Technical Report

Remote Data Mirroring
Logistic Regression Results

May 20, 2022

Version: 0.9

1 Remote Data Mirroring

The self-adaptive Remote Data Mirroring (RDM) network [1] is based on the operational model presented in [2]. The RDM network under consideration consists of 25 RDM Mirrors (servers), to hold multiple copies of data, with 300 physical links in total that can used to transfer data between the mirrors. Each network link has an associated operational cost[1] and a measurable throughput, latency and loss rate used to determine the reliability, performance and cost of the RDM system [3, 4]. The goal here is to satisfy the quality objectives of Minimization of Costs (MC), Maximization of Performance (MP)[2] and Maximization of Reliability (MR) under environmental uncertainty of link failures and varying ranges of bandwidth consumption [1]. For this purpose, the network is required to continuously take adaptive actions of switching between the topological configurations of Minimum Spanning Tree (MST) and Redundant Topology (RT) to maintain better levels of satisfaction of quality objectives. Both the configurations offer a different impact on the quality objectives' satisfaction. The topological configuration of RT provides a higher level reliability than MST topology but it has a negative impact on the satisfaction of the MC and MP as the cost of maintaining non-stop RT topology will be high and due to data redundancy, the performance can be reduced. On the other hand, MST topology supports the satisfaction of MC and MP by maintaining a minimum spanning tree for the network. The simulation tool of *RDMSim* [5] has been used to simulate the RDM network for experiments.

1.1 Experiment Scenarios

Experiments were performed by introducing different scenarios of the environmental conditions under which the RDM network works as follows:

Stable Scenario S_0 representing the RDM network performing under normal environmental conditions

Detrimental Scenario representing the RDM network performing under the dynamic environment when different disturbance levels (increased packet loss or network link failures) in the network environment are introduced. There are 6 scenarios of detrimental situations defined by the simulated environment of *RDMSim*:

Scenario S_1 Unexpected Packet Loss during MST:

An unexpected data packet loss during the execution of MST generates a decrease in the reliability of the system. A MST topology connects all remote sites in the RDM network by the identification of a minimum spanning tree on the network of links among each remote site. Data packet loss may represent network link failures in the RDM system, which may be caused due to problems with the equipment such as failure of a switch or a router.

Scenario S_2 Unexpected Packet Loss during RT:

Unexpected data packet loss during the execution of the RT Topology, are generating an unusual rate of data forwarding, which would increase cost in terms of bandwidth consumption and would decrease the system's performance. In case of RDM , the cost for inter-site links communication refers to the data sent over them. Therefore, during RT topology, that involves a bigger number of inter-site network links than a MST, is more expensive. Costs increase as the number of network links increases and a decrease in the system's performance could also be expected.

Scenario S_3 Simultaneous occurrence of Scenario S_1 and S_2 It represents the situation where simultaneous occurrence of Scenarios S_1 and S_2 is observed.

Scenario S_4 MST topology execution failures An unexpected data packet loss during the execution of MST generates a decrease in the reliability of the system and effects the operational cost and performance of the system.

[1] In RDM system, Operational Cost is measured in terms of intersite network traffic. [3]

[2] In the case of RDM network, we are measuring performance in terms of total time to write the data i.e. the sum of the time to write each copy of data on each remote site. [3]

Scenario S_5 RT topology execution failures Unexpected data packet loss during the execution of the RT Topology, are generating an unusual rate of data forwarding, which would increase cost in terms of bandwidth consumption and would decrease the system's performance along with affecting reliability of the network.

Scenario S_6 Significant Site Failure It represents the situation where simultaneous occurrence of Scenarios S_4 and S_5 is observed.

The remaining report is organized as follows. In Section 2, an overview of the Logistic Regression technique is provided which is followed by the experiments for the single-objective and multi-objective partially observable markov decision process in Section 3.

2 Logistic Regression

Logistic Regression is a binary classification technique [6]. It is a generalization of linear regression model to the binary classification setting. Both linear regression and logistic regression fall in the category of supervised learning models as they both make use of labeled data to make predictions. As opposed to linear regression which is used to predict continuous values, logistic regression is used to predict discrete values. The model takes as an input a number of independent variables and the output is a discrete valued variable. For example, in an Internet of Things (IoT) network, given the traffic load and interference on the network links, we want to predict whether it satisfies the quality objective of minimization of energy consumption (MEC) for the network. Here, the traffic load and link interference are the independent variables and the MEC satisfaction is a discrete valued dependent variable having a binary value. The MEC Satisfaction can have a value of True when it meets a required satisfaction threshold and False otherwise.

Hence, Logistic regression is considered as an extension of linear regression where the dependent variable can only have k number of classes. When k=2, it is known as binary logistic regression and for k>2, it is known as multiple or multinomial logistic regression. For a formal definition, we use the following notation:

Notation:

Let $x^{(i)}$ denotes the "input independent variables" (input features) and $y^{(i)}$ denotes the "output dependent variable" that we want to predict. We denote a pair $(x^{(i)}, y^{(i)})$ to represent a training example and the list of m training examples is called a training set denoted as $(x^{(i)}, y^{(i)}); i = 1, ..., m$. Hence, X represents the input space and Y represents the output space.

The formal definition for the typical regression problem is as follows:

***Formal Definition**: Given a training set, the goal is to learn a hypothesis function h which is a good predictor of the value of y given the corresponding input x. Formally defined as:*

$$h : X \to Y$$

The hypothesis function h is typically represented as a linear function of x to approximate y as follows:

$$h(x) = \theta_0 + \theta_1 x_1 + \theta_2 x_2 + ... + \theta_n x_n \tag{1}$$

where $x_1 - x_n$ represents the input features and the θ_i's are the parameters (also called weights) parameterizing the space of linear function's mapping from X to Y. Futhremore, to simplify the notation, the convention of letting $x_0 = 1$ (the *intercept* term) is introduced, so that:

$$h(x) = \sum_{i=0}^{n} \theta_i x_i = \theta^T x \tag{2}$$

Using the hypothesis function presented in equation 2 gives us a continuous real value whereas the output variable y in logistic regression is a discrete valued. Hence, for this purpose, the functions like Logistic Sigmoid function or Softmax function are used to modify the existing hypothesis function as follows:

Logistic Function:

The logistic function is a model of the sigmoid function representing an S shaped curve that can be mathematically represented as follows:

$$P(y) = \frac{1}{1 + e^{-z}} \tag{3}$$

The goal is to compute the probability that an observed set of input features x belongs to class y=1, using the Sigmoid function. In this case, our z parameter, is the linear hypothesis function *h(x)*. We will denote this new hypothesis function as g(z):

$$g(z) = P(y = 1) = \frac{1}{1 + e^{-(\theta_0 + \theta_1 x_1 + \theta_2 x_2 + ... + \theta_n x_n)}} \tag{4}$$

The parameters θ values, are selected to maximize the likelihood of predicting the probability of belonging to a particular class. If probability for observations is greater that 0.5, the observation will belong to class 1 and vice versa.

Softmax Function:

The Softmax function, as opposed to Sigmoid Function, gives a vector of values for each output class y. Given an observation of input features x it gives a vector of values to represent the probability of belonging to each output class. The sum of all the probability values in the vector is equal to 1. Mathematically, the Softmax function is computed as follows:

$$P(y^{(i)} = k | x^{(i)}; \theta) = \frac{exp(\theta^T x)}{\sum_{j=1}^{k} exp(\theta^T x)} \tag{5}$$

As Softmax function provides us with the membership probability for each class, we have used softmax function as part of our logistic regression classification.

Learning parameters θs:

Given a training set, the learning of θs can be done by making the result of hypothesis function close to y. Formally, a cost function known as the *least square cost function* is defined to measure how close $g(z^{(i)})$ is to the corresponding $y^{(i)}$ as follows:

$$J(\theta) = \frac{1}{2} \sum_{i=1}^{m} \left(g_\theta(z^{(i)}) - y^{(i)} \right)^2 \tag{6}$$

The θ parameters are chosen so that the cost function $J(\theta)$ is minimized. For the purpose of optimization of θ, we have used the Stochastic Gradient Descent (SGD) algorithm [7].

2.1 Stable Scenario S_0

Parameter Tuning

For the purpose of tuning of the parameters of the model, we have used Stochastic Gradient Descent (SGD) Algorithm. We have executed SGD for 20000 iterations with different learning rates for the results computed for each NFR separately as shown in Fig. 1, 2 and 3 respectively. On the basis of loss and the accuracy scores presented in Table 1, we have selected the learning rate of 0.05 for the model to evaluate the test set.

Table 1: Learning Rate Accuracy Score

Learning Rate	Accuracy Score MC	Accuracy Score MR	Accuracy Score MP
0.0001	0.9323308270676691	0.9924812030075187	0.9147869674185464
0.0003	0.9699248120300752	0.9899749373433584	0.9573934837092731
0.0005	0.9774436090225563	0.9899749373433584	0.9674185463659147
0.0007	0.9799498746867168	0.9899749373433584	0.9674185463659147
0.0009	0.9849624060150376	0.9899749373433584	0.9699248120300752
0.001	0.9849624060150376	0.9899749373433584	0.9699248120300752
0.003	0.9924812030075187	0.9899749373433584	0.9924812030075187
0.005	0.9924812030075187	0.9899749373433584	0.9974937343358395
0.007	0.9924812030075187	0.9899749373433584	0.9974937343358395
0.009	0.9949874686716792	0.9899749373433584	0.9974937343358395
0.01	0.9949874686716792	0.9899749373433584	0.9974937343358395
0.03	1.0	1.0	1.0
0.05	1.0	1.0	1.0
0.07	1.0	1.0	1.0
0.09	1.0	1.0	1.0

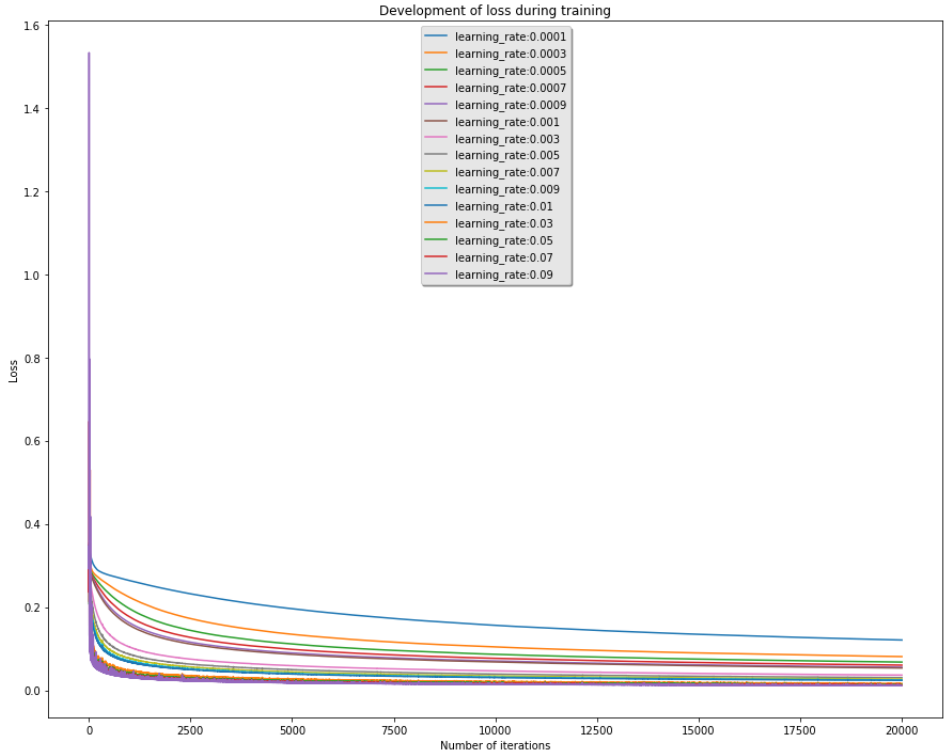

Figure 1: Learning Rate Optimization MC under stable scenario

Classification Results

The classification results for the NFRs using logistic regression under stable scenario are presented in Tables 2, 3 and 4. The results show an accuracy score of 0.9939879759519038 for MC, 0.9839679358717435 for MR and 0.9639278557114228 for MP with a Precision of 0.9920844327176781, 0.9691119691119691 and 1.0 respectively.

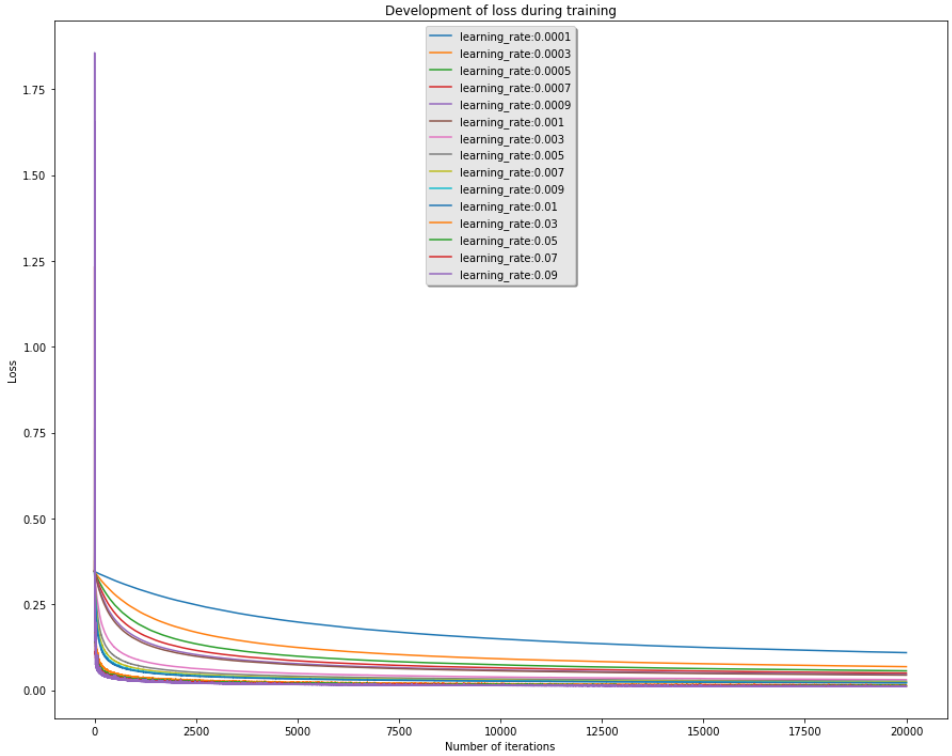

Figure 2: Learning Rate Optimization MR under stable scenario

Classification Results for MC

For the 500 simulation time steps, under stable scenario, the model correctly classifies the satisfaction state of MC with an exception of 3 simulation time steps as shown in Fig.4. For these 3 simulation time steps, the actual satisfaction state for MC was False but it was predicted as True.

Moreover, based on the results presented in Table.2, we can deduce the extent to which MC can be considered as satisfied, when both the bandwidth consumption and satisfaction probability are considered. For example, at time step 486 the bandwidth consumption is 4785 GBps and the satisfaction probability is 0.902529311. The satisfaction state predicted by the model is also False with the 9.99999711e-01 probability of being False. It means that given the input values, there is almost 99 percent chance of MC not being satisfied i.e. having satisfaction state as False.

Classification Results for MR

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MR with an exception of 8 simulation time steps as shown in Fig.5. For these 8 time steps, the actual satisfaction state for MR was False but it was predicted as True.

Moreover, based on the results presented in Table.3, we can deduce the extent of the satisfaction state of MR, when both the active links and satisfaction probability are considered. For example, at time step 485, the active links are 102 and the satisfaction probability is 0.890476277. The output satisfaction state predicted by the model is False similar to the actual state with the 0.58052763 probability of being False. It means that given the input values, there is around 58 percent chance of MR not being satisfied i.e. having satisfaction state as False.

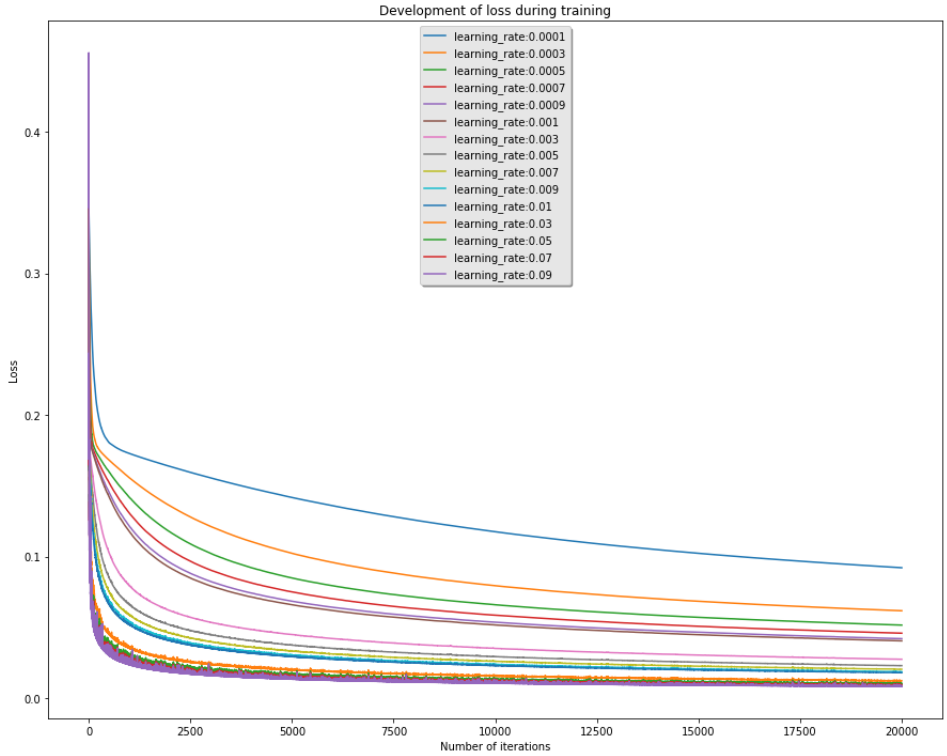

Figure 3: Learning Rate Optimization MP under stable scenario

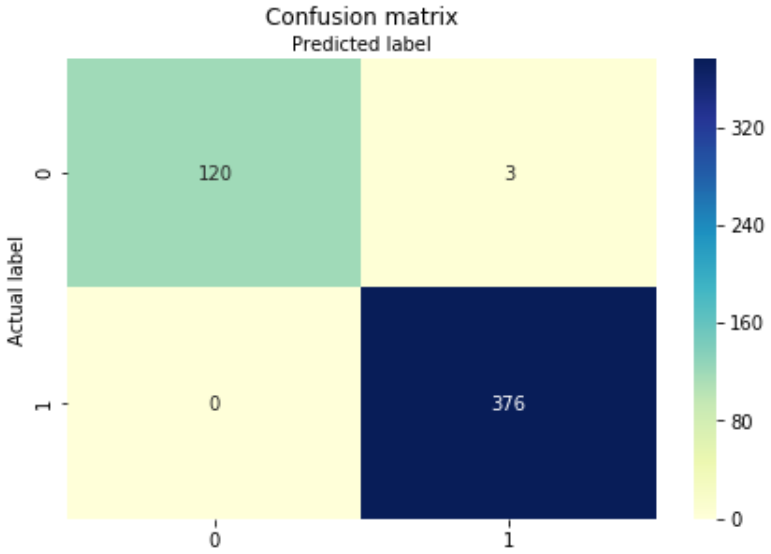

Figure 4: Confusion Matrix for Classification of Satisfaction State of MC under stable scenario

Classification Results for MP

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MP with an exception of 18 simulation time steps as shown in Fig.6. For these 18 time steps, the actual satisfaction state for MP

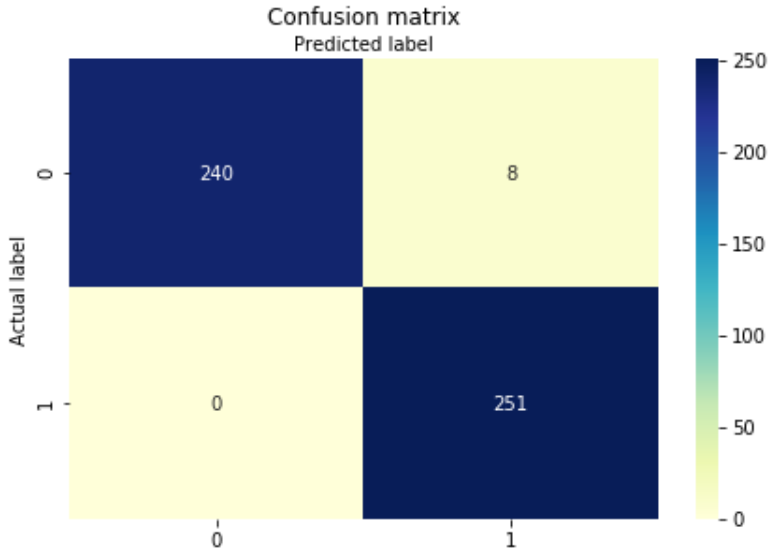

Figure 5: Confusion Matrix for Classification of Satisfaction State of MR under stable scenario

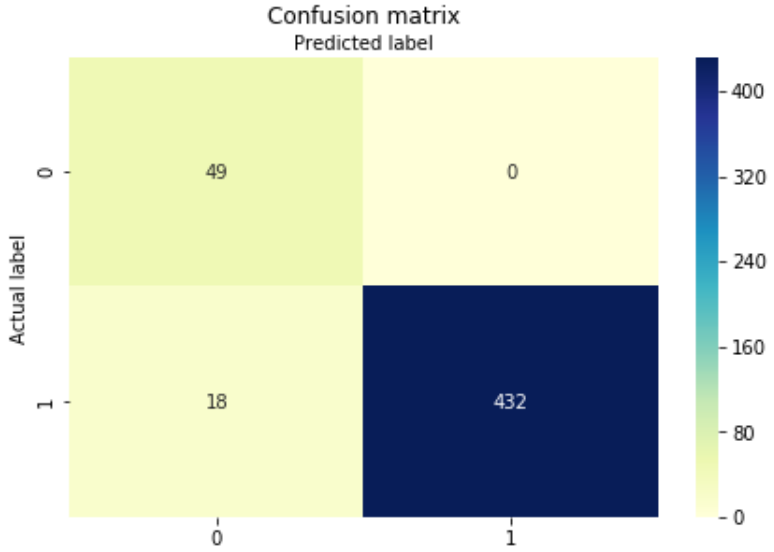

Figure 6: Confusion Matrix for Classification of Satisfaction State of MP under Stable Scenario

was True but it was predicted as False.

Moreover, based on the results presented in Table.4, we can deduce the extent of the satisfaction state of MP, when both the writing time and satisfaction probability are considered. For example, at time step 485, the writing time is 1224 ms and the satisfaction probability is 0.831446787. The output satisfaction state predicted by the model is True similar to the actual state with the 1.00000000e+00 probability of being True. It means that given the input values, there is 100 percent chance of MP to be satisfied i.e. having satisfaction state as True.

Table 2: Classification Results for Minimization of Operational Cost for time steps 485-491 under stable scenario

Time Step	Bandwidth Consumption	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
485	2142	0.878681003	True	True	[2.61534582e-09 9.99999997e-01]
486	4785	0.902529311	False	False	[9.99999711e-01 2.88560381e-07]
487	3260	0.816721721	True	True	[0.00783909 0.99216091]
488	3818	0.86974671	False	False	[0.91550021 0.08449979]
489	1728	0.875243403	True	True	[1.1179818e-11 1.0000000e+00]
490	567	0.903931281	True	True	[2.29250183e-18 1.00000000e+00]
491	1540	0.906253481	True	True	[8.60828833e-13 1.00000000e+00]

Table 3: Classification Results for Maximization of Reliability for time steps 485-491 under stable scenario

Time Step	Active Links	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
485	102	0.890476277	False	False	[0.58052763 0.41947237]
486	165	0.89421477	True	True	[2.22102897e-11 1.00000000e+00]
487	163	0.942541195	True	True	[9.92672271e-11 1.00000000e+00]
488	166	0.896645408	True	True	[1.5497682e-11 1.0000000e+00]
489	64	0.892796789	False	False	[9.99999792e-01 2.08364658e-07]
490	27	0.838290613	False	False	[1.00000000e+00 2.04770175e-13]
491	77	0.835466106	False	False	[9.99917754e-01 8.22461637e-05]

Table 4: Classification Results for Maximization of Performance for time steps 485-491 under stable scenario

Time Step	Writing Time	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
485	1224	0.831446787	True	True	[8.81073611e-11 1.00000000e+00]
486	1815	0.910477271	True	True	[1.46393484e-06 9.99998536e-01]
487	1956	0.847364808	True	True	[2.15692261e-05 9.99978431e-01]
488	1826	0.90915029	True	True	[1.77658183e-06 9.99998223e-01]
489	960	0.913417868	True	True	[6.7420196e-13 1.0000000e+00]
490	459	0.913903067	True	True	[1.31257655e-16 1.00000000e+00]
491	1155	0.91532629	True	True	[1.85751074e-11 1.00000000e+00]

Table 5: Learning Rate Accuracy Score under Scenario 1 (Cross Validation Set)

Learning Rate	Accuracy Score MC	Accuracy Score MR	Accuracy Score MP
0.0001	0.9624060150375939	0.9849624060150376	0.9398496240601504
0.0003	0.9799498746867168	0.9974937343358395	0.9674185463659147
0.0005	0.9849624060150376	0.9974937343358395	0.974937343358396
0.0007	0.9849624060150376	0.9974937343358395	0.9849624060150376
0.0009	0.9874686716791979	0.9974937343358395	0.9874686716791979
0.001	0.9874686716791979	0.9974937343358395	0.9874686716791979
0.003	0.9924812030075187	0.9974937343358395	0.9949874686716792
0.005	0.9974937343358395	0.9974937343358395	0.9949874686716792
0.007	0.9974937343358395	0.9974937343358395	0.9974937343358395
0.009	0.9974937343358395	0.9974937343358395	0.9974937343358395
0.01	0.9974937343358395	1.0	0.9974937343358395
0.03	1.0	1.0	1.0
0.05	0.9974937343358395	1.0	1.0
0.07	0.9974937343358395	1.0	1.0
0.09	0.9974937343358395	1.0	1.0

2.2 Scenario S_1

Parameter Tuning

We have executed SGD algorithm for 10,000 iterations with different learning rates for the results computed for each NFR separately as shown in Fig. 7, 8 and 9 respectively. On the basis of loss and the accuracy scores presented in Table 5, we have selected the learning rate of 0.03 for the model to evaluate the test set.

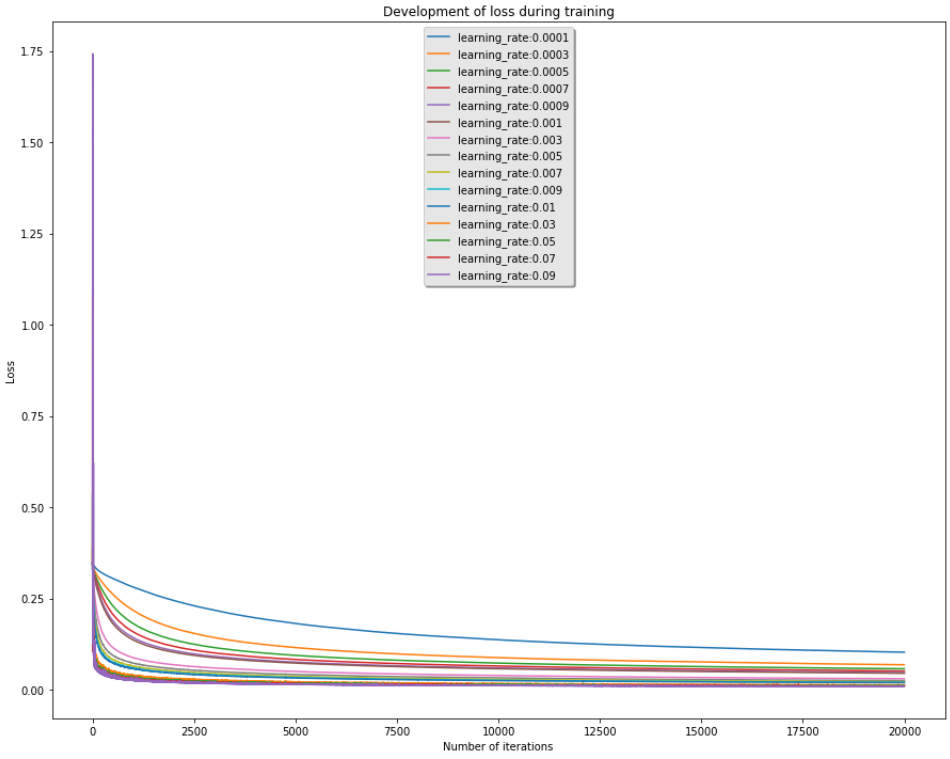

Figure 7: Learning Rate Optimization for MC under Scenario 1

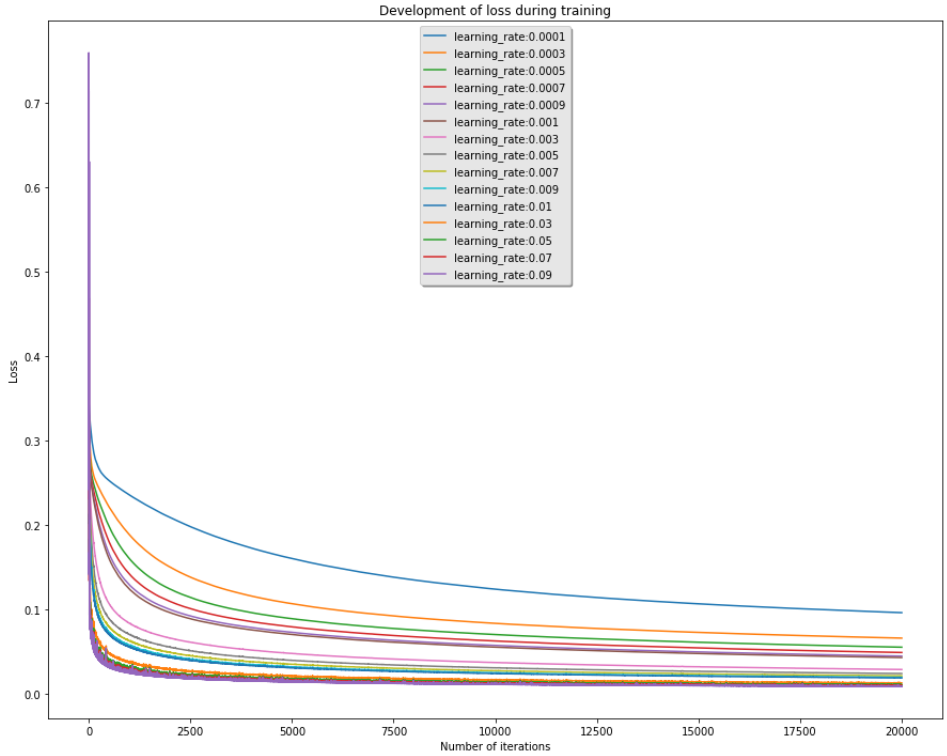

Figure 8: Learning Rate Optimization for MR under Scenario 1

Classification Results

The classification results for the NFRs using logistic regression are presented in Tables 6, 7 and 8. The results show an accuracy score of 0.98196 for MC, 1.0 for MR and MP with a Precision of 1.0 for all three NFRs.

Classification Results for MC

For the 500 simulation time steps, under Scenario 1 of *RDMSim*, the model correctly classifies the satisfaction state of MC with an exception of 9 simulation time steps as shown in Fig.10. For these 9 simulation time steps, the actual satisfaction state for MC was True but it was predicted as False.

Moreover, based on the results presented in Table.6, we can deduce the extent to which MC can be considered as satisfied, when both the bandwidth consumption and satisfaction probability are considered. For example, at time step 480, the bandwidth consumption is 5550 GBps and the satisfaction probability is 0.725491276. The satisfaction state predicted by the model is also False with the 9.9999e-01 probability of being False. It means that given the input values, there is around 99 percent chance of MC not being satisfied i.e. having satisfaction state as False.

Classification Results for MR

For all of the 500 simulation time steps comprising the test set, the model correctly classifies the satisfaction state of MR as shown in Fig.11.

Moreover, based on the results presented in Table.7, we can deduce the extent of the satisfaction state of MR, when both the active links and satisfaction probability are considered. For example, at time step 480, the active links are 222 and the satisfaction probability is 0.958693166. The output satisfaction state

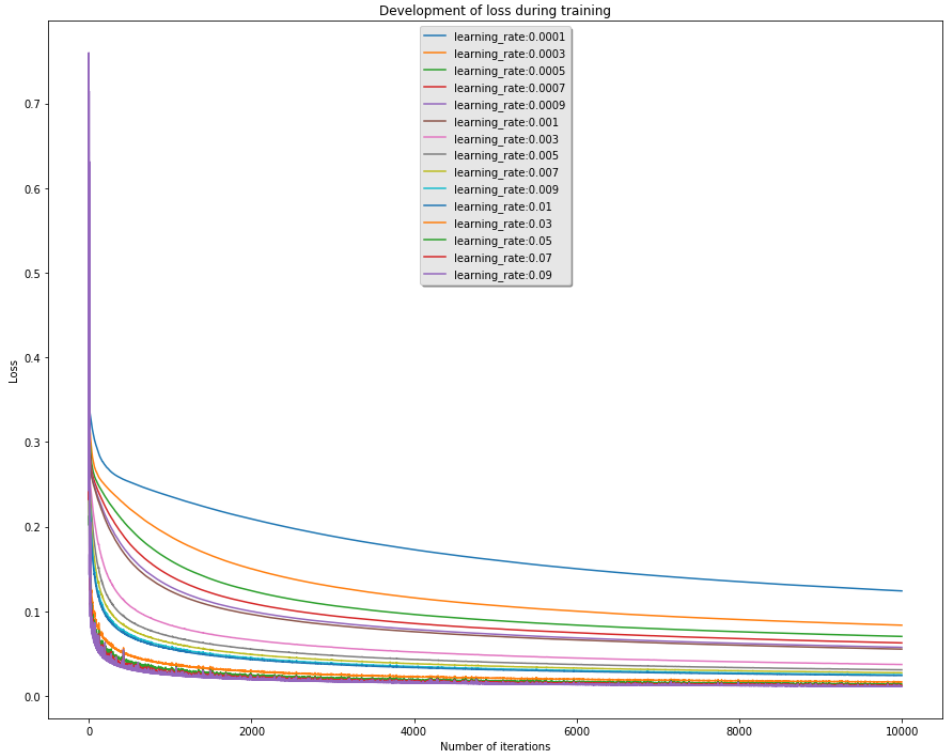

Figure 9: Learning Rate Optimization for MP under Scenario 1

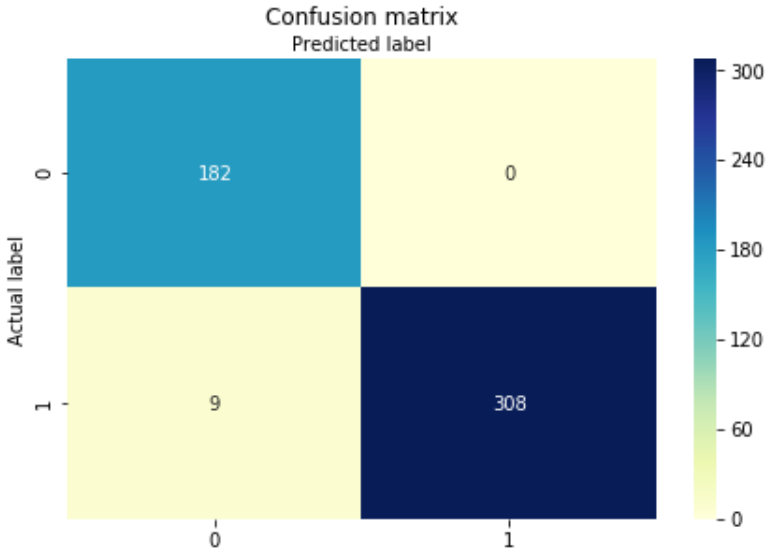

Figure 10: Confusion Matrix for Classification of Satisfaction State of MC under Scenario 1

predicted by the model is True similar to the actual state with the 1.000e+00 probability of being True. It means that given the input values, there is 100 percent chance of MR being satisfied i.e. having satisfaction state as True.

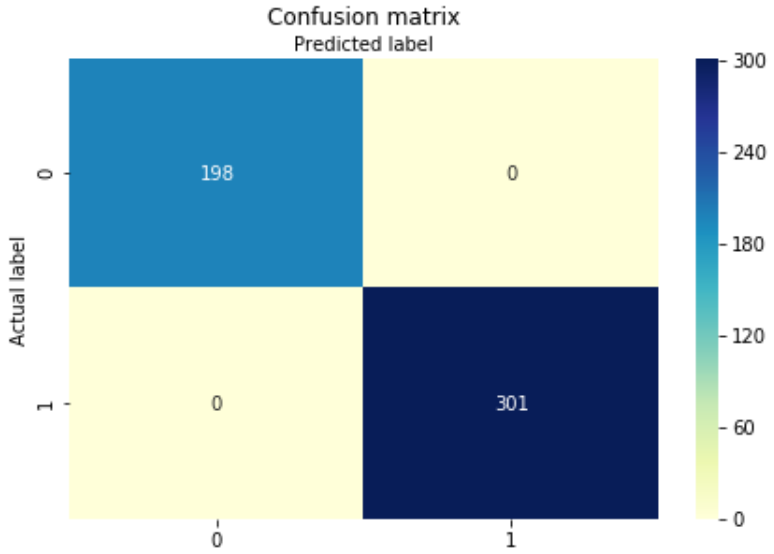

Figure 11: Confusion Matrix for Classification of Satisfaction State of MR under Scenario 1

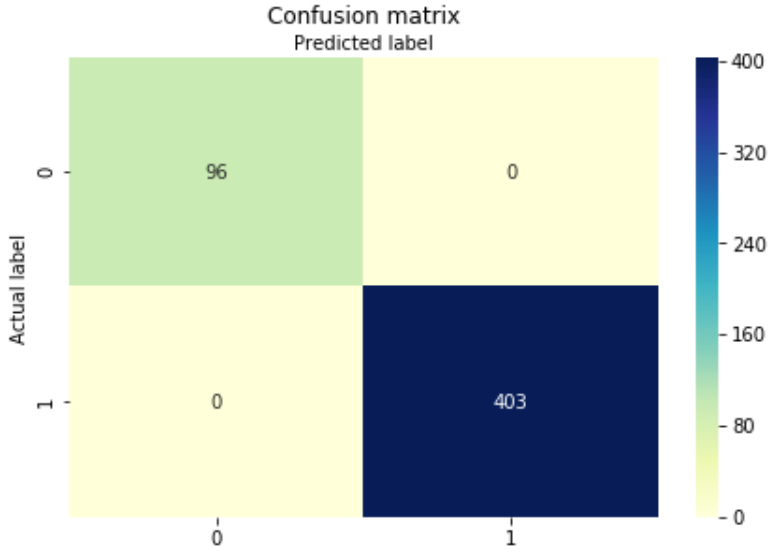

Figure 12: Confusion Matrix for Classification of Satisfaction State of MP under Scenario 1

Classification Results for MP

For all of the 500 simulation time steps in the test set, the model correctly classifies the satisfaction state of MP as shown in Fig.12.

Moreover, based on the results presented in Table.8, we can deduce the extent of the satisfaction state of MP, when both the writing time and satisfaction probability are considered. For example, at time step 480, the writing time is 2220 ms and the satisfaction probability is 0.716539246. The output satisfaction state predicted by the model is True similar to the actual state with the 0.99268 probability of being True. It means that given the input values, there is around 99 percent chance of MP to be satisfied i.e. having satisfaction state as True.

Table 6: Classification Results for MC for time steps 480-486 under Scenario 1

Step	Bandwidth Consumed	SatProb	Actual State	Predicted State	Probability per class
480	5550	0.725491276	False	False	[9.9999e-01 1.7512e-08]
481	4833	0.783454523	False	False	[9.999e-01 1.0986e-05]
482	4725	0.791813864	False	False	[9.9997e-01 2.8903e-05]
483	2625	0.864214984	True	True	[4.7506e-04 9.9952e-01]
484	1944	0.902410103	True	True	[1.1948e-06 9.99998805e-01]
485	5175	0.867215377	False	False	[9.9999e-01 1.2182e-06]
486	3525	0.873227415	True	True	[0.4484 0.5516]

Table 7: Classification Results for MR for time steps 480-486 under Scenario 1

Step	Active Links	SatProb	Actual State	Predicted State	Probability per class
480	222	0.958693166	True	True	[6.2172e-14 1.000e+00]
481	179	0.964496786	True	True	[3.9134e-09 9.9999e-01]
482	225	0.952357296	True	True	[2.8922e-14 1.000e+00]
483	125	0.83784989	True	True	[0.0047 0.9953]
484	81	0.766044144	False	False	[0.99759 0.00241]
485	225	0.902908016	True	True	[3.03155e-14 1.0000e+00]
486	141	0.83331521	True	True	[7.7584e-05 9.9992e-01]

2.3 Scenario S_2

Parameter Tuning

We have executed SGD algorithm for 20,000 iterations with different learning rates for the results computed for each NFR separately as shown in Fig. 13, 14 and 15 respectively. On the basis of loss and the accuracy scores presented in Table 9, we have selected the learning rate of 0.05 for the model to evaluate the Test set. For the learning rate of 0.05, the accuracy score for MC is 0.9979959919839679, MR is 0.9959919839679359 and MP is 0.9979959919839679.

2.3.1 Classification Results

The classification results for the NFRs using logistic regression are presented in Tables 10, 11 and 12. The results show an accuracy score of 0.8216432865731463 for MC, 0.8176352705410822 for MR and 0.7595190380761523 for MP with a Precision of 1.0, 0.7299703264094956 and 1.0 respectively.

Classification Results for MC

For the 500 simulation time steps, under Scenario 2, the model correctly classifies the satisfaction state of MC with an exception of 89 simulation time steps as shown in Fig.16. For these 89 simulation time steps, the actual satisfaction state for MC was True but it was predicted as False.

Moreover, based on the results presented in Table.10, we can deduce the extent to which MC can be considered as satisfied, when both the bandwidth consumption and satisfaction probability are considered. For example, at time step 489 the bandwidth consumption is 2592 GBps and the satisfaction probability is 0.904068481. The satisfaction state predicted by the model is True with the 9.99761470e-01 probability of

Table 8: Classification Results for MP for time steps 480-486 under Scenario 1

Step	Writing Time	SatProb	Actual State	Predicted State	Probability per class
480	2220	0.716539246	True	True	[0.00732 0.99268]
481	2148	0.699744551	True	True	[0.00347 0.99653]
482	2475	0.699741136	True	True	[0.1258 0.87419]
483	1375	0.80810347	True	True	[3.3625e-07 9.9999e-01]
484	1215	0.910140268	True	True	[3.5665e-08 9.9999e-01]
485	2925	0.849803269	False	False	[0.9282 0.0717]
486	2820	0.823122431	False	False	[0.81396 0.18604]

Table 9: Learning Rate Accuracy Score under Scenario 2 (Cross Validation Set)

Learning Rate	Accuracy Score MC	Accuracy Score MR	Accuracy Score MP
0.0001	0.935871743486974	0.9899799599198397	0.9198396793587175
0.0003	0.9839679358717435	0.9919839679358717	0.9338677354709419
0.0005	0.9919839679358717	0.9939879759519038	0.9438877755511023
0.0007	0.9939879759519038	0.9959919839679359	0.9559118236472945
0.0009	0.9959919839679359	0.9939879759519038	0.9679358717434869
0.001	0.9959919839679359	0.9939879759519038	0.9679358717434869
0.003	0.9959919839679359	0.9979959919839679	0.9779559118236473
0.005	0.9959919839679359	0.9979959919839679	0.9819639278557114
0.007	0.9959919839679359	0.9979959919839679	0.9859719438877755
0.009	0.9959919839679359	0.9979959919839679	0.9859719438877755
0.01	0.9959919839679359	0.9979959919839679	0.9879759519038076
0.03	0.9979959919839679	0.9959919839679359	0.9919839679358717
0.05	0.9979959919839679	0.9959919839679359	0.9979959919839679
0.07	0.9979959919839679	0.9959919839679359	0.9979959919839679
0.09	0.9979959919839679	0.9959919839679359	0.9979959919839679

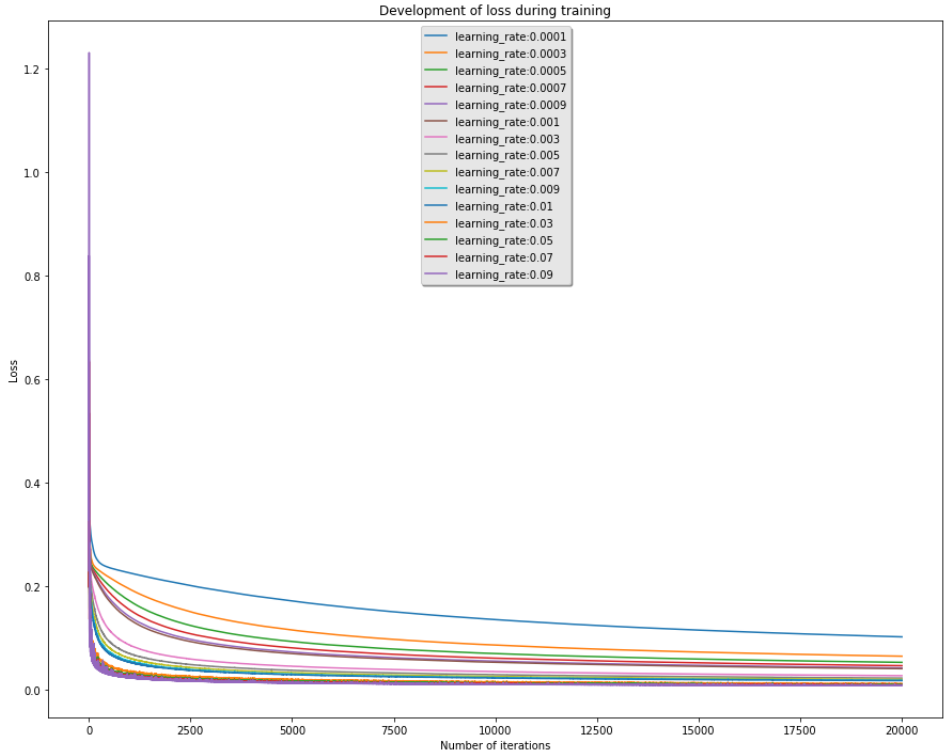

Figure 13: Learning Rate Optimization for MC under Scenario 2

being True. It means that given the input values, there is almost 99 percent chance of MC to be satisfied i.e. having satisfaction state as True.

Classification Results for MR

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MR with an exception of 91 simulation time steps as shown in Fig.17. For these 91 time steps, the actual satisfaction state for MR was False but it was predicted as True.

Moreover, based on the results presented in Table.11, we can deduce the extent of the satisfaction state of MR, when both the active links and satisfaction probability are considered. For example, at time step

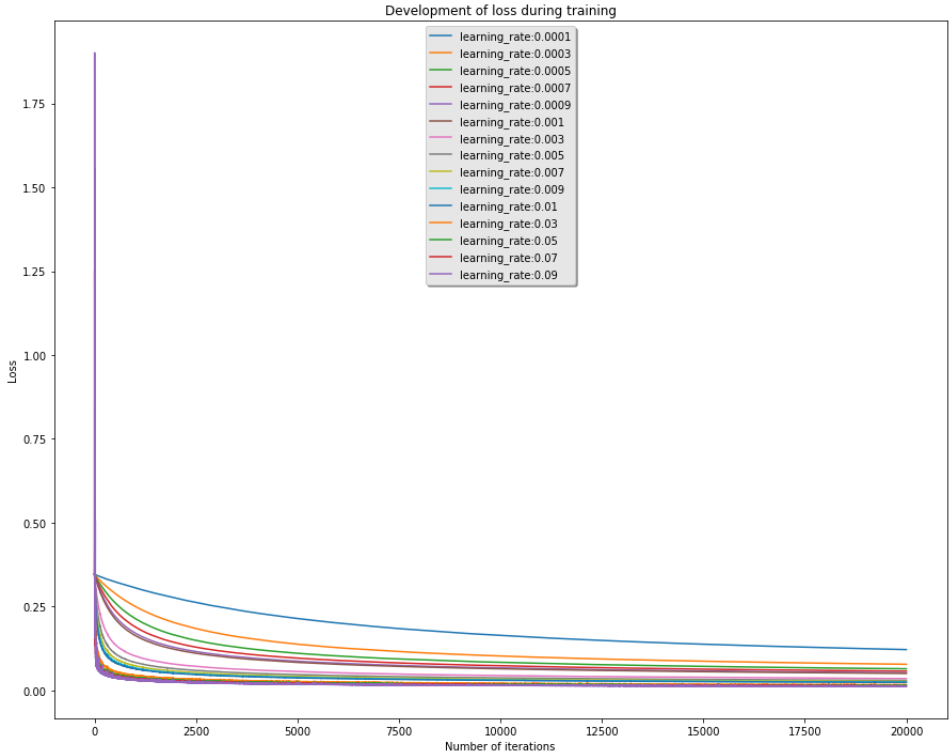

Figure 14: Learning Rate Optimization for MR under Scenario 2

486 the active links are 48 and the satisfaction probability is 0.835354651. The output satisfaction state predicted by the model is False similar to the actual state with the 9.99999996e-01 probability of being False. It means that given the input values, there is around 99 percent chance of MR being not satisfied i.e. having satisfaction state as False.

Classification Results for MP

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MP with an exception of 120 simulation time steps as shown in Fig.18. For these 120 time steps, the actual satisfaction state for MP was True but it was predicted as False.

Moreover, based on the results presented in Table.12, we can deduce the extent of the satisfaction state of MP, when both the writing time and satisfaction probability are considered. For example, at time step 487 the writing time is 1521 ms and the satisfaction probability is 0.915477939. The output satisfaction state predicted by the model is True similar to the actual state with the 9.99475989e-01 probability of being True. It means that given the input values, there is around 99 percent chance of MP to be satisfied i.e. having satisfaction state as True.

2.4 Scenario S_3

Parameter Tuning

We have executed SGD algorithm for 20,000 iterations with different learning rates for the results computed for each NFR separately as shown in Fig. 19, 20 and 21 respectively. On the basis of loss and the accuracy scores presented in Table 13, we have selected the learning rate of 0.09 for the model to evaluate the test set.

Table 10: Classification Results for Minimization of Operational Cost for time steps 485-491 under Scenario 2

Time Step	Bandwidth Consumption	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
485	1265	0.905418947	True	True	[5.9032768e-15 1.0000000e+00]
486	1344	0.906354254	True	True	[2.26675581e-14 1.00000000e+00]
487	3393	0.906444334	True	False	[0.99767138 0.00232862]
488	2882	0.878908448	True	True	[0.41408166 0.58591834]
489	2592	0.904068481	True	True	[2.38529928e-04 9.99761470e-01]
490	4050	0.905254055	False	False	[9.99999988e-01 1.23761037e-08]
491	3608	0.878539014	False	False	[9.99997682e-01 2.31770276e-06]

Table 11: Classification Results for Maximization of Reliability for time steps 485-491 under Scenario 2

Time Step	Active Links	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
485	55	0.837094713	False	False	[9.99999714e-01 2.85528913e-07]
486	48	0.835354651	False	False	[9.99999996e-01 3.54554585e-09]
487	117	0.83523595	True	True	[3.65562284e-11 1.00000000e+00]
488	131	0.890294742	True	True	[1.12091232e-14 1.00000000e+00]
489	96	0.892214353	False	True	[4.37378837e-05 9.99956262e-01]
490	135	0.837284883	True	True	[4.44491953e-16 1.00000000e+00]
491	164	0.890580591	True	True	[1.04345014e-23 1.00000000e+00]

Table 12: Classification Results for Maximization of Performance for time steps 485-491 under Scenario 2

Time Step	Writing Time	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
485	990	0.914541562	True	True	[2.08476773e-09 9.99999998e-01]
486	528	0.915397479	True	True	[4.11149948e-14 1.00000000e+00]
487	1521	0.915477939	True	True	[5.24010637e-04 9.99475989e-01]
488	1310	0.91533598	True	True	[3.73879569e-06 9.99996261e-01]
489	1920	0.913995064	True	False	[0.85929554 0.14070446]
490	2430	0.914412491	True	False	[9.99998940e-01 1.06026511e-06]
491	3116	0.831266169	False	False	[1.00000000e+00 5.36958162e-14]

Table 13: Learning Rate Accuracy Score under Scenario 3 (Cross Validation Set)

Learning Rate	Accuracy Score MC	Accuracy Score MR	Accuracy Score MP
0.0001	0.9323308270676691	0.9649122807017544	0.9674185463659147
0.0003	0.9774436090225563	0.974937343358396	0.9674185463659147
0.0005	0.9899749373433584	0.9799498746867168	0.9699248120300752
0.0007	0.9899749373433584	0.9824561403508771	0.9699248120300752
0.0009	0.9899749373433584	0.9824561403508771	0.9774436090225563
0.001	0.9899749373433584	0.9849624060150376	0.9774436090225563
0.003	0.9924812030075187	0.9949874686716792	0.9849624060150376
0.005	0.9924812030075187	0.9949874686716792	0.9924812030075187
0.007	0.9924812030075187	0.9949874686716792	0.9924812030075187
0.009	0.9924812030075187	0.9949874686716792	0.9924812030075187
0.01	0.9924812030075187	0.9949874686716792	0.9924812030075187
0.03	0.9924812030075187	0.9924812030075187	0.9949874686716792
0.05	0.9924812030075187	0.9924812030075187	0.9949874686716792
0.07	0.9924812030075187	0.9924812030075187	0.9949874686716792
0.09	0.9949874686716792	0.9924812030075187	0.9949874686716792

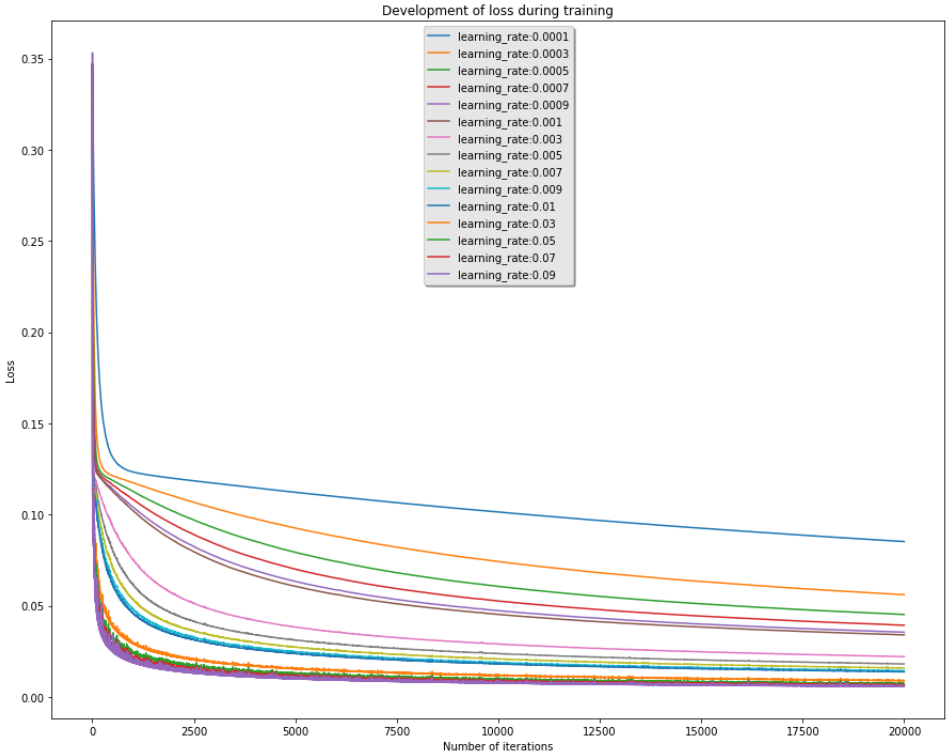

Figure 15: Learning Rate Optimization for MP under Scenario 2

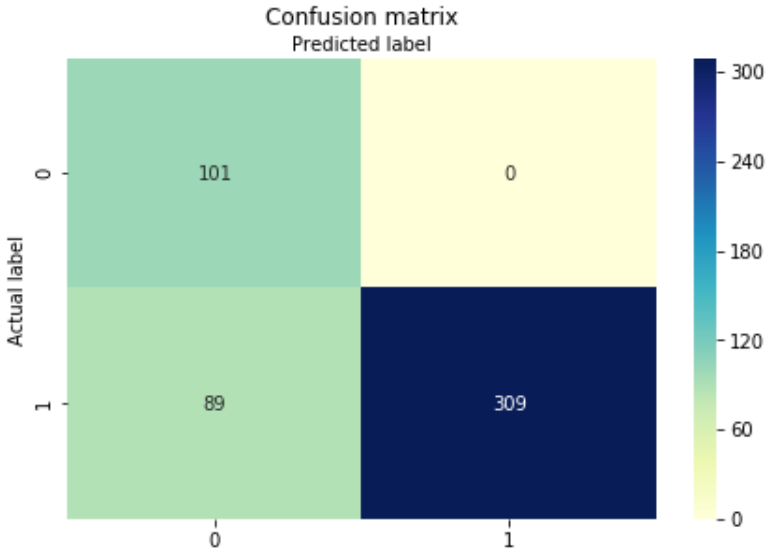

Figure 16: Confusion Matrix for Classification of Satisfaction State of MC under Scenario 2

Classification Results

The classification results for the NFRs using logistic regression are presented in Tables 14, 15 and 16. The results show an accuracy score of 0.9539078156312625 for MC, 0.8577154308617234 for MR and 0.9298597194388778

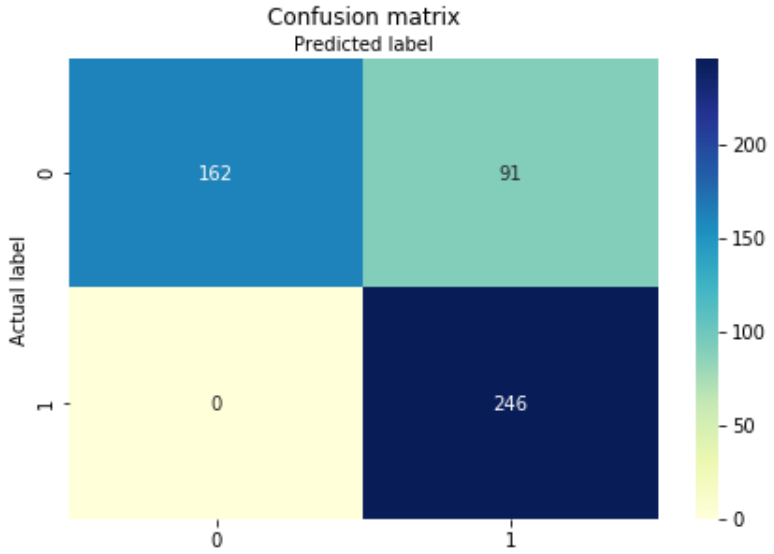

Figure 17: Confusion Matrix for Classification of Satisfaction State of MR under Scenario 2

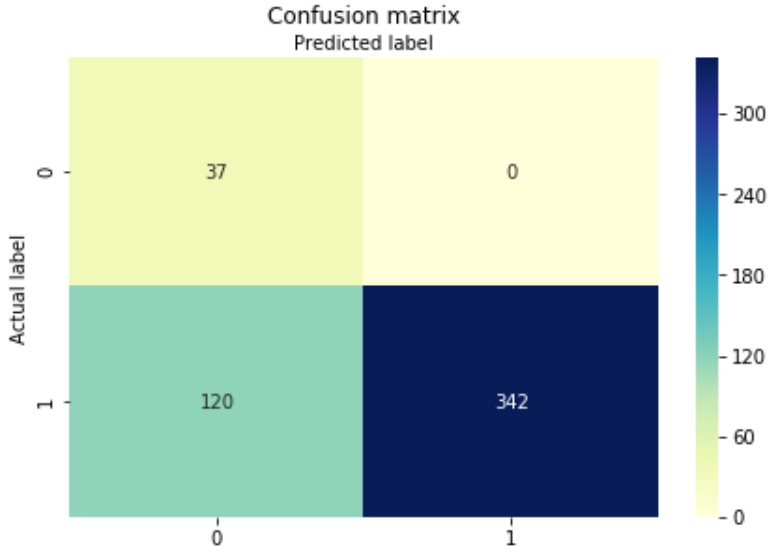

Figure 18: Confusion Matrix for Classification of Satisfaction State of MP under Scenario 2

for MP with a Precision of 1.0, 0.72265625 and 1.0 respectively.

Classification Results for MC

For the 500 simulation time steps, under Scenario 3, the model correctly classifies the satisfaction state of MC with an exception of 23 simulation time steps as shown in Fig.22. For these 23 simulation time steps, the actual satisfaction state for MC was True but it was predicted as False.

Moreover, based on the results presented in Table.14, we can deduce the extent to which MC can be considered as satisfied, when both the bandwidth consumption and satisfaction probability are considered. For example, at time step 480 the bandwidth consumption is 1743 GBps and the satisfaction probability is

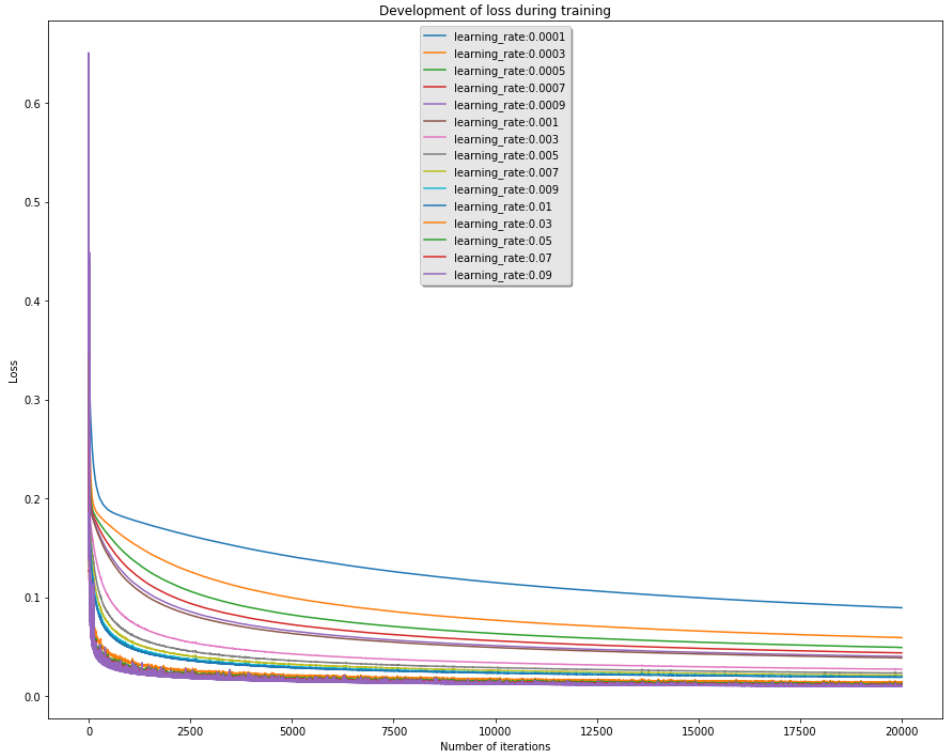

Figure 19: Learning Rate Optimization for MC under Scenario 3

0.882159225. The satisfaction state predicted by the model is also True with the 1.00000000e+00 probability of being True. It means that given the input values, there is almost 100 percent chance of MC to be satisfied i.e. having satisfaction state as True.

Classification Results for MR

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MR with an exception of 71 simulation time steps as shown in Fig.23. For these 71 time steps, the actual satisfaction state for MR was False but it was predicted as True.

Moreover, based on the results presented in Table.15, we can deduce the extent of the satisfaction state of MR, when both the active links and satisfaction probability are considered. For example, at time step 480 the active links are 83 and the satisfaction probability is 0.760346638. The output satisfaction state predicted by the model is False similar to the actual state with the 0.6215068 probability of being False. It means that given the input values, there is around 62 percent chance of MR being not satisfied i.e. having satisfaction state as False.

Classification Results for MP

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MP with an exception of 35 simulation time steps as shown in Fig.24. For these 35 time steps, the actual satisfaction state for MP was True but it was predicted as False.

Moreover, based on the results presented in Table.16, we can deduce the extent of the satisfaction state of MP, when both the writing time and satisfaction probability are considered. For example, at time step 483 the writing time is 1625 ms and the satisfaction probability is 0.82608141. The output satisfaction state predicted by the model is True similar to the actual state with the 9.99999675e-01 probability of being True.

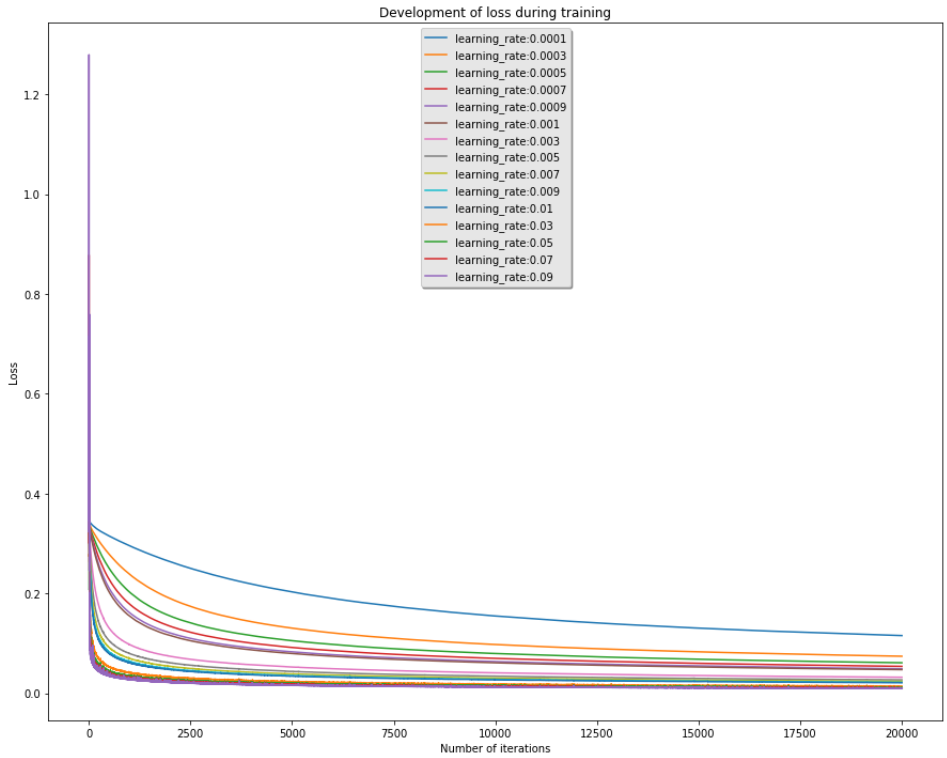

Figure 20: Learning Rate Optimization for MR under Scenario 3

It means that given the input values, there is around 99 percent chance of MP to be satisfied i.e. having satisfaction state as True.

2.5 Scenario S_4

Parameter Tuning

We have executed SGD algorithm for 20,000 iterations with different learning rates for the results computed for each NFR separately as shown in Fig. 25, 26 and 27 respectively. On the basis of loss and the accuracy scores presented in Table 17, we have selected the learning rate of 0.05 for the model to evaluate the Test set.

Table 14: Classification Results for Minimization of Operational Cost for time steps 480-486 under Scenario 3

Time Step	Bandwidth Consumption	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
480	1743	0.882159225	True	True	[6.01325426e-15 1.00000000e+00]
481	3456	0.906763092	True	False	[0.57270496 0.42729504]
482	2825	0.88168976	True	True	[7.25566539e-05 9.99927443e-01]
483	3375	0.904302433	True	True	[0.25365054 0.74634946]
484	3220	0.878140645	True	True	[0.36316451 0.63683549]
485	2499	0.878631862	True	True	[1.06356697e-07 9.99999894e-01]
486	2576	0.90641962	True	True	[9.41678384e-09 9.99999991e-01]

Table 15: Classification Results for Maximization of Reliability for time steps 480-486 under Scenario 3

Time Step	Active Links	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
480	83	0.760346638	False	False	[0.6215068 0.3784932]
481	144	0.705506515	True	True	[1.14288145e-21 1.00000000e+00]
482	113	0.791704843	True	True	[5.03655241e-11 1.00000000e+00]
483	125	0.774822075	True	True	[3.55882942e-15 1.00000000e+00]
484	115	0.774049861	True	True	[1.09094801e-11 1.00000000e+00]
485	119	0.762482692	True	True	[4.62584522e-13 1.00000000e+00]
486	112	0.762116019	True	True	[1.27472652e-10 1.00000000e+00]

Table 16: Classification Results for Maximization of Performance for time steps 480-486 under Scenario 3

Time Step	Writing Time	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
480	913	0.917690489	True	True	[7.51084744e-15 1.00000000e+00]
481	2592	0.916426307	True	False	[0.99789089 0.00210911]
482	2260	0.835471399	True	True	[0.39195878 0.60804122]
483	1625	0.82608141	True	True	[3.24507668e-07 9.99999675e-01]
484	1725	0.912554245	True	True	[1.06072267e-06 9.99998939e-01]
485	1428	0.915758838	True	True	[1.08946361e-09 9.99999999e-01]
486	1120	0.916160158	True	True	[9.00649702e-13 1.00000000e+00]

Table 17: Learning Rate Accuracy Score under Scenario 4 (Cross Validation Set)

Learning Rate	Accuracy Score MC	Accuracy Score MR	Accuracy Score MP
0.0001	0.9724310776942355	0.9899749373433584	0.9423558897243107
0.0003	0.9799498746867168	0.9974937343358395	0.9774436090225563
0.0005	0.9899749373433584	0.9974937343358395	0.9849624060150376
0.0007	0.9899749373433584	0.9974937343358395	0.9849624060150376
0.0009	0.9899749373433584	0.9974937343358395	0.9874686716791979
0.001	0.9924812030075187	0.9974937343358395	0.9874686716791979
0.003	0.9949874686716792	0.9949874686716792	0.9899749373433584
0.005	0.9974937343358395	0.9949874686716792	0.9974937343358395
0.007	1.0	0.9974937343358395	0.9974937343358395
0.009	1.0	0.9974937343358395	0.9974937343358395
0.01	1.0	0.9974937343358395	0.9974937343358395
0.03	1.0	0.9974937343358395	0.9974937343358395
0.05	1.0	0.9974937343358395	0.9974937343358395
0.07	1.0	0.9974937343358395	0.9974937343358395
0.09	1.0	0.9974937343358395	0.9974937343358395

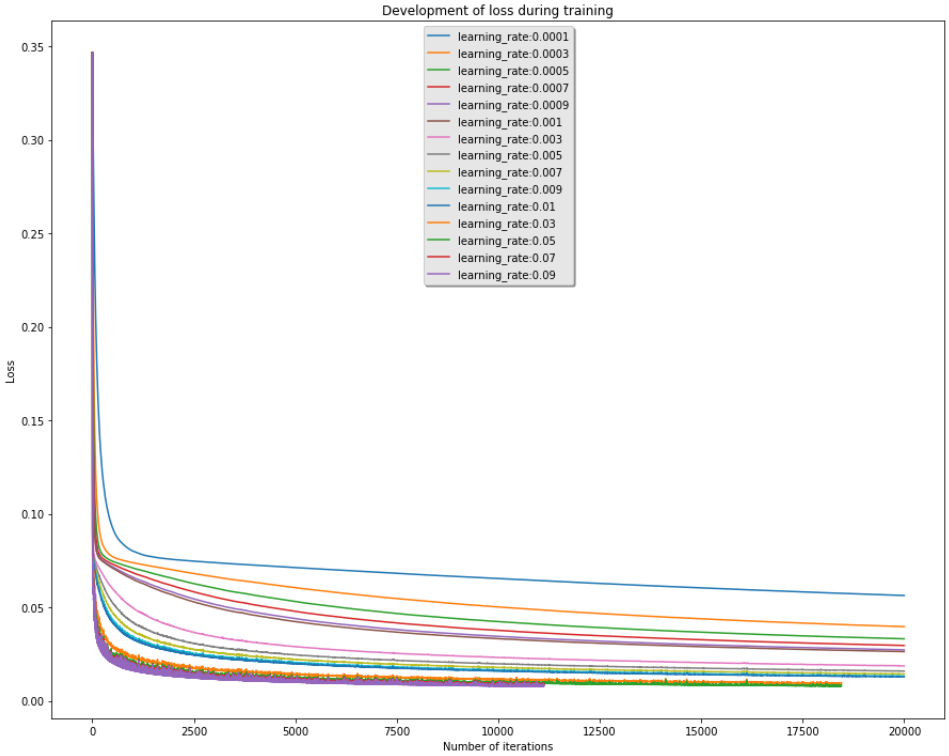

Figure 21: Learning Rate Optimization for MP under Scenario 3

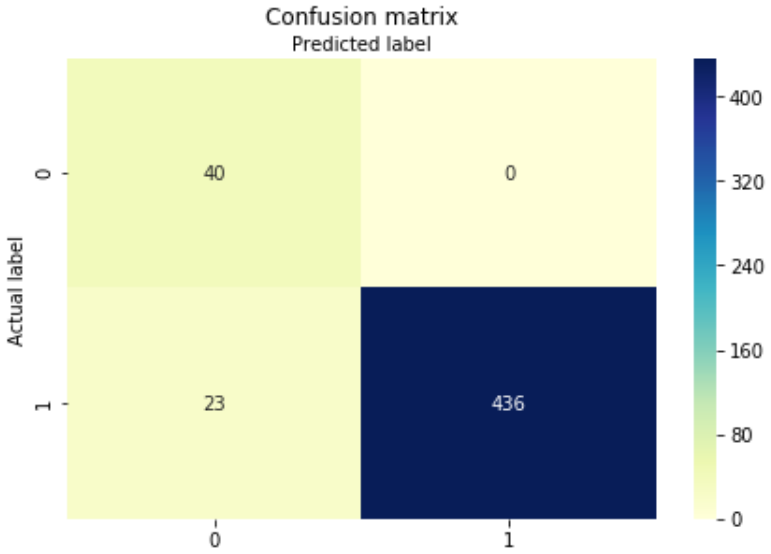

Figure 22: Confusion Matrix for Classification of Satisfaction State of MC under Scenario 3

Classification Results

The classification results for the NFRs using logistic regression are presented in Tables 18, 19 and 20. The results show an accuracy score of 0.9859719438877755 for MC, 0.8577154308617234 for MR and 0.9939879759519038

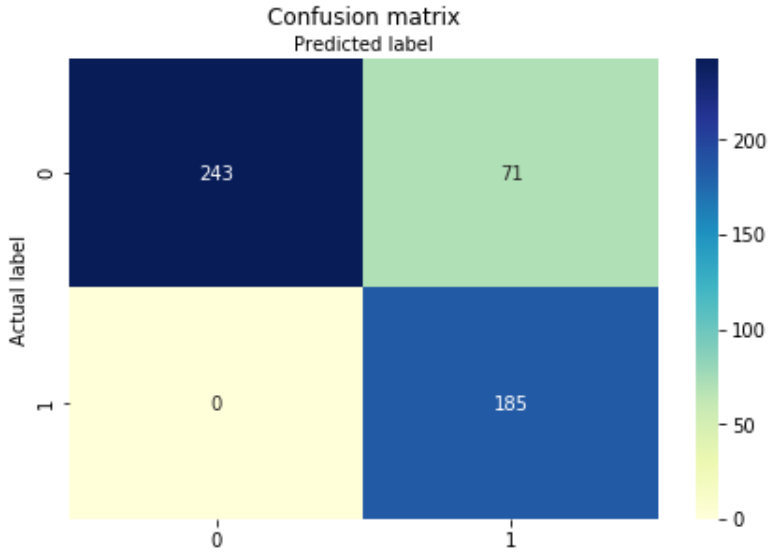

Figure 23: Confusion Matrix for Classification of Satisfaction State of MR under Scenario 3

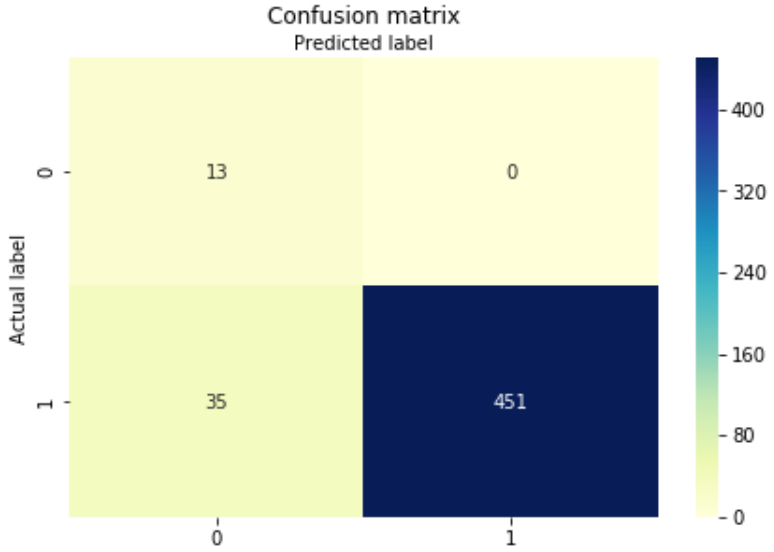

Figure 24: Confusion Matrix for Classification of Satisfaction State of MP under Scenario 3

for MP with a Precision of 1.0.

Classification Results for MC

For the 500 simulation time steps, under Scenario 4, the model correctly classifies the satisfaction state of MC with an exception of 7 simulation time steps as shown in Fig.28. For these 7 simulation time steps, the actual satisfaction state for MC was True but it was predicted as False.

Moreover, based on the results presented in Table.18, we can deduce the extent to which MC can be considered as satisfied, when both the bandwidth consumption and satisfaction probability are considered. For example, at time step 480 the bandwidth consumption is 2317.8 GBps and the satisfaction probability is

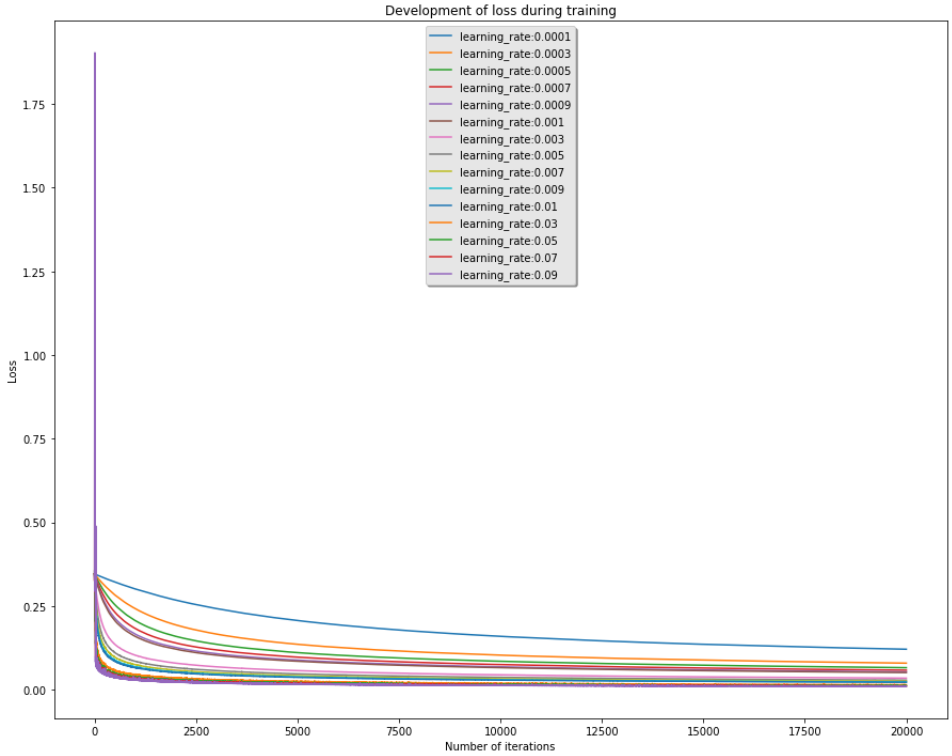

Figure 25: Learning Rate Optimization for MC under Scenario 4

0.829105937. The satisfaction state predicted by the model is also True with the 9.99999970e-01 probability of being True. It means that given the input values, there is 99 percent chance of MC to be satisfied i.e. having satisfaction state as True.

Classification Results for MR

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MR with an exception of only 1 simulation time step as shown in Fig.29. For this one time step, the actual satisfaction state for MR was True but it was predicted as False.

Moreover, based on the results presented in Table.19, we can deduce the extent of the satisfaction state of MR, when both the active links and satisfaction probability are considered. For example, at time step 480 the active links are 101 and the satisfaction probability is 0.707430978. The output satisfaction state predicted by the model is False similar to the actual state with the 0.85981951 probability of being False. It means that given the input values, there is around 85 percent chance of MR not being satisfied i.e. having satisfaction state as False.

Classification Results for MP

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MP with an exception of 3 simulation time steps as shown in Fig.30. For these 3 time steps, the actual satisfaction state for MP was True but it was predicted as False.

Moreover, based on the results presented in Table.20, we can deduce the extent of the satisfaction state of MP, when both the writing time and satisfaction probability are considered. For example, at time step 482 the writing time is 2295 ms and the satisfaction probability is 0.715493263. The output satisfaction state predicted by the model is True similar to the actual state with the 0.99856246 probability of being True.

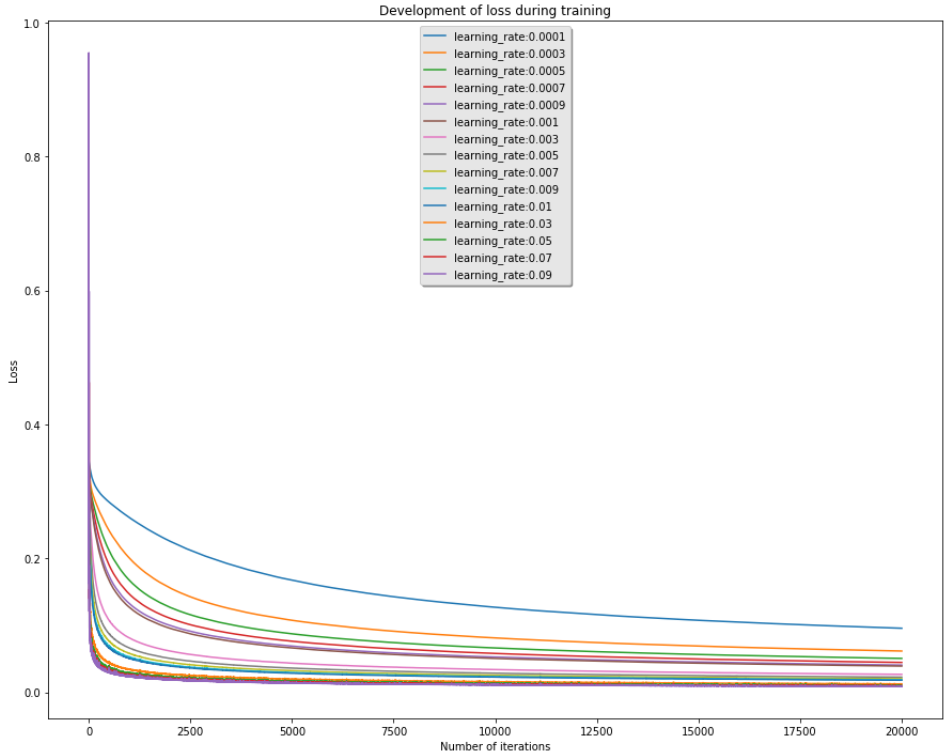

Figure 26: Learning Rate Optimization for MR under Scenario 4

It means that given the input values, there is around 99 percent chance of MP to be satisfied i.e. having satisfaction state as True.

2.6 Scenario S_5

Parameter Tuning

We have executed SGD algorithm for 20,000 iterations with different learning rates for the results computed for each NFR separately as shown in Fig. 31, 32 and 33 respectively. On the basis of loss and the accuracy scores presented in Table 21, we have selected the learning rate of 0.3 for the model to evaluate the test set.

Table 18: Classification Results for Minimization of Operational Cost for time steps 480-486 under Scenario 4

Time Step	Bandwidth Consumption	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
480	2317.812966	0.829105937	True	True	[3.04968209e-08 9.99999970e-01]
481	4420	0.858285042	False	False	[9.99992490e-01 7.50957241e-06]
482	3060	0.806895924	True	True	[8.79561011e-04 9.99120439e-01]
483	2391.931089	0.746101155	True	True	[8.39588927e-08 9.99999916e-01]
484	755.1363952	0.796469635	True	True	[1.22281049e-17 1.00000000e+00]
485	5771	0.854079338	False	False	[1.00000000e+00 5.67363465e-14]
486	4200	0.807092062	True	True	[9.99840880e-01 1.59120437e-04]

Table 19: Classification Results for Maximization of Reliability for time steps 480-486 under Scenario 4

Time Step	Active Links	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
480	101	0.707430978	False	False	[0.85981951 0.14018049]
481	221	0.94123164	True	True	[2.91045778e-19 1.00000000e+00]
482	153	0.959312548	True	True	[2.44756384e-08 9.99999976e-01]
483	84	0.792773551	False	False	[9.99687707e-01 3.12293311e-04]
484	32	0.716732387	False	False	[1.00000000e+00 1.33452219e-12]
485	199	0.908432481	True	True	[1.01147563e-15 1.00000000e+00]
486	168	0.945876097	True	True	[9.55980058e-11 1.00000000e+00]

Table 20: Classification Results for Maximization of Performance for time steps 480-486 under Scenario 4

Time Step	Writing Time	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
480	1221.315878	0.844334395	True	True	[2.00311346e-12 1.00000000e+00]
481	4199	0.845519857	False	False	[1.00000000e+00 4.84515531e-13]
482	2295	0.715493263	True	True	[0.00143754 0.99856246]
483	916.1225406	0.662968754	True	True	[1.31267176e-14 1.00000000e+00]
484	422.4350357	0.811583637	True	True	[8.10881706e-19 1.00000000e+00]
485	3383	0.843091203	False	False	[9.99998170e-01 1.83048638e-06]
486	2352	0.716116614	True	True	[0.00412284 0.99587716]

Table 21: Learning Rate Accuracy Score under Scenario 5 (Cross Validation Set)

Learning Rate	Accuracy Score MC	Accuracy Score MR	Accuracy Score MP
0.0001	0.9273182957393483	0.9899749373433584	0.924812030075188
0.0003	0.9674185463659147	0.9899749373433584	0.9649122807017544
0.0005	0.974937343358396	0.9899749373433584	0.9849624060150376
0.0007	0.9824561403508771	0.9924812030075187	0.9874686716791979
0.0009	0.9824561403508771	0.9924812030075187	0.9899749373433584
0.001	0.9799498746867168	0.9924812030075187	0.9899749373433584
0.003	0.974937343358396	0.9924812030075187	0.9974937343358395
0.005	0.9774436090225563	0.9924812030075187	0.9974937343358395
0.007	0.9774436090225563	0.9974937343358395	1.0
0.009	0.9774436090225563	0.9974937343358395	1.0
0.01	0.9774436090225563	0.9949874686716792	1.0
0.03	0.9849624060150376	0.9949874686716792	0.9974937343358395
0.05	0.9849624060150376	0.9949874686716792	0.9974937343358395
0.07	0.9899749373433584	0.9924812030075187	0.9974937343358395
0.09	0.9949874686716792	0.9924812030075187	0.9974937343358395
0.1	0.9949874686716792	0.9924812030075187	0.9974937343358395
0.3	0.9974937343358395	0.9924812030075187	0.9974937343358395
0.5	0.9724310776942355	0.9949874686716792	0.9974937343358395
0.7	0.9849624060150376	0.9799498746867168	0.9974937343358395
0.9	0.9849624060150376	0.9974937343358395	0.9974937343358395

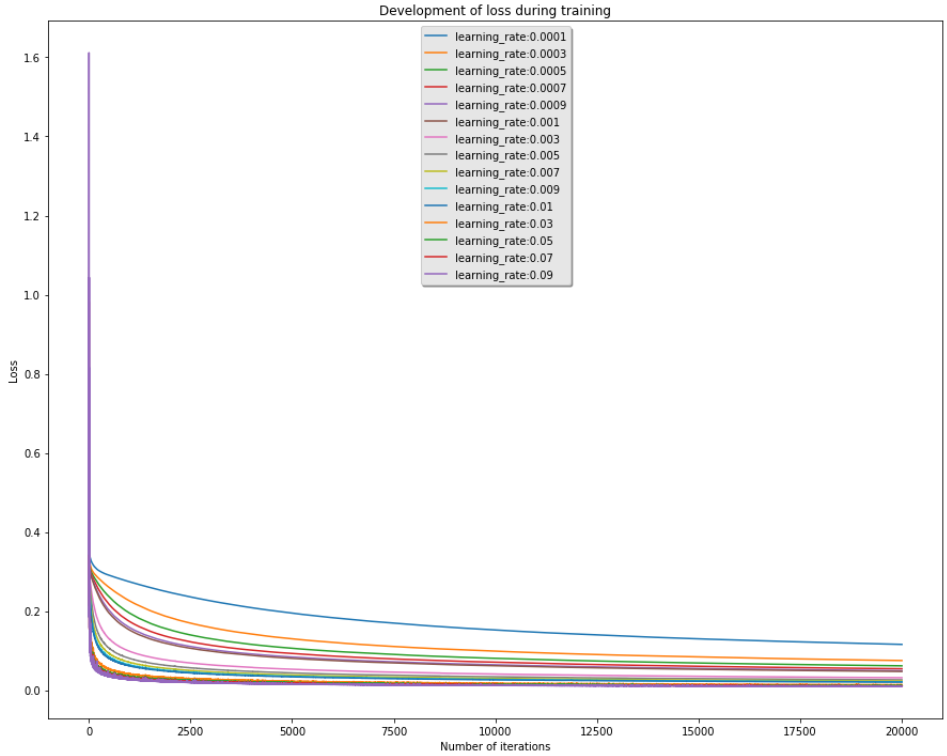

Figure 27: Learning Rate Optimization for MP under Scenario 4

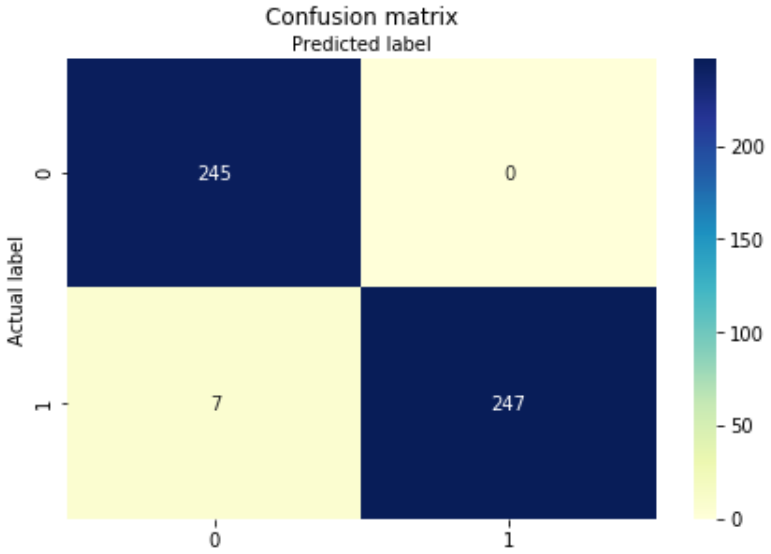

Figure 28: Confusion Matrix for Classification of Satisfaction State of MC under Scenario 4

Classification Results

The classification results for the NFRs using logistic regression are presented in Tables 22, 23 and 24. The results show an accuracy score of 0.8617234468937875 for MC, 0.8677354709418837 for MR and 0.9899799599198397

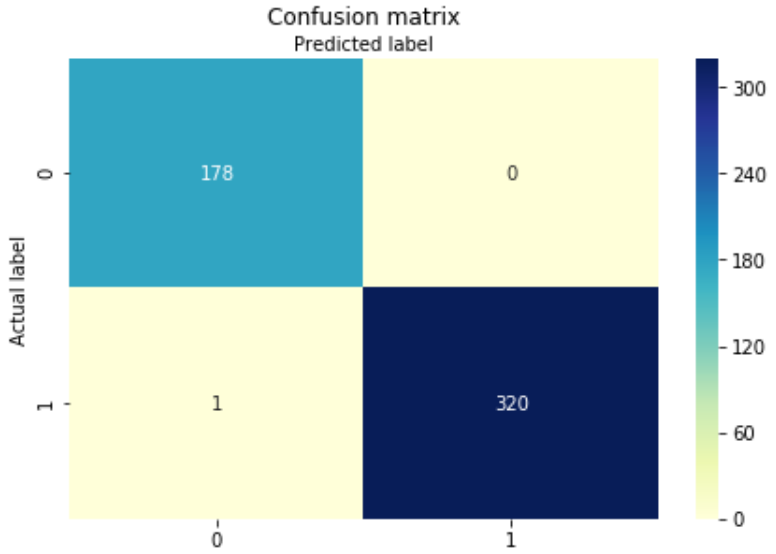

Figure 29: Confusion Matrix for Classification of Satisfaction State of MR under Scenario 4

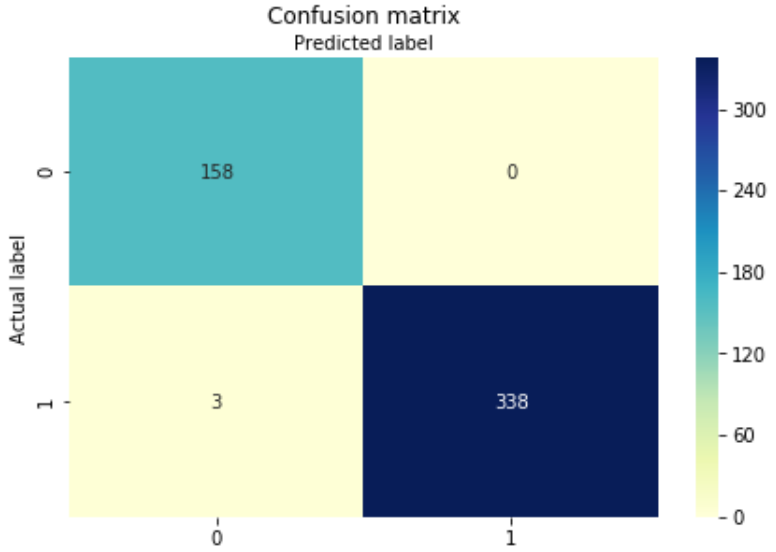

Figure 30: Confusion Matrix for Classification of Satisfaction State of MP under Scenario 4

for MP with a Precision of 1.0, 0.7676056338028169 and 0.9891540130151844 respectively.

Classification Results for MC

For the 500 simulation time steps, under Scenario 5, the model correctly classifies the satisfaction state of MC with an exception of 69 simulation time steps as shown in Fig.34. For these 69 simulation time steps, the actual satisfaction state for MC was True but it was predicted as False.

Moreover, based on the results presented in Table.22, we can deduce the extent to which MC can be considered as satisfied, when both the bandwidth consumption and satisfaction probability are considered. For example, at time step 476 the bandwidth consumption is 3614 GBps and the satisfaction probability is

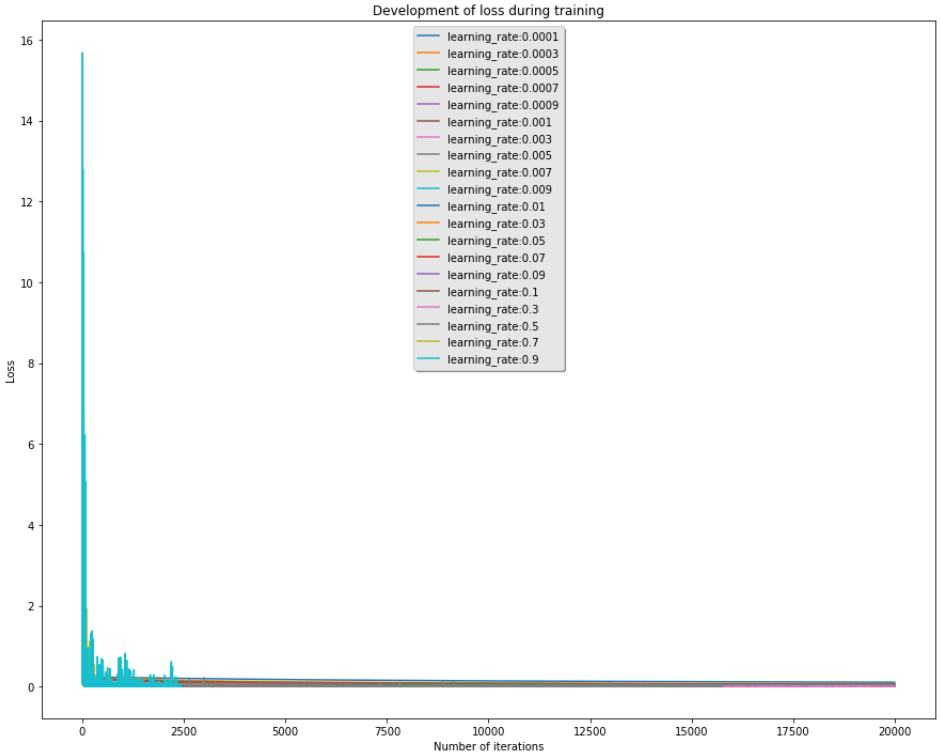

Figure 31: Learning Rate Optimization for MC under Scenario 5

0.878204047. The satisfaction state predicted by the model is also False with the 9.99999999e-01 probability of being False. It means that given the input values, there is almost 99 percent chance of MC not being satisfied i.e. having satisfaction state as False.

Classification Results for MR

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MR with an exception of 66 simulation time steps as shown in Fig.35. For these 66 time steps, the actual satisfaction state for MR was False but it was predicted as True.

Moreover, based on the results presented in Table.23, we can deduce the extent of the satisfaction state of MR, when both the active links and satisfaction probability are considered. For example, at time step 473 the active links are 152 and the satisfaction probability is 0.89023413. The output satisfaction state predicted by the model is True similar to the actual state with the 1.00000000e+00 probability of being True. It means that given the input values, there is 100 percent chance of MR being satisfied i.e. having satisfaction state as True.

Classification Results for MP

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MP with an exception of 5 simulation time steps as shown in Fig.36. For these 5 time steps, the actual satisfaction state for MP was False but it was predicted as True.

Moreover, based on the results presented in Table.24, we can deduce the extent of the satisfaction state of MP, when both the Writing Time and satisfaction probability are considered. For example, at time step 473 the writing time is 2280 ms and the satisfaction probability is 0.915390173. The output satisfaction state predicted by the model is True similar to the actual state with the 9.99996237e-01 probability of being True.

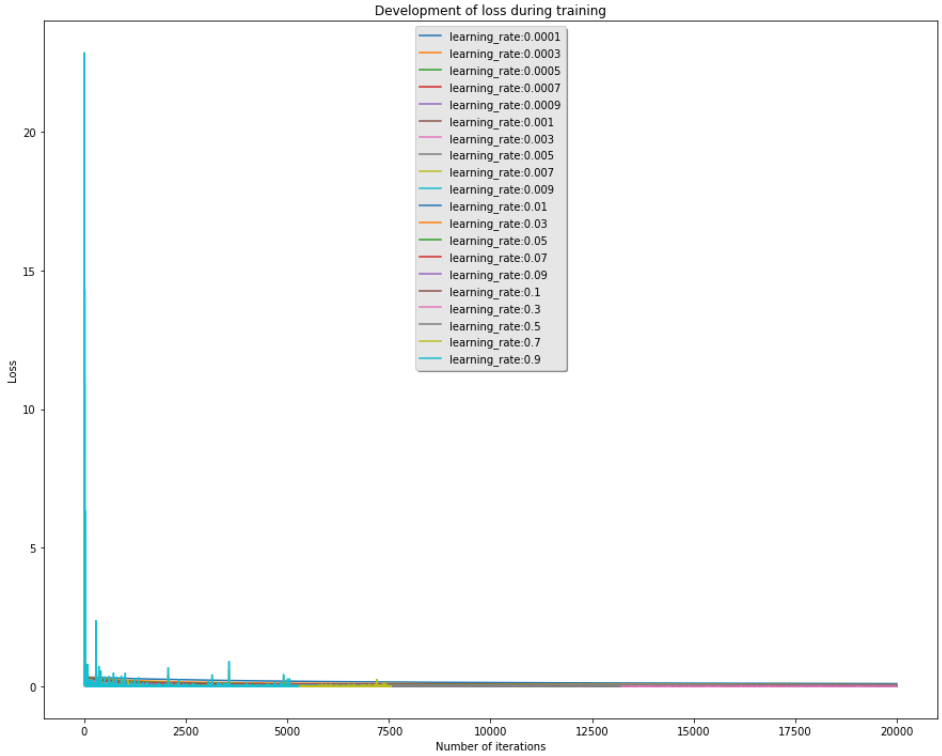

Figure 32: Learning Rate Optimization for MR under Scenario 5

It means that given the input values, there is around 99 percent chance of MP to be satisfied i.e. having satisfaction state as True.

2.7 Scenario S_6

Parameter Tuning

We have executed SGD algorithm for 20,000 iterations with different learning rates for the results computed for each NFR separately as shown in Fig. 37, 38 and 39 respectively. On the basis of loss and the accuracy scores presented in Table 25, we have selected the learning rate of 0.05 for the model to evaluate the Test set.

Table 22: Classification Results for Minimization of Operational Cost for time steps 473-479 under Scenario 5

Time Step	Bandwidth Consumption	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
473	4408	0.906345948	False	False	[1.0000000e+00 3.5406141e-22]
474	648	0.877414365	True	True	[3.34037192e-39 1.00000000e+00]
475	3120	0.902542864	True	False	[0.86871502 0.13128498]
476	3614	0.878204047	False	False	[9.99999999e-01 6.85227918e-10]
477	3718	0.87377789	False	False	[1.00000000e+00 1.23300691e-11]
478	1365	0.873550311	True	True	[1.28264167e-27 1.00000000e+00]
479	1350	0.903755478	True	True	[2.3041287e-28 1.0000000e+00]

Table 23: Classification Results for Maximization of Reliability for time steps 473-479 under Scenario 5

Time Step	Active Links	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
473	152	0.89023413	True	True	[3.71535467e-33 1.00000000e+00]
474	24	0.891779606	False	False	[1.00000000e+00 3.21694423e-31]
475	156	0.840988967	True	True	[2.10150919e-35 1.00000000e+00]
476	139	0.890831364	True	True	[9.18519447e-27 1.00000000e+00]
477	169	0.894566022	True	True	[1.73390845e-41 1.00000000e+00]
478	65	0.894716076	False	False	[1.00000000e+00 4.39253492e-11]
479	45	0.838531021	False	False	[1.00000000e+00 1.35993889e-20]

Table 24: Classification Results for Maximization of Performance for time steps 473-479 under Scenario 5

Time Step	Writing Time	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
473	2280	0.915390173	True	True	[3.76316700e-06 9.99996237e-01]
474	360	0.829764862	True	True	[2.68764217e-32 1.00000000e+00]
475	2808	0.910490776	False	False	[0.95545854 0.04454146]
476	2780	0.830773311	False	True	[0.36105904 0.63894096]
477	1690	0.82250093	True	True	[3.34636837e-15 1.00000000e+00]
478	715	0.909877203	True	True	[1.75834229e-26 1.00000000e+00]
479	720	0.913696145	True	True	[2.3339642e-26 1.0000000e+00]

Table 25: Learning Rate Accuracy Score under Scenario 6 (Cross Validation Set)

Learning Rate	Accuracy Score MC	Accuracy Score MR	Accuracy Score MP
0.0001	0.9273182957393483	0.9824561403508771	0.9674185463659147
0.0003	0.9649122807017544	0.9924812030075187	0.974937343358396
0.0005	0.9649122807017544	0.9924812030075187	0.9799498746867168
0.0007	0.9674185463659147	0.9974937343358395	0.9849624060150376
0.0009	0.9699248120300752	0.9974937343358395	0.9874686716791979
0.001	0.9699248120300752	0.9974937343358395	0.9924812030075187
0.003	0.9799498746867168	1.0	0.9949874686716792
0.005	0.9824561403508771	1.0	0.9974937343358395
0.007	0.9849624060150376	1.0	0.9974937343358395
0.009	0.9899749373433584	1.0	1.0
0.01	0.9899749373433584	1.0	1.0
0.03	0.9924812030075187	1.0	1.0
0.05	0.9924812030075187	0.9974937343358395	1.0
0.07	0.9924812030075187	0.9974937343358395	0.9974937343358395
0.09	0.9924812030075187	0.9974937343358395	0.9949874686716792

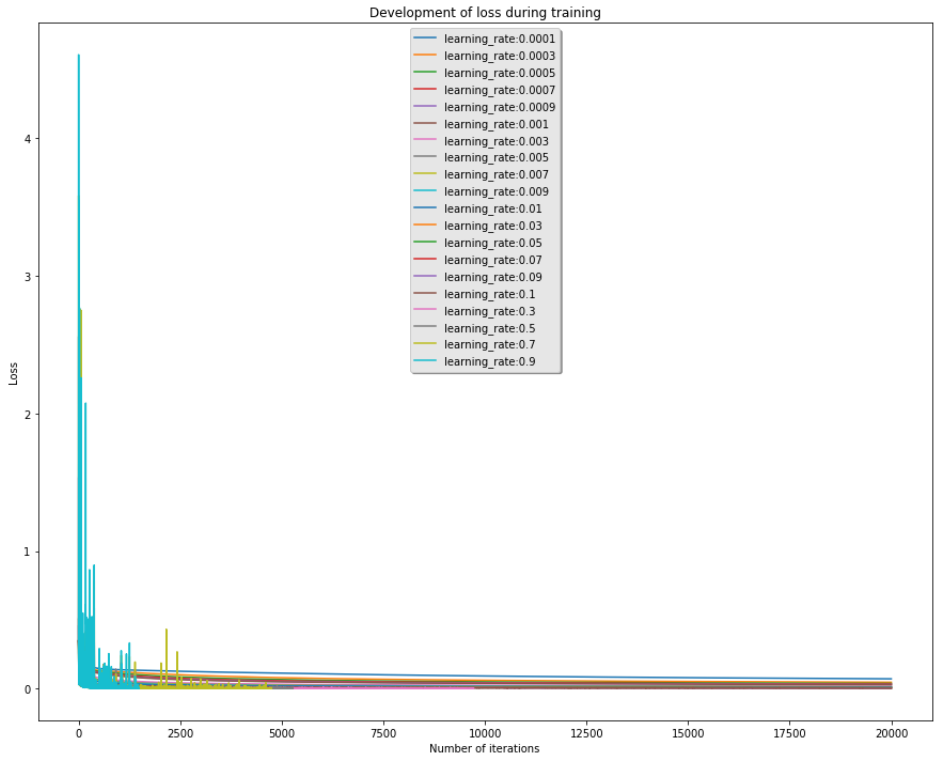

Figure 33: Learning Rate Optimization for MP under Scenario 5

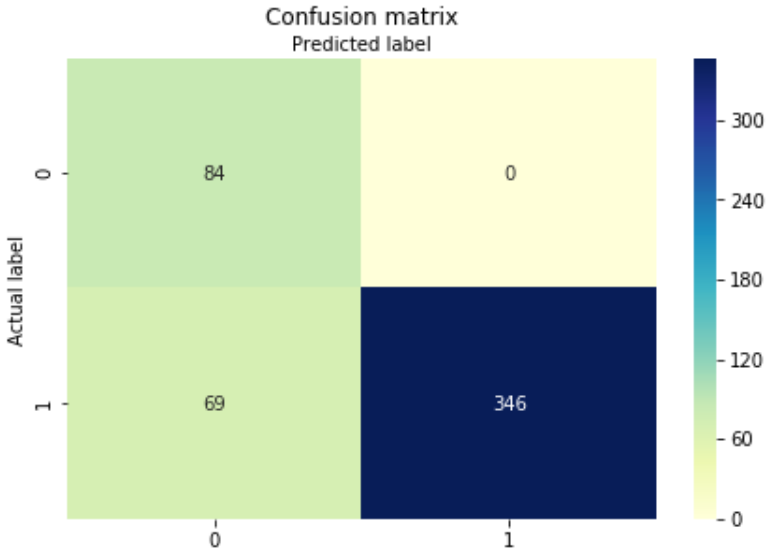

Figure 34: Confusion Matrix for Classification of Satisfaction State of MC under Scenario 5

Classification Results

The classification results for the NFRs using logistic regression are presented in Tables 26, 27 and 28. The results show an accuracy score of 0.9418837675350702 for MC, 0.8236472945891784 for MR and 0.9939879759519038

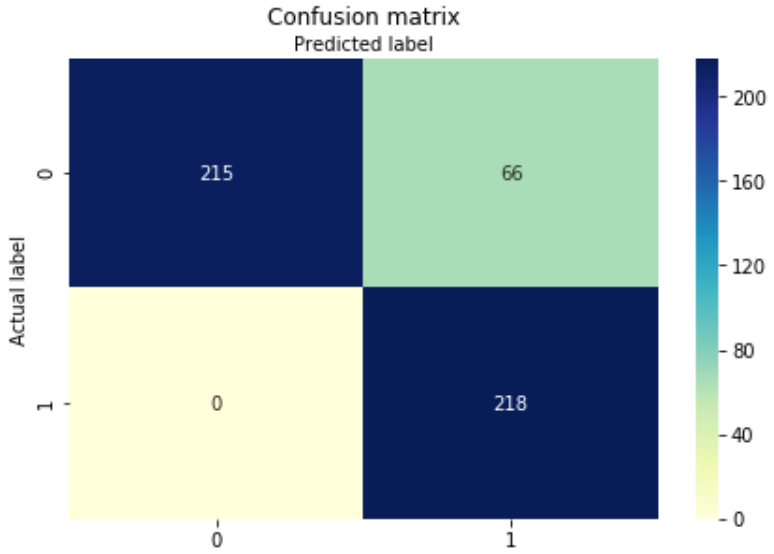

Figure 35: Confusion Matrix for Classification of Satisfaction State of MR under Scenario 5

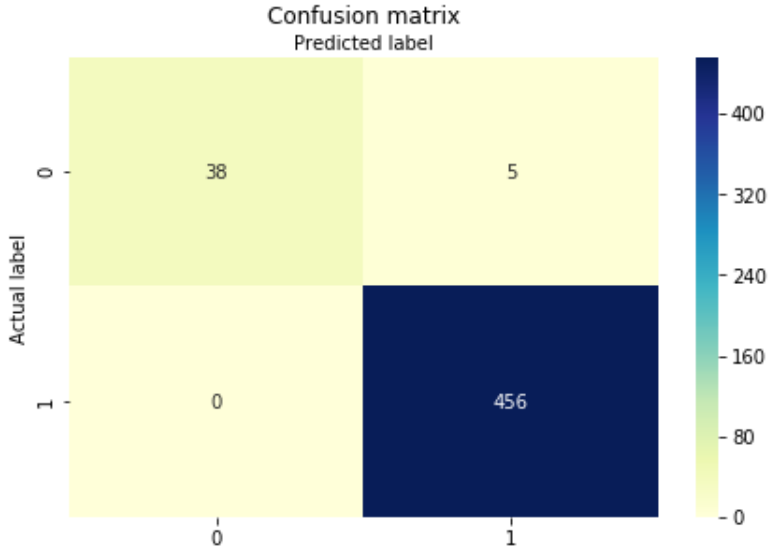

Figure 36: Confusion Matrix for Classification of Satisfaction State of MP under Scenario 5

for MP with a Precision of 1.0, 0.6834532374100719 and 0.9936974789915967 respectively.

Classification Results for MC

For the 500 simulation time steps, under Scenario 5, the model correctly classifies the satisfaction state of MC with an exception of 29 simulation time steps as shown in Fig.40. For these 29 simulation time steps, the actual satisfaction state for MC was True but it was predicted as False.

Moreover, based on the results presented in Table.26, we can deduce the extent to which MC can be considered as satisfied, when both the bandwidth consumption and satisfaction probability are considered. For example, at time step 480 the bandwidth consumption is 2811.18 GBps and the satisfaction probability is

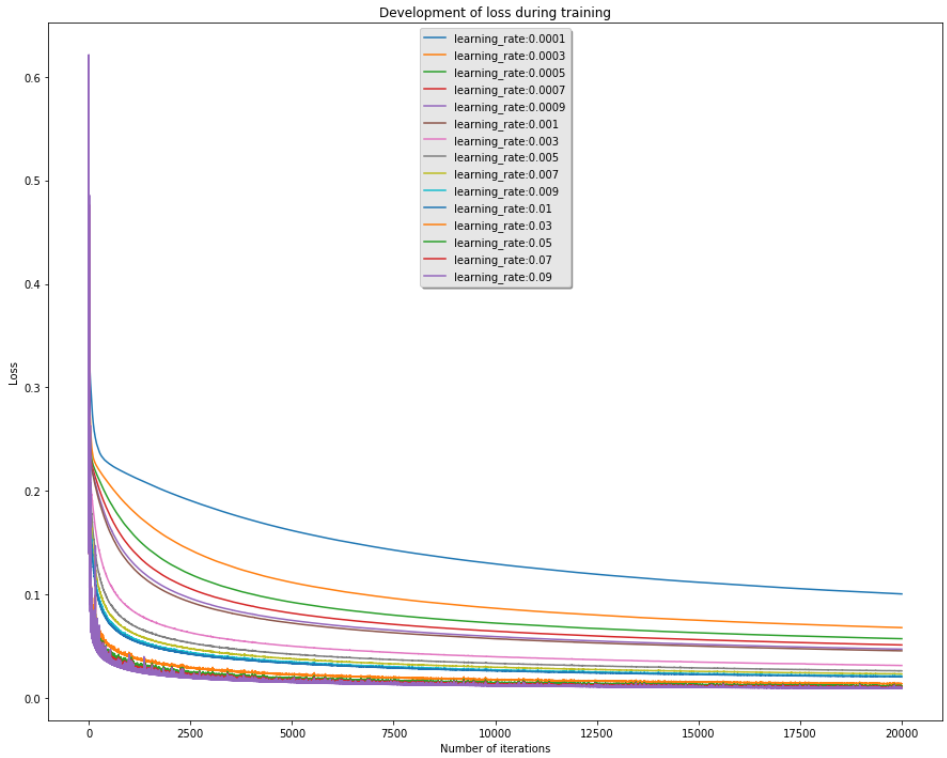

Figure 37: Learning Rate Optimization for MC under Scenario 6

0.800333179. The satisfaction state predicted by the model is also False with the 9.99938632e-01 probability of being True. It means that given the input values, there is almost 99 percent chance of MC being satisfied i.e. having satisfaction state as True.

Classification Results for MR

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MR with an exception of 88 simulation time steps as shown in Fig.41. For these 88 time steps, the actual satisfaction state for MR was False but it was predicted as True.

Moreover, based on the results presented in Table.27, we can deduce the extent of the satisfaction state of MR, when both the active links and satisfaction probability are considered. For example, at time step 481 the active links are 131 and the satisfaction probability is 0.774904176. The output satisfaction state predicted by the model is True similar to the actual state with the 1.00000000e+00 probability of being True. It means that given the input values, there is 100 percent chance of MR being satisfied i.e. having satisfaction state as True.

Classification Results for MP

For the 500 simulation time steps, the model correctly classifies the satisfaction state of MP with an exception of 3 simulation time steps as shown in Fig.42. For these 3 time steps, the actual satisfaction state for MP was False but it was predicted as True.

Moreover, based on the results presented in Table.28, we can deduce the extent of the satisfaction state of MP, when both the Writing Time and satisfaction probability are considered. For example, at time step 480 the writing time is 2047.139 ms and the satisfaction probability is 0.818595404. The output satisfaction state predicted by the model is True similar to the actual state with the 9.99996418e-01 probability of being

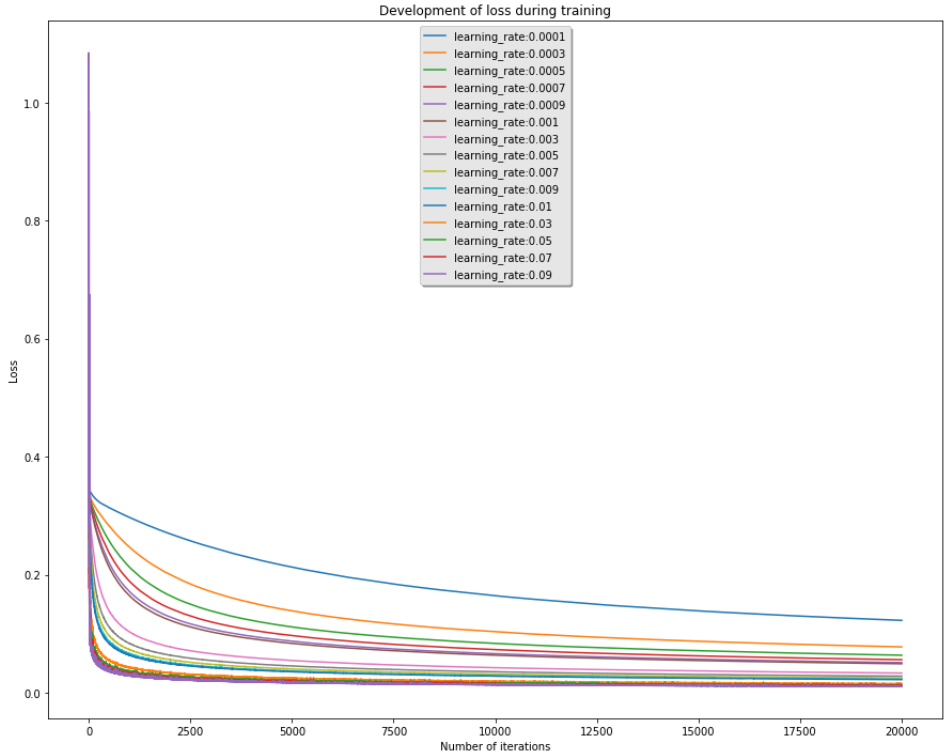

Figure 38: Learning Rate Optimization for MR under Scenario 6

True. It means that given the input values, there is around 99 percent chance of MP to be satisfied i.e. having satisfaction state as True.

Table 26: Classification Results for Minimization of Operational Cost for time steps 480-486 under Scenario 6

Time Step	Bandwidth Consumption	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
480	2811.180718	0.800333179	True	True	[6.13683882e-05 9.99938632e-01]
481	4088.490433	0.819174751	False	False	[9.99996410e-01 3.59039826e-06]
482	2056.129307	0.779324397	True	True	[1.32854633e-10 1.00000000e+00]
483	4550.743946	0.800471075	False	False	[9.99999999e-01 8.85099580e-10]
484	3098.344859	0.75329296	True	True	[0.01514099 0.98485901]
485	1921.293336	0.757097342	True	True	[1.56265609e-11 1.00000000e+00]
486	2695.519972	0.824877382	True	True	[6.26526436e-06 9.99993735e-01]

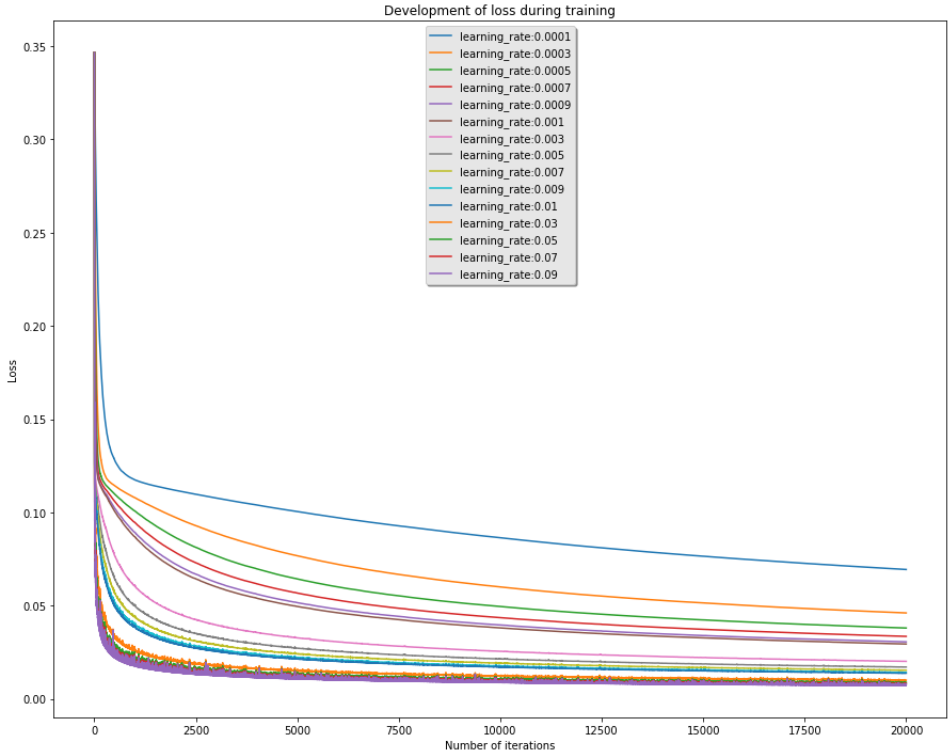

Figure 39: Learning Rate Optimization for MP under Scenario 6

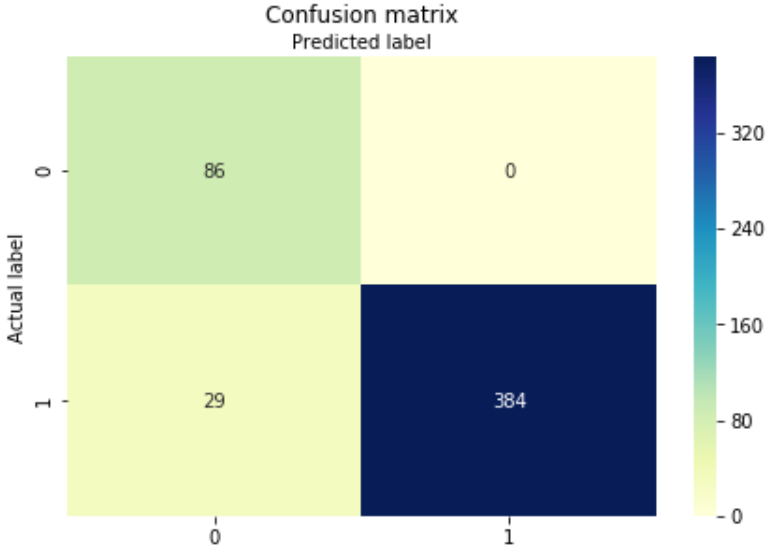

Figure 40: Confusion Matrix for Classification of Satisfaction State of MC under Scenario 6

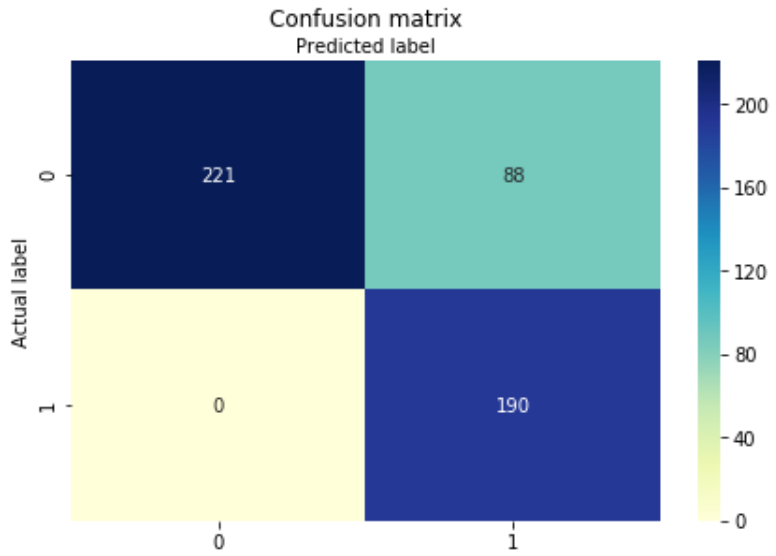

Figure 41: Confusion Matrix for Classification of Satisfaction State of MR under Scenario 6

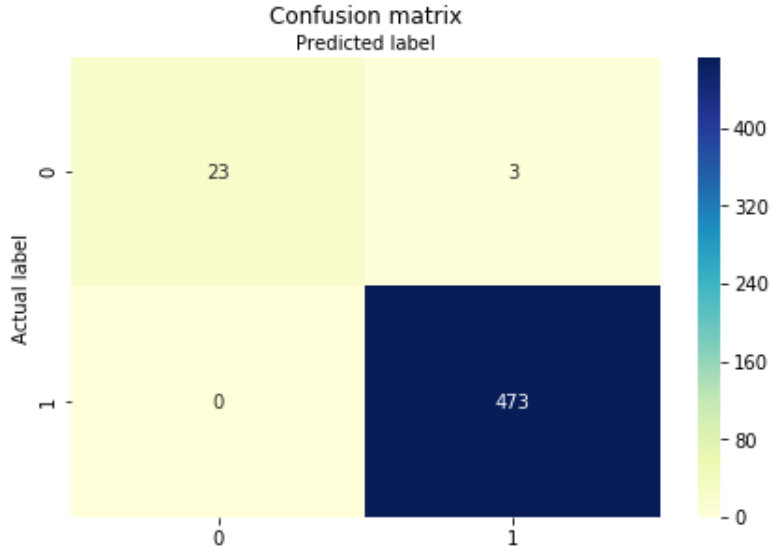

Figure 42: Confusion Matrix for Classification of Satisfaction State of MP under Scenario 6

Table 27: Classification Results for Maximization of Reliability for time steps 480-486 under Scenario 6

Time Step	Active Links	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
480	102	0.697876925	False	True	[1.78852523e-07 9.99999821e-01]
481	131	0.774904176	True	True	[4.87920152e-16 1.00000000e+00]
482	64	0.789328323	False	False	[9.99952326e-01 4.76743050e-05]
483	139	0.698271471	True	True	[2.5325624e-18 1.0000000e+00]
484	112	0.774522882	True	True	[1.81788075e-10 1.00000000e+00]
485	86	0.779436015	False	True	[0.00751181 0.99248819]
486	95	0.698377304	False	True	[2.01618762e-05 9.99979838e-01]

Table 28: Classification Results for Maximization of Performance for time steps 480-486 under Scenario 6

Time Step	Writing Time	Satisfaction Probability	Actual Satisfaction State	Predicted Satisfaction State	Prediction Probability for Satisfaction
480	2047.138671	0.818595404	True	True	[3.58208131e-06 9.99996418e-01]
481	1728.466235	0.674782101	True	True	[2.59154191e-08 9.99999974e-01]
482	707.4143466	0.820974076	True	True	[1.78731255e-16 1.00000000e+00]
483	2978.726221	0.841578812	False	False	[0.97882051 0.02117949]
484	1727.069223	0.71163708	True	True	[2.10726291e-08 9.99999979e-01]
485	1324.932629	0.829141928	True	True	[9.56712729e-12 1.00000000e+00]
486	1763.638539	0.833946736	True	True	[2.19921434e-08 9.99999978e-01]

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