.9	29,134.8
12	25,724.8	29,220.8	38,326.5	44,839.9

†Source: Bank Of Thailand

5.2.2 Testing Data

Testing data contains 48 input data having GDP growth rates and saving deposit rates and 48 output data which are issued banknotes from 1993 to 1996. The inputs, monthly GDP growth rates and saving deposit rates are shown in Table 5.4 and 5.5 respectively. The outputs, the values of issued banknotes are shown in Table 5.6.

1. GDP Growth Rates (%)† January 1993 - December 1996

Table 5.4 - GDP Growth Rates (1993-1996)

Yr./Month	1	2	3	4	5	6	7	8	9	10	11	12
1993	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
1994	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
1995	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6
1996	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4

2. Saving Deposit Rates (%)† January 1993 - December 1996

Table 5.5 - Saving Deposit Rates (1993-1996)

Yr./Month	1	2	3	4	5	6	7	8	9	10	11	12
1993	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.50	5.50	5.00
1994	4.75	4.75	4.75	4.88	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
1995	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
1996	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

3. Values of Monthly Issued Banknotes (millions of baht)†:

January 1993 - December 1996

Table 5.6 - Monthly Values of Issued Banknotes (1993-1996)

Month/Year	1993	1994	1995	1996
1	43,602.0	38,841.0	66,891.9	52,247.9
2	27,070.8	48,897.8	36,347.0	81,851.2
3	33,257.7	40,234.6	54,341.1	55,349.9
4	36,465.7	40,095.5	47,390.8	63,575.0
5	30,295.9	35,854.5	49,523.5	59,175.1
6	32,663.3	41,868.3	60,171.6	55,453.6
7	35,680.2	38,582.6	43,736.6	57,428.6
8	33,303.7	41,695.3	50,761.3	56,515.8
9	34,797.3	44,203.2	48,968.7	54,438.3
10	36,064.7	41,047.2	51,040.1	63,874.3
11	37,681.9	44,719.7	55,638.3	61,797.1
12	55,203.0	66,992.2	72,967.0	80,139.2

Source: Bank Of Thailand

5.2.3 Initial Parameters

Epoch and learning rate are adjustable parameters. Weight and bias are randomly initialized. Epoch and learning rate are set at 10,000 and 1.2379×10^{-8} which calculated from 0.0001*maxlinlr(P,1). See [4] for details of the usage of the maxlinlr function.

5.2.4 Experimental Objectives

The objectives are as follows:

1. Investigate the use of different initial weight and bias.

2. Investigate the trend of sum-squared error while increasing the number of epochs.

3. Investigate the use of different learning rates.

5.3 Training and Results

5.3.1. Investigation of the use of different initial weight and bias.

Initial weight and bias which the program randomly generates affect the sum-squared error of training data. A number of initial conditions were tested on the data mentioned in 5.2.1 and 5.2.2 to find out the weight and bias that generates minimum sum-squared error of training data. Four of them are chosen to demonstrate the consequences of using different initial weight and bias as shown in Table 5.7.

Table 5.7 - Training Selection

Initial Condition No.	Weight	Bias	SSE of Training Data
1	-0.5732 0.4858	-0.1452	316.0340
2	-0.4882 0.1531	-0.8181	1108.8400
3	-0.2086 0.4382	-0.9565	**27.9732**
4	-0.1895 0.4623	-0.9542	44.5252

As seen in Table 5.7, different initial conditions result in different sum-squared errors. The difference is that the initial weight and bias are randomly selected for each training. For next training, the initial condition no. 3 is selected due to its minimum sum-squared error of training data. The final weight and bias are [-0.2086, 0.4382] and [-0.9565] respectively.

5.3.2. Investigation of the trend of sum-squared error while increasing the number of epochs.

From previous training, weight, and bias are selected for initialization at [-0.2086, 0.4382], and [-0.9565]. The number of epoch is set at 40,000 after testing some numbers. Then the number of epochs is increased to determine its effect. The results are shown in Table 5.8 and Figure 5.1.

Table 5.8 - Searching for the Best Weight and Bias

Epoch	Weight	Bias	SSE of Training Data
40,000	-0.2053 0.4065	-0.9580	22.5880
80,000	-0.1899 0.3866	-0.9581	20.0246
120,000	-0.1752 0.3681	-0.9582	17.7768
160,000	-0.1614 0.3508	-0.9582	15.7990
200,000	-0.1485 0.3346	-0.9582	14.0637
240,000	-0.1365 0.3194	-0.9582	12.5423
280,000	-0.1252 0.3052	-0.9581	11.2092
320,000	-0.1146 0.2919	-0.9580	10.0386
360,000	-0.1047 0.2794	-0.9579	9.01056
400,000	-0.0954 0.2677	-0.9578	8.10739
440,000	-0.0867 0.2567	-0.9576	7.31416
480,000	-0.0786 0.2464	-0.9574	6.61664

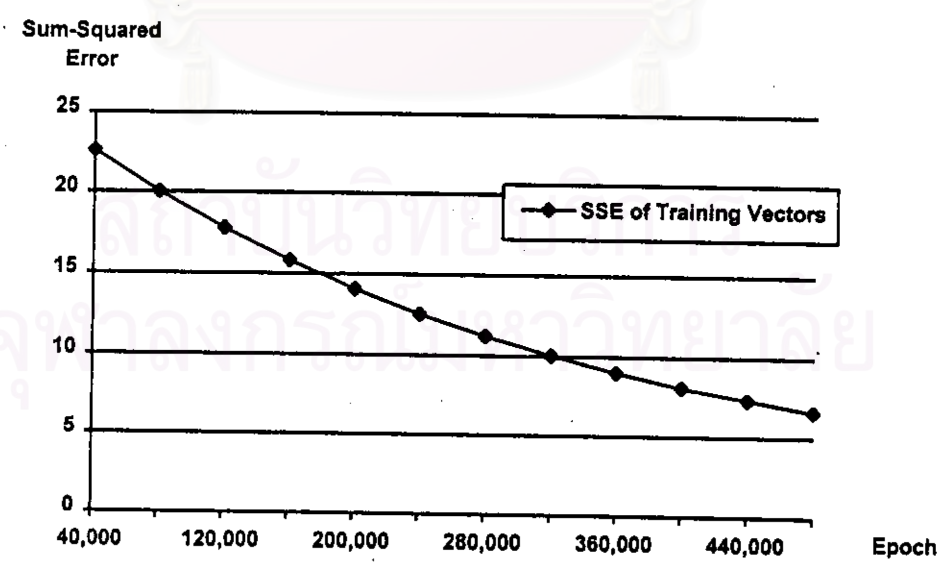

Figure 5.1 - SSE of Training Data

From Table 5.8, weight, bias, and sum-squared error of training data keep decreasing as the training is continued but the rate of decreasing of sum-squared error is lower than epoch increases as demonstrated in Figure 5.1.

Then the epoch is changed to be 200,000 and training data are trained for two more times. Eventually the weight and bias are [-0.0206 0.1731] and [-0.9546]. Then these values will be brought to further training in order to find the learning rate that generates the minimum sum-squared error of training data.

5.3.3 Investigation of the use of different learning rates.

Learning rate is another parameter to focus on. It has an effect on the training result. Therefore weight, bias, and other parameters, except learning rate, are initialized at the same values for each training. Epoch is set at 50,000 for longer training in order to gain lower SSE of training ventors. The weight and bias which brought from previous training are [-0.0206 0.1731] and [-0.9546]. The learning rates vary from 0.00001*M up to 2.90000*M.

Table 5.9 - Learning Selection

Training No.	Learning Rate	Weight	Bias	SSE of Training Data
1	0.00001*M	-0.0201 0.1724	-0.9546	2.94235
2	0.00005*M	-0.0181 0.1699	-0.9544	2.85764
3	0.00009*M	-0.0162 0.1674	-0.9542	2.77824
4	0.00010*M	-0.0157 0.1668	-0.9542	2.759180
5	0.00050*M	0.0004 0.1463	-0.9523	2.202220
6	0.00090*M	0.0120 0.1315	-0.9502	1.909530
7	0.00100*M	0.0144 0.1285	-0.8945	1.861190
8	0.00500*M	0.0401 0.0930	-0.9254	1.543990
9	0.00900*M	0.0401 0.0900	-0.9006	1.493340
10	0.01000*M	0.0398 0.0896	-0.4399	1.481060
11	0.05000*M	0.0299 0.0744	-0.6698	1.069590
12	0.09000*M	0.0216 0.0617	-0.4819	0.781617
13	0.10000*M	0.0197 0.0588	-0.4399	0.724302
14	0.50000*M	-0.0141 0.0071	0.3258	0.127436
15	0.90000*M	-0.0198 0.0016	0.4543	0.110610
16	0.99000*M	-0.0202 -0.0022	0.4629	0.110341
17	0.99900*M	-0.0202 -0.0022	0.4636	0.110324
18	1.00000*M	-0.0202 -0.0022	0.4636	0.110322
19	1.10000*M	-0.0205 -0.0026	0.4696	0.110204
20	1.50000*M	-0.0209 -0.0032	0.4785	0.110124
21	**1.90000*M**	**-0.0209 -0.0033**	**0.4799**	**0.110122**
22	2.00000*M	-0.0209 -0.0033	0.4801	0.110123
23	2.10000*M	∝ ∝	∝	∝
24	2.50000*M	∝ ∝	∝	∝
25	2.90000*M	∝ ∝	∝	∝

Remark: M stands for maxlinlr function which equals to 2.2386e-004 for these input data.

From Table 5.9, the learning rate that generates the minimum sum-squared error of training data is 1.9000*M where the sum-squared error of training data is 0.110122. Higher learning rates produce lower sum-squared error. But if learning rate is too high, the result will be diverged in stead of converged. As shown in Figure 5.1, while increasing learning rate, the sum-squared error is decreasing until at the learning rate is 2.00000*M, sum-squared error starts increasing to infinity.

It can be concluded from the experiment that too low learning rates lead to slow training and too high learning rates produce diverged result. Hence proper learning rate should be well chosen before further training.

5.3.4 Confirmation of minimum sum-squared error.

The training is continued for more 50,000 epoch in order to find the minimum error. The training no. 15 and 19 are also selected to training for the same amount of epoch and verify the minimum error. The results are shown in Table 5.10.

Table 5.10 - Minimum Sum-Squared Error

Training No.	Learning Rate	Weight	Bias	SSE of Training Data
1	0.900*M	-0.0209 -0.0033	0.4798	0.110122
2	1.100*M	-0.0209 -0.0033	0.4801	0.110122
3	**1.900*M**	-0.0209 -0.0033	0.4802	0.110122

From Table 5.10, even learning rates are different, there is no difference of sum-squared error of training data. Hence it can be concluded that 0.110122 is the minimum sum-squared error of training data that Widrow-Hoff can find. Also it can concluded that higher learning rates produce lower sum-squared error. In other words, higher learning rates consumes less time than lower learning rates to produce the same sum-squared errors.

5.4 Conclusion

The following conclusion is made based on the experimentation using Widrow-Hoff method to forecast new banknotes:

1. Initial weight and bias effect on the sum-squared error of training data. Therefore proper weight and bias should be initialized for the training in order to gain faster result.

2. While increasing the number of epochs, the sum-squared error of training data continue decreasing. As mentioned earlier, the decreasing rate of sum-squared error is reduced while the number of epochs is rising.

3. Usually different learning rates with the same number of epoch result in different sum-squared errors. There is an exception, if minimum sum-squared error is found, different learning rates may give the same sum-squared error. Decreased learning rates produce higher sum-squared errors while increased learning rates give lower sum-squared errors. But when the learning rates are too high, sum-squared errors become increasing or diverging instead of decreasing or converging. This indicates instability of using improper learning rates.

4. Higher learning rates take less time to train for the same sum-squared error as lower learning rates do. Finally the minimum sum-squared error of training data is 0.110122 which gives 2.4423 as the sum-squared error of testing data. The result will be compared to that of backpropagation in next chapter.