CHAPTER IV

EXPERIMENTAL RESULTS

To meet the objective of QoS management functions at server site and client site, we introduce transmission rate adaptation as a case study of the QoS management functions. The experiment and results are presented in Section 4.1. Thereafter we provide a new incoming request scheduling policy, called MCB, as a strategy to improve the quality of service of the system according to the QoS management function. The experiment and results of the incoming request scheduling are shown in Section 4.2.

4.1 Transmission Rate Adaptation

As a case study of the QoS management functions, Section 3.3, the problem of transmission rate adaptation is formulated in (3.5). Assumption of this study is features adaptation have positive impact to the factors which will increase user satisfaction. Transmission delay (D) is an instance of feature, while transmission rate (R) and packet length (L) are instances of factor.

This study uses ns-2 [83] as a tool for Wireless Internet simulation. The system comprises of one fixed server, one mobile client, and one access point. This study observes average delay time (D, transmission delay) by varying bandwidth (R, transmission rate), packet length (L), distance, and number of sliding window. By passing 40,000 data packets, the experimental results are shown in Figure 4.1 to 4.4.

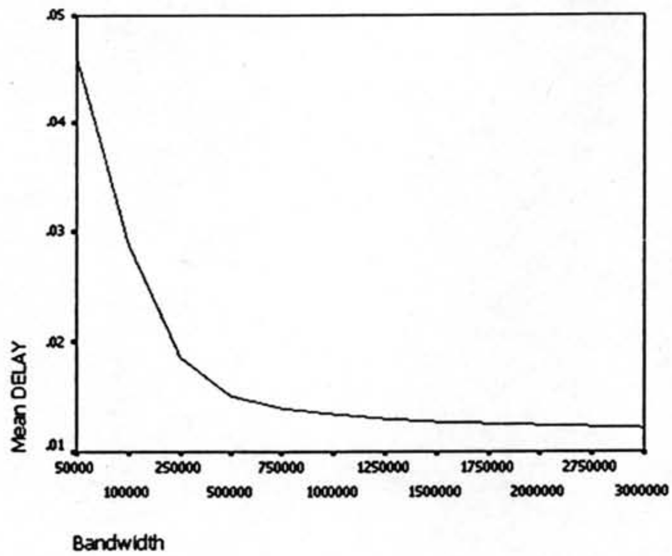

Figure 4.1: Average delay time and bandwidth variation

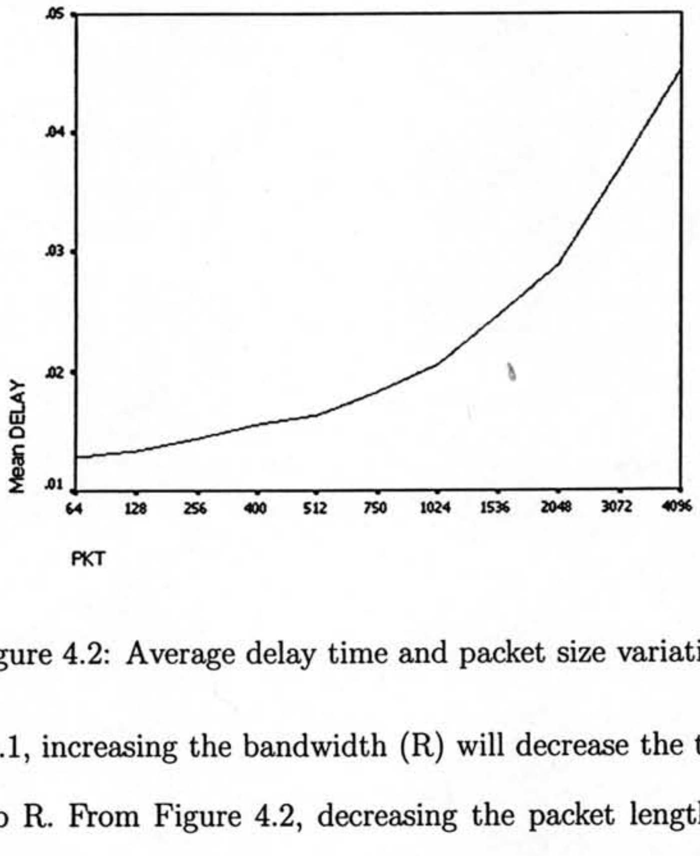

Figure 4.2: Average delay time and packet size variation

From Figure 4.1, increasing the bandwidth (R) will decrease the transmission delay (D); D reverses to R. From Figure 4.2, decreasing the packet length (L, PKT in the Figure) will increase the transmission delay (R); D follows to L. Both experiment fixed one sliding window and distance to 50. Bandwidth testing sets packet length to 128, while packet length testing sets bandwidth to 1M. Moreover, the impact of the transmis-

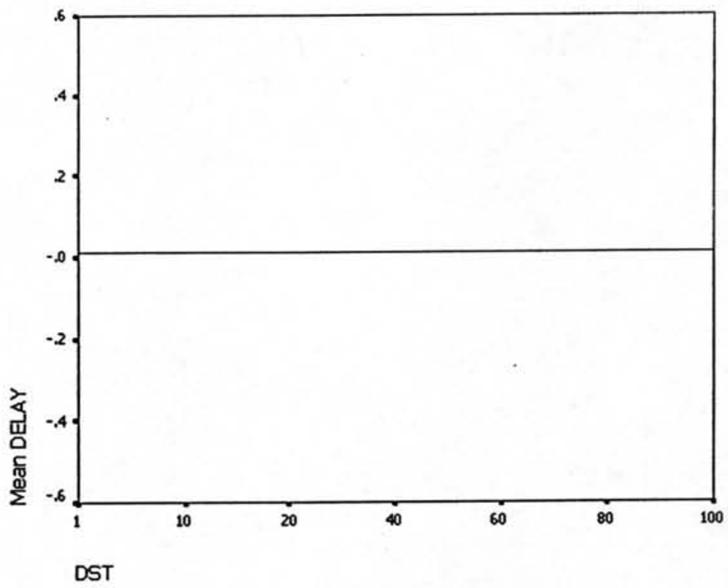

Figure 4.3: Average delay time and transmission distance variation

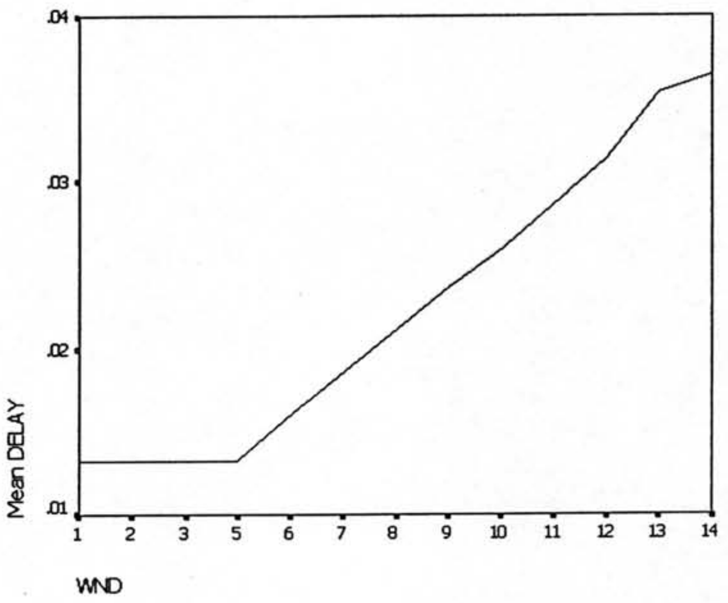

Figure 4.4: Average delay time and number of sliding window variation

sion distance on the transmission delay are shown in Figure 4.3. The graph shows that increasing of distance (DST) have non-impact on the transmission delay. Lastly, Figure 4.4 shows that there are no influence of number of sliding window (WND) variation over the transmission delay if the size is less than or equal to 5, but the transmission delay will be increased linearly if the window size is more than 5. The experimental results show that the bandwidth (R) and the packet length are the critical factors that have an effect on the transmission delay. Further, reducing transmission delay has direct impact to increase user satisfaction. Therefore, transmission rate (R) is selected to put in server site QoS management function, Section 3.3.2, while transmission delay (D) is putted in client site QoS management function, Section 3.3.3.

4.2 Incoming Request Scheduling

To verify the proposed scheduling model in Section 3.4, the simulation model, assumptions, environment, and methodology are set as the following.

4.2.1 The Simulation Model

We implement a web server's incoming request scheduling simulator based on MATLAB 7.0 environment. We reproduce our simulator from incoming request handling part of the web server component of ns-2 [83]. The incoming request queuing problem is modeled in the M/G/1 queuing system. We consider a single server queue. The queue has request arrival in a Poisson process with an average arrival rate λ. It has generally distributed service time with service rate μ. The Poisson process is a continuous-time, discrete-state process where the intervals between successive events are independent and identically distributed according to an exponential distribution $F(x) = 1 - e^{-\lambda x}, x > 0$. The server utilization, ρ, equals to λ/μ, while the probability that the server is idle, ν_0, equals to $1 - \rho$. For more definitions and notations of queuing system, see [54, 55, 59, 84, 85].

In this study, FIFO, EDF, SPT, and MCB scheduling policies are applied to the simulation model. To measure each scheduling policy, the experiment is set to a steady state, where the entire system has stabilized, as presented in the following assumptions. Corresponding to MCB scheduling policy's objective, average waiting time, maximum waiting time, and Sd. waiting time are performance measurement criteria of the experiment.

4.2.2 Assumptions

We assume that the system is a single server queue. Every scheduling policy run on non-preemptive characteristic where a request is processed, other requests cannot interrupt it. Incoming request's buffer in the queuing system has infinite size, thus buffer overflow problem can be ignored. Samples of the general method to find the processing time is presented by Ye et al. [48] and ns-2 [83]. A request document size is divided by service rate to decide the processing time of the request. To enable direct performance measurement and to control the bias of each scheduling policy, the system's running time is assessed from the system's processing times, while the other times, such as request getting time and scheduling time, are trivial times. And, we assume that there are no timeout of the request on any case. We assume that our web server supports HTTP/1.0 [86] which provides a non-persistent connection and only one object is sent over a connection. Request arrival time is a Poisson distribution and inter-arrival time is an exponential distribution, $F(x) = 1 - e^{-\lambda x}, x > 0$. Each incoming request comes with arrival time, deadline, and request document size information, which can be used to calculate the request processing time. Finally, the request document size and deadline are assumed to be a Normal distribution. Consequently, the system model becomes the M/G/1 queuing model.

4.2.3 Environment

We assign a fixed processing rate to the server, 300 Kbytes per second, with a fixed processing cycle. The document size of the request has average size 75 Kbytes per request with Sd. 10 Kbytes. Thus the server's service rate (μ); the server's processing rate divided by the average request size, equals to 4 requests per second. The request's deadline has average time 2.0 seconds with Sd. 0.2. Estimated success rate is the capability of the system that can process the requests. It is equals to $100 \times 1/\rho$ or $100 \times \mu/\lambda$. We decide to test the system in two situations, depending on the estimated success rate. First, medium loaded case is a situation where the estimated success rate is between 25-75%. Second, heavily loaded case is a situation where the estimated success rate is less than 25%. We determine the estimated success rate at 40% and 7%, estimate, for the medium loaded and heavily loaded cases, respectively. Therefore, for the medium loaded case, arrival rate or λ is 10 requests per second, while for the heavily loaded case, arrival rate is 60 requests per second (the result is rounded from 57). Each running case has thirty minutes period. Thus, for the medium loaded case, total number of request is 18,000 requests, and for the heavily loaded case, total number of request is 108,000 requests. For both cases, we test system on non-deadline checking manner in order to measure the real performance of each policy and on deadline checking manner to assess the dealine effect on each policy.

4.2.4 Methodology

We generate five data sets according to the assumptions and the environment of our experiment. We test the system in two situations: without deadline checking and deadline checking. The first situation, without deadline checking, the system will not check deadline of each request, thus there are no rejected request this situation. We use this situation to measure the performance of each comparative policy. The second situation, deadline checking, the system will check whether it can complete the request within the request deadline, if not, it will reject that request. We use this situation to present the effect of deadline checking on each comparative policy. In both situations, the incoming requests arrive at the web server in accordance with the Poisson process of rate λ. Request waiting resistances, which determine request's deadlines, and request document sizes, which determine request's service times, are defined to be independent general random variables with the Normal distribution function. Our experiment methodology is designed as follows:

Step 1. The experiment starts with a medium loaded case without deadline.

Step 1.1 For medium loaded case without deadline, 18,000 requests of each data set are generated.

Step 1.2 At this step, the weight aggregation at the scheduling level (3.8) is concerned. By varying w_1, w_2, and w_3, 66 scheduling policies are generated including FIFO, EDF, SPT, and 63-MCBs. We add an equivalent weighting option, $w_1 = 3.33, w_2 = 3.33$, and $w_3 = 3.33$ to the experiment, called MCB-3. Thus, 67 scheduling policies are considered. For our comparative, we choose two equivalent weighting's policies as instances of MCB. The first is MCB-3. The second is the policy that $w_1 = 5, w_2 = 5$, and $w_3 = 0$, called MCB-2. This policy is selected because it is an instance of bi-criteria policy or two criteria considerate policy; that concerns processing time and deadline. The output of this process is waiting time of each request.

Step 1.3 From the output, average waiting time, maximum waiting time, and Sd. waiting time are calculated for each policy. The results are then presented in three-dimensional graph of average waiting time, maximum waiting time, and Sd. waiting time. Comparative of the three calculated values of every policies are represented in two-dimensional graph. Lastly, comparison of five policies: FIFO, EDF, SPT, MCB-2, and MCB-3 are introduced.

Step 1.4 Repeat Step 1.2 with the medium loaded case with deadline.

Step 1.5 Repeat Step 1.1 to 1.4 for the remaining 4 data sets. Totally, there are 5 data sets with 18,000 requests of each data set, for a medium loaded case.

Step 2. Iterate Step 1, with the following situations: heavily loaded without deadline and heavily loaded case with deadline. Totally, there are 5 data sets with 108,000 requests of each data set.

Step 3. The outcomes of Step 1 and Step 2, which is average waiting time, maximum waiting time, and Sd. waiting time of each scheduling policy, is used to calculate weight aggregations of the performance measurement level (3.9). The selected five policies: FIFO, EDF, STP, MCB-2, and MCB-3, are determined by varying λ_1, λ_2, and λ_3 values. Total 66 alternatives for each individual policy are dealt. The results of this process are plotted in two-dimensional graphs.

4.3 The Simulation Results

4.3.1 At Scheduling Level

Non-deadline Checking Situation

In this section, we present our results in detail, showing the effect of our proposed technique. From (3.8), we determine sixty-three MCB policies by varying the weight values. In addition, one equivalent weighting's MCB policy ($w_1 = w_2 = w_3 = 3.33$) or MCB-3 is added for a balanced situation. These sixty-four MCB policies are compared with FIFO, EDF, and SPT. The first data set of medium loaded and heavily loaded cases are selected as instances of our results. Table 4.1 and 4.2 show some samples of the scheduling results for medium loaded and heavily loaded cases without deadline, respectively. As can be seen, broadly, average waiting time is decreased when w_1 increases while maximum and Sd. waiting times are increased. The average waiting time then changes in contradiction to maximum and Sd. waiting times. The details of each scheduling result are represented in the following graphs.

Table 4.1: Scheduling result of medium loaded case without deadline

No	Policy	w_1	w_2	w_3	Avg wait	Max wait	Sd wait
1	FIFO	0	0	10	1348.5725	2691.4514	779.3574
2	MCB	0	1	9	1348.5725	2691.4514	779.3575
3	MCB	0	2	8	1348.5723	2691.4514	779.3578
4	MCB	0	3	7	1348.5722	2691.4514	779.3578
5	MCB	0	4	6	1348.5847	2691.4656	779.3601
6	MCB	0	5	5	1348.5848	2691.4656	779.3601
7	MCB	0	6	4	1348.5847	2691.4656	779.3601
8	MCB	0	7	3	1348.5846	2691.4656	779.3599
9	MCB	0	8	2	1348.5720	2691.4514	779.3574
10	MCB	0	9	1	1348.5845	2691.4656	779.3597
11	EDF	0	10	0	1348.5845	2691.4656	779.3595
12	MCB	1	0	9	1343.9228	2718.4122	778.3673
13	MCB	1	1	8	1343.9221	2718.4122	778.3673
14	MCB	1	2	7	1343.9215	2718.4122	778.3674

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Table 4.1: (*continued*)

No	Policy	w_1	w_2	w_3	Avg wait	Max wait	Sd wait
15	MCB	1	3	6	1343.9208	2718.4122	778.3675
16	MCB	1	4	5	1343.9198	2718.4122	778.3677
17	MCB	1	5	4	1343.9189	2718.4122	778.3681
18	MCB	1	6	3	1343.9180	2718.4122	778.3684
19	MCB	1	7	2	1343.9172	2718.4122	778.3686
20	MCB	1	8	1	1343.9163	2718.1263	778.3686
21	MCB	1	9	0	1343.9154	2717.8987	778.3688
22	MCB	2	0	8	1338.2596	2761.6498	778.2853
23	MCB	2	1	7	1338.2578	2761.6498	778.2860
24	MCB	2	2	6	1338.2559	2761.6498	778.2865
25	MCB	2	3	5	1338.2538	2761.6498	778.2873
26	MCB	2	4	4	1338.2518	2761.6498	778.2883
27	MCB	2	5	3	1338.2499	2761.6498	778.2889
28	MCB	2	6	2	1338.2479	2761.6498	778.2896
29	MCB	2	7	1	1338.2459	2761.6498	778.2903
30	MCB	2	8	0	1338.2442	2761.6498	778.2908
31	MCB	3	0	7	1331.2291	2841.7183	779.9190
32	MCB	3	1	6	1331.2255	2841.7183	779.9212
33	MCB	3	2	5	1331.2218	2842.0069	779.9235
34	MCB	3	3	4	1331.2182	2842.2570	779.9255
35	MCB	3	4	3	1331.2145	2842.2570	779.9278

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Table 4.1: (*continued*)

No	Policy	w_1	w_2	w_3	Avg wait	Max wait	Sd wait
36	MCB	3	5	2	1331.2112	2842.2570	779.9298
37	MCB	3	6	1	1331.2075	2842.2570	779.9324
38	MCB	3	7	0	1331.2036	2842.2570	779.9348
39	MCB-3	3.33	3.33	3.33	1328.4591	2889.1752	781.0977
40	MCB	4	0	6	1322.1754	2951.8248	784.8666
41	MCB	4	1	5	1322.1693	2951.8248	784.8720
42	MCB	4	2	4	1322.1629	2951.8248	784.8780
43	MCB	4	3	3	1322.1565	2951.8248	784.8838
44	MCB	4	4	2	1322.1505	2951.8248	784.8891
45	MCB	4	5	1	1322.1439	2951.8248	784.8953
46	MCB	4	6	0	1322.1375	2951.8248	784.9013
47	MCB	5	0	5	1310.1762	3048.3286	796.3939
48	MCB	5	1	4	1310.1665	3048.3286	796.4068
49	MCB	5	2	3	1310.1556	3048.3286	796.4211
50	MCB	5	3	2	1310.1436	3048.3286	796.4368
51	MCB	5	4	1	1310.1327	3048.3286	796.4510
52	MCB-2	5	5	0	1310.1231	3048.3286	796.4642
53	MCB	6	0	4	1293.6000	3266.8117	821.7090
54	MCB	6	1	3	1293.5819	3266.8117	821.7428
55	MCB	6	2	2	1293.5628	3266.8117	821.7789
56	MCB	6	3	1	1293.5438	3266.8117	821.8144

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Table 4.1: (*continued*)

No	Policy	w_1	w_2	w_3	Avg wait	Max wait	Sd wait
57	MCB	6	4	0	1293.5257	3267.0873	821.8484
58	MCB	7	0	3	1269.2961	3764.9624	877.8183
59	MCB	7	1	2	1269.2637	3764.9624	877.9021
60	MCB	7	2	1	1269.2314	3765.5463	877.9852
61	MCB	7	3	0	1269.2002	3766.1049	878.0665
62	MCB	8	0	2	1237.3836	3976.6267	987.7022
63	MCB	8	1	1	1237.3444	3976.6267	987.8527
64	MCB	8	2	0	1237.3038	3976.9463	988.0064
65	MCB	9	0	1	1210.3683	4352.8493	1141.3530
66	MCB	9	1	0	1210.3378	4352.8493	1141.5717
67	SPT	10	0	0	1201.3418	4468.0986	1288.7449

The scheduling function refers to (3.8),$\sum w_i = 10$, w_1 is normalized processing time's weight, w_2 is normalized deadline's weight, and w_3 is normalized arrival time's weight.

No	Policy	w_1	w_2	w_3	Avg wait	Max wait	Sd wait
1	FIFO	0	0	10	1348.5725	2691.4514	779.3574
11	EDF	0	10	0	1348.5845	2691.4656	779.3595
39	MCB-3	3.33	3.33	3.33	1328.4591	2889.1752	781.0977
52	MCB-2	5	5	0	1310.1231	3048.3286	796.4642
67	SPT	10	0	0	1201.3418	4468.0986	1288.7449

Table 4.2: Scheduling result of heavily loaded case without deadline

No	Policy	w_1	w_2	w_3	Avg wait	Max wait	Sd wait
1	FIFO	0	0	10	12598.1523	25195.4693	7273.7269
2	MCB	0	1	9	12598.1523	25195.5058	7273.7269
3	MCB	0	2	8	12598.1525	25195.5058	7273.7269
4	MCB	0	3	7	12598.1527	25195.5058	7273.7270
5	MCB	0	4	6	12598.1527	25195.5058	7273.7271
6	MCB	0	5	5	12598.1527	25195.5058	7273.7271
7	MCB	0	6	4	12598.1529	25195.5058	7273.7270
8	MCB	0	7	3	12598.1531	25195.6559	7273.7269
9	MCB	0	8	2	12598.1531	25195.6559	7273.7268
10	MCB	0	9	1	12598.1533	25195.6559	7273.7267
11	EDF	0	10	0	12598.1534	25195.6559	7273.7267
12	MCB	1	0	9	12564.5476	25212.9966	7272.0469
13	MCB	1	1	8	12564.5431	25212.9966	7272.0470
14	MCB	1	2	7	12564.5385	25212.6873	7272.0471
15	MCB	1	3	6	12564.5336	25212.6873	7272.0474
16	MCB	1	4	5	12564.5288	25212.6873	7272.0474
17	MCB	1	5	4	12564.5241	25212.6873	7272.0477
18	MCB	1	6	3	12564.5194	25212.6873	7272.0478
19	MCB	1	7	2	12564.5146	25212.6873	7272.0480
20	MCB	1	8	1	12564.5096	25212.6873	7272.0480
21	MCB	1	9	0	12564.5050	25212.6873	7272.0480

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Table 4.2: (*continued*)

No	Policy	w_1	w_2	w_3	Avg wait	Max wait	Sd wait
22	MCB	2	0	8	12523.4297	25240.8650	7271.8386
23	MCB	2	1	7	12523.4181	25240.8650	7271.8394
24	MCB	2	2	6	12523.4066	25240.8650	7271.8402
25	MCB	2	3	5	12523.3949	25240.8650	7271.8412
26	MCB	2	4	4	12523.3828	25240.8650	7271.8421
27	MCB	2	5	3	12523.3713	25240.8650	7271.8431
28	MCB	2	6	2	12523.3598	25240.5377	7271.8441
29	MCB	2	7	1	12523.3481	25240.5377	7271.8450
30	MCB	2	8	0	12523.3362	25240.5377	7271.8461
31	MCB	3	0	7	12471.7781	25289.7010	7273.9443
32	MCB	3	1	6	12471.7563	25289.7010	7273.9469
33	MCB	3	2	5	12471.7339	25289.7010	7273.9494
34	MCB	3	3	4	12471.7118	25289.7010	7273.9525
35	MCB	3	4	3	12471.6891	25289.7010	7273.9555
36	MCB	3	5	2	12471.6671	25289.7010	7273.9576
37	MCB	3	6	1	12471.6451	25289.7010	7273.9601
38	MCB	3	7	0	12471.6227	25289.7010	7273.9625
39	MCB-3	3.33	3.33	3.33	12451.4910	25298.0557	7275.3261
40	MCB	4	0	6	12405.6595	25387.4610	7279.5159
41	MCB	4	1	5	12405.6215	25387.4610	7279.5217
42	MCB	4	2	4	12405.5838	25387.8006	7279.5270

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Table 4.2: (*continued*)

No	Policy	w_1	w_2	w_3	Avg wait	Max wait	Sd wait
43	MCB	4	3	3	12405.5459	25387.8006	7279.5320
44	MCB	4	4	2	12405.5079	25387.8006	7279.5373
45	MCB	4	5	1	12405.4699	25387.8006	7279.5432
46	MCB	4	6	0	12405.4315	25387.8006	7279.5487
47	MCB	5	0	5	12318.5404	25450.8959	7291.2102
48	MCB	5	1	4	12318.4772	25451.2187	7291.2226
49	MCB	5	2	3	12318.4142	25451.2187	7291.2342
50	MCB	5	3	2	12318.3511	25451.2187	7291.2463
51	MCB	5	4	1	12318.2877	25451.2187	7291.2581
52	MCB-2	5	5	0	12318.2247	25451.5194	7291.2696
53	MCB	6	0	4	12200.5197	25657.0724	7315.0350
54	MCB	6	1	3	12200.4133	25657.6967	7315.0670
55	MCB	6	2	2	12200.3094	25657.6967	7315.0945
56	MCB	6	3	1	12200.2054	25658.6257	7315.1214
57	MCB	6	4	0	12200.1017	25658.6257	7315.1482
58	MCB	7	0	3	12037.9525	25889.9947	7365.0079
59	MCB	7	1	2	12037.7877	25890.3183	7365.0728
60	MCB	7	2	1	12037.6224	25890.3183	7365.1379
61	MCB	7	3	0	12037.4574	25890.9411	7365.2025
62	MCB	8	0	2	11830.1942	26416.9213	7467.8748
63	MCB	8	1	1	11829.9790	26416.9213	7468.0161

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Table 4.2: (*continued*)

No	Policy	w_1	w_2	w_3	Avg wait	Max wait	Sd wait
64	MCB	8	2	0	11829.7640	26417.2386	7468.1569
65	MCB	9	0	1	11646.9210	26896.9589	7633.6234
66	MCB	9	1	0	11646.7685	26897.2957	7633.8385
67	SPT	10	0	0	11582.5782	26961.5782	7813.6926

The scheduling function refers to (3.8),$\sum w_i = 10$, w_1 is normalized processing time's weight, w_2 is normalized deadline's weight, and w_3 is normalized arrival time's weight.

No	Policy	w_1	w_2	w_3	Avg wait	Max wait	Sd wait
1	FIFO	0	0	10	12598.1523	25195.4693	7273.7269
11	EDF	0	10	0	12598.1534	25195.6559	7273.7267
39	MCB-3	3.33	3.33	3.33	12451.4910	25298.0557	7275.3261
52	MCB-2	5	5	0	12318.2247	25451.5194	7291.2696
67	SPT	10	0	0	11582.5782	26961.5782	7813.6926

Figure 4.5 and 4.6 show the density of successful data in histogram of the two data cases. Only FIFO, EDF, SPT, MCB-2, and MCB-3 are presented for comparative. MCB-3 is selected as an instance of MCB scheduling policies for fair weighting. MCB-2 ($w_1 = w_2 = 5,\ w_3 = 0$) is selected as an instance of bi-criteria policy. In the Figures, Y-axis scales of SPT (10^{-3} and 10^{-4}, respectively) have higher scale than the other four policies (10^{-4} and 10^{-5}, respectively). The probability density function (PDF) is used to measure the probability of various continuous outcomes. SPT has the highest density of successful request. At the same time, FIFO, EDF, MCB-2, and MCB-3 have results in the same direction.

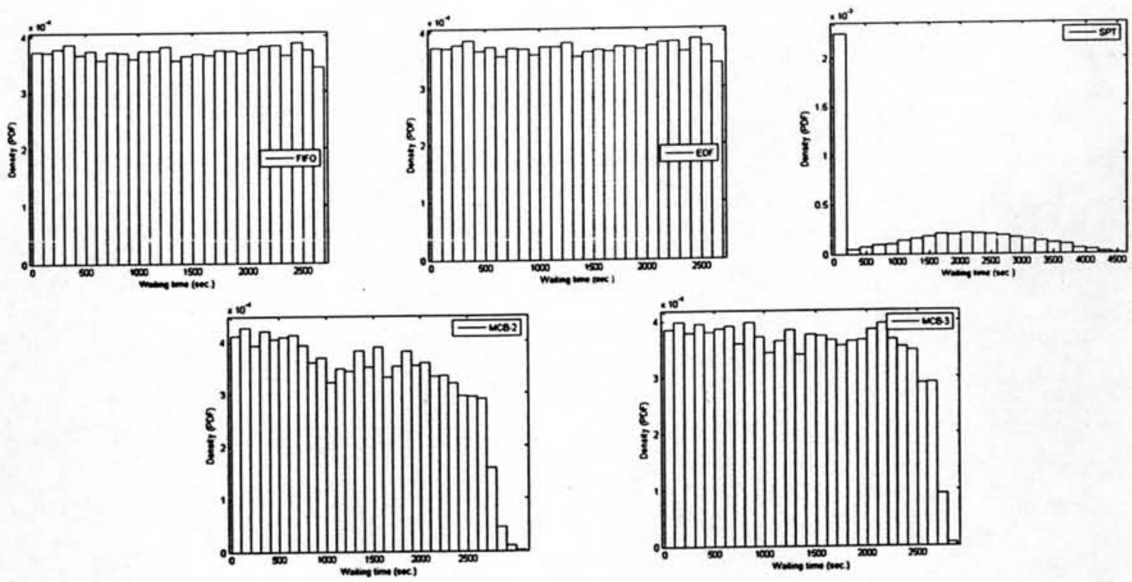

Figure 4.5: Density of successful data for medium loaded case without deadline's data histogram

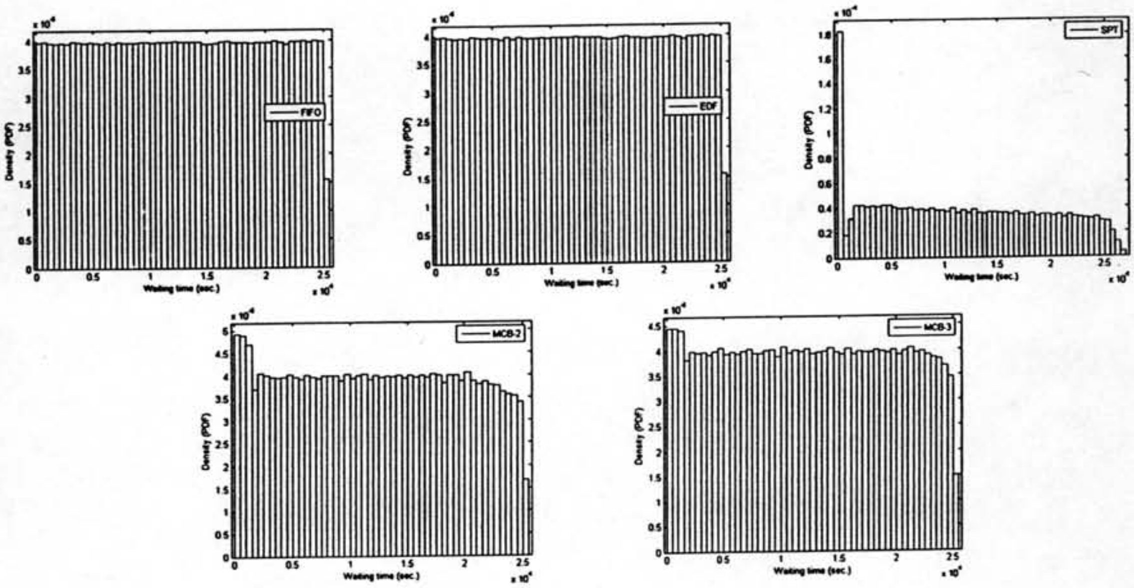

Figure 4.6: Density of successful data for heavily loaded case without deadline's data histogram

Figure 4.7 to 4.9 present average waiting time, maximum waiting time, and Sd. waiting time of first data set of medium loaded and heavily loaded cases, respectively. Results of FIFO, EDF, and SPT are also represented in the Figures. For FIFO approach, w_3 equals to 10 while w_1 and w_2 equal to zero. For EDF approach, w_2 equals to 10 while w_1 and w_3 equal to zero. For SPT approach that has low average waiting time, w_1 equals to 10 while w_2 and w_3 equal to zero. From the Figures, w_1 is the major impacts of average, maximum, and Sd. waiting times. Increasing of w_1 reduces average waiting time, and in contrast, raises maximum and Sd. waiting times. These conflicting results are used to measure the performance of each scheduling policy in the following Subsection.

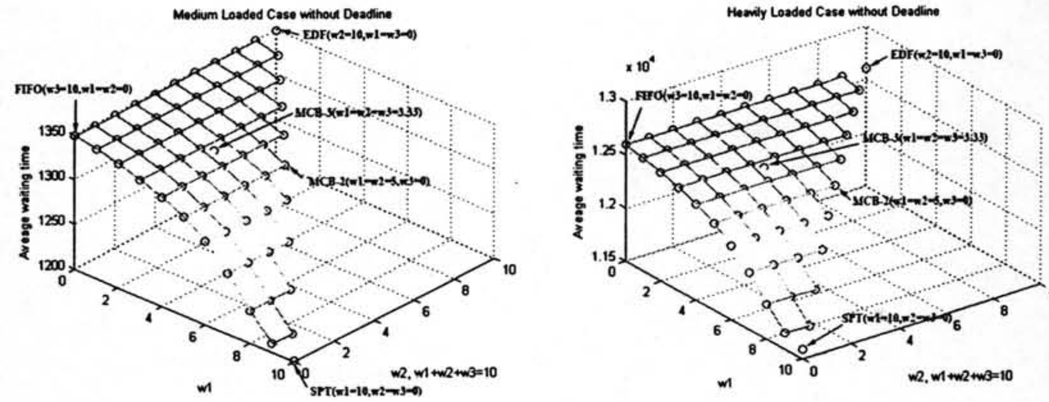

Figure 4.7: Average waiting time of medium and heavily loaded cases without deadline

Comparative waiting time consumption of each scheduling policy at scheduling level are exposed in two dimensional graphs, Figure 4.10 and 4.11. In each graph, 67 scheduling policies are presented on X-axis, including FIFO at 1, EDF at 11, SPT at 67, MCB-2 at 52, MCB-3 at 39, and the remainders of MCBs. From the Figures, FIFO and EDF have high average waiting time with low maximum and Sd. waiting times. SPT produces the lowest average waiting time with the highest maximum and Sd. waiting times. Comparing only on the five selected policies, MCB-2 and MCB-3 appear to be

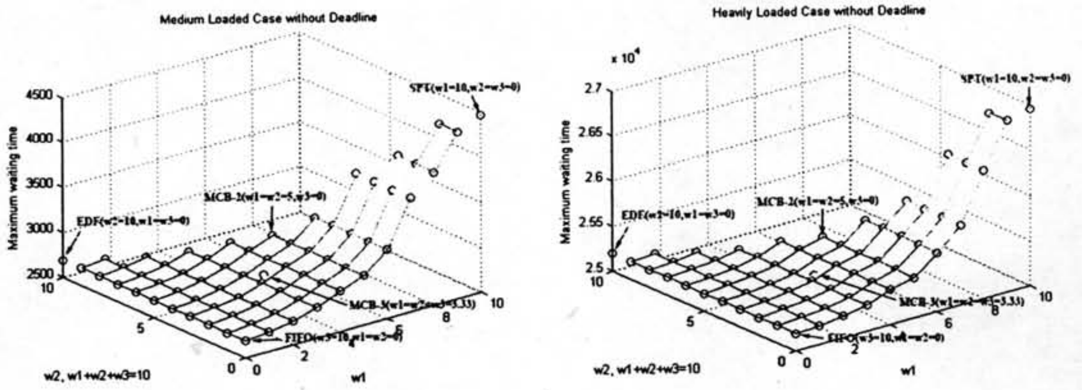

Figure 4.8: Maximum waiting time of medium and heavily loaded cases without deadline

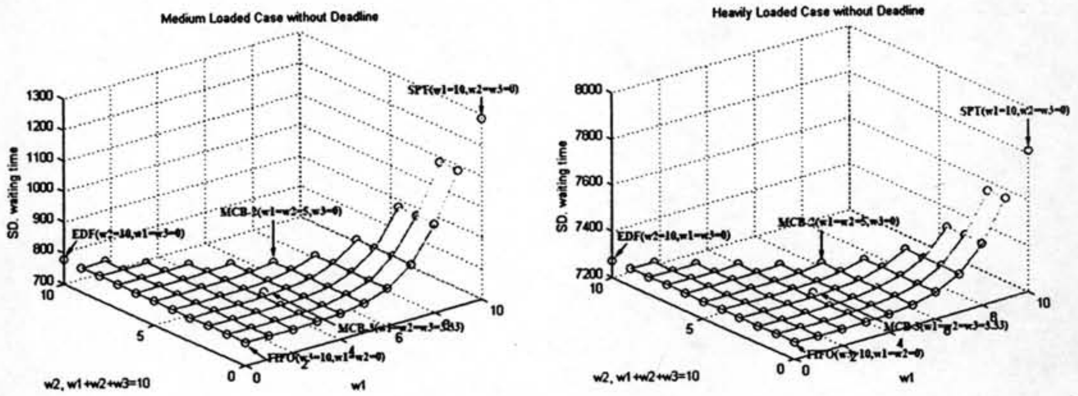

Figure 4.9: Standard deviation waiting time of medium and heavily loaded cases without deadline

the optimal policy. For clarification, we use these three waiting time values as criteria in the performance measurement level and weight aggregation method to quantify the performance of each policy.

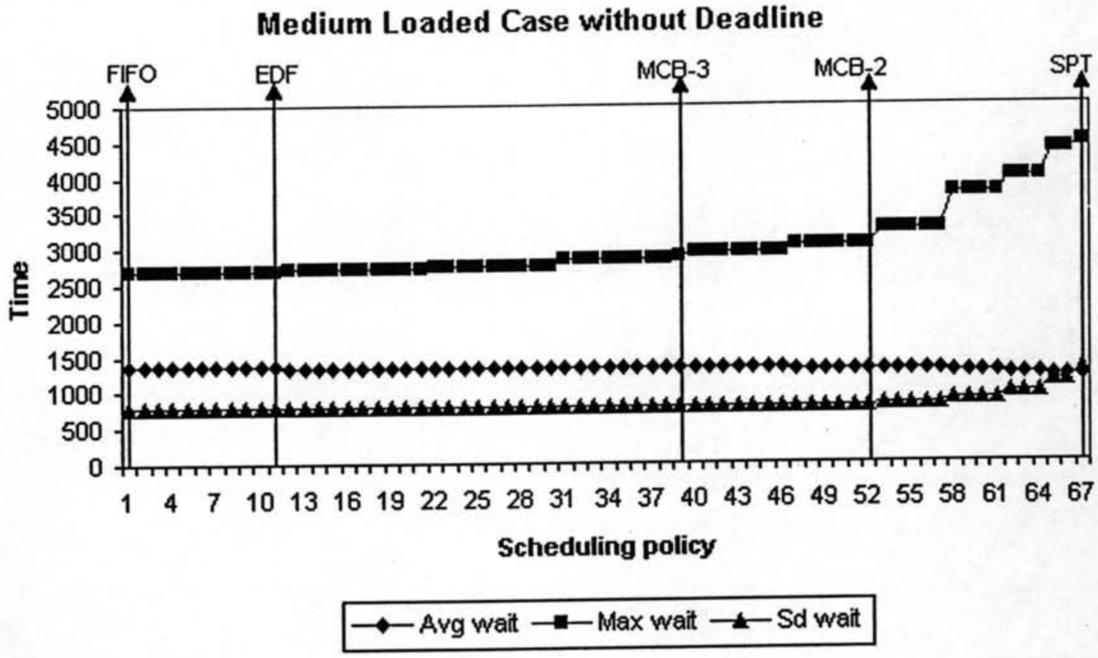

Figure 4.10: Medium loaded cases without deadline's time consumption

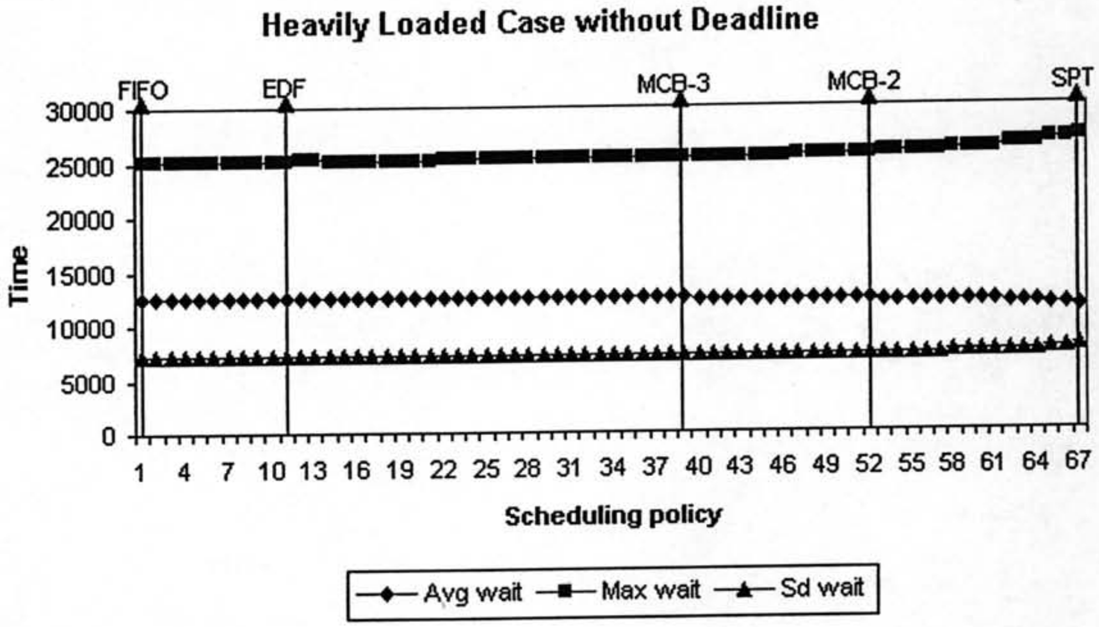

Figure 4.11: Heavily loaded case without deadline's time consumption

Deadline Checking Situation

In this situation, the request will be rejected if its deadline exceeds the system time. Raw scheduling data of medium loaded and heavily loaded cases are shown in Table 4.3 and 4.4, respectively. The details of each scheduling result are represented in the following graphs. As can be seen, in both Tables, values of average and Sd. waiting times can be separated into 2 groups: first group, w_1 equals to zero, has higher values, second group, w_1 more than zero, has lower values. While, maximum waiting times are uneven.

Table 4.3: Scheduling result of medium loaded case with deadline

No	Policy	w_1	w_2	w_3	Rejected requests	Avg wait	Max wait	Sd wait
1	FIFO	0	0	10	10,638	1.6795	2.2054	0.1809
2	MCB	0	1	9	9,934	1.6890	2.2912	0.1833
3	MCB	0	2	8	10,501	1.6937	2.3538	0.1876
4	MCB	0	3	7	9,932	1.7011	2.3562	0.1911
5	MCB	0	4	6	10,633	1.7034	2.3686	0.1974
6	MCB	0	5	5	10,613	1.7044	2.3874	0.2040
7	MCB	0	6	4	10,595	1.7035	2.3628	0.2115
8	MCB	0	7	3	10,589	1.6951	2.4022	0.2195
9	MCB	0	8	2	10,581	1.6836	2.4423	0.2254
10	MCB	0	9	1	10,564	1.6652	2.4427	0.2316
11	EDF	0	10	0	10,553	1.6388	2.4441	0.2358
12	MCB	1	0	9	10,530	1.0071	2.1739	0.4313
13	MCB	1	1	8	10,507	1.0123	2.2026	0.4366

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Table 4.3: (*continued*)

No	Policy	w_1	w_2	w_3	Rejected requests	Avg wait	Max wait	Sd wait
14	MCB	1	2	7	9,930	1.0133	2.2426	0.4306
15	MCB	1	3	6	9,930	1.0072	2.1916	0.4324
16	MCB	1	4	5	9,930	1.0076	2.2237	0.4319
17	MCB	1	5	4	9,928	1.0059	2.2177	0.4315
18	MCB	1	6	3	9,926	1.0098	2.2207	0.4355
19	MCB	1	7	2	9,925	1.0098	2.2236	0.4331
20	MCB	1	8	1	9,928	1.0080	2.2225	0.4317
21	MCB	1	9	0	9,927	1.0054	2.2018	0.4289
22	MCB	2	0	8	9,926	0.9946	2.1409	0.4323
23	MCB	2	1	7	9,926	0.9894	2.1808	0.4312
24	MCB	2	2	6	9,930	0.9917	2.1825	0.4323
25	MCB	2	3	5	9,932	0.9907	2.2521	0.4285
26	MCB	2	4	4	9,929	0.9880	2.2654	0.4274
27	MCB	2	5	3	9,927	0.9902	2.2031	0.4310
28	MCB	2	6	2	9,926	0.9892	2.1971	0.4318
29	MCB	2	7	1	9,928	0.9893	2.1934	0.4274
30	MCB	2	8	0	9,930	0.9871	2.1933	0.4247
31	MCB	3	0	7	9,928	0.9832	2.1788	0.4267
32	MCB	3	1	6	9,927	0.9857	2.2261	0.4304
33	MCB	3	2	5	9,932	0.9863	2.1745	0.4283
34	MCB	3	3	4	9,932	0.9820	2.2656	0.4282

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Table 4.3: (*continued*)

No	Policy	w_1	w_2	w_3	Rejected requests	Avg wait	Max wait	Sd wait
35	MCB	3	4	3	9,933	0.9863	2.2654	0.4266
36	MCB	3	5	2	9,934	0.9828	2.1841	0.4293
37	MCB	3	6	1	9,934	0.9821	2.1875	0.4288
38	MCB	3	7	0	9,930	0.9837	2.4366	0.4287
39	MCB-3	3.33	3.33	3.33	9,927	0.9764	2.3026	0.4324
40	MCB	4	0	6	9,929	0.9767	2.1529	0.4298
41	MCB	4	1	5	9,930	0.9796	2.2440	0.4281
42	MCB	4	2	4	9,932	0.9788	2.2183	0.4296
43	MCB	4	3	3	9,931	0.9746	2.2209	0.4299
44	MCB	4	4	2	9,932	0.9807	2.1956	0.4300
45	MCB	4	5	1	9,932	0.9836	2.1888	0.4282
46	MCB	4	6	0	9,932	0.9788	2.2179	0.4278
47	MCB	5	0	5	9,932	0.9807	2.1723	0.4274
48	MCB	5	1	4	9,932	0.9798	2.3097	0.4277
49	MCB	5	2	3	9,932	0.9792	2.1510	0.4279
50	MCB	5	3	2	9,929	0.9788	2.2417	0.4297
51	MCB	5	4	1	9,932	0.9790	2.2419	0.4299
52	MCB-2	5	5	0	9,931	0.9755	2.1883	0.4257
53	MCB	6	0	4	9,930	0.9797	2.2804	0.4289
54	MCB	6	1	3	9,933	0.9777	2.1971	0.4271
55	MCB	6	2	2	9,933	0.9763	2.4444	0.4283

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Table 4.3: (*continued*)

No	Policy	w_1	w_2	w_3	Rejected requests	Avg wait	Max wait	Sd wait
56	MCB	6	3	1	9,932	0.9769	2.1927	0.4262
57	MCB	6	4	0	9,934	0.9730	2.1711	0.4287
58	MCB	7	0	3	9,930	0.9782	2.1678	0.4271
59	MCB	7	1	2	9,935	0.9760	2.1914	0.4277
60	MCB	7	2	1	9,934	0.9746	2.2319	0.4265
61	MCB	7	3	0	9,934	0.9742	2.3373	0.4265
62	MCB	8	0	2	9,933	0.9700	2.1711	0.4298
63	MCB	8	1	1	9,931	0.9721	2.1347	0.4286
64	MCB	8	2	0	9,935	0.9720	2.1346	0.4285
65	MCB	9	0	1	9,935	0.9713	2.2566	0.4300
66	MCB	9	1	0	9,935	0.9691	2.2561	0.4322
67	SPT	10	0	0	9,934	0.9664	2.1796	0.4288

The scheduling function refers to (3.8),$\sum w_i = 10$, w_1 is normalized processing time's weight,

w_2 is normalized deadline's weight, and w_3 is normalized arrival time's weight.

No	Policy	w_1	w_2	w_3	Rejected requests	Avg wait	Max wait	Sd wait
1	FIFO	0	0	10	10,638	1.6795	2.2054	0.1809
11	EDF	0	10	0	10,553	1.6388	2.4441	0.2358
39	MCB-3	3.33	3.33	3.33	9,927	0.9764	2.3026	0.4324
52	MCB-2	5	5	0	9,931	0.9755	2.1883	0.4257
67	SPT	10	0	0	9,934	0.9664	2.1796	0.4288

Table 4.4: Scheduling result of heavily loaded case with deadline

No	Policy	w_1	w_2	w_3	Rejected request	Avg wait	Max wait	Sd wait
1	FIFO	0	0	10	100,516	1.9791	2.4249	0.1105
2	MCB	0	1	9	98,556	1.9843	2.4279	0.1121
3	MCB	0	2	8	99,735	1.9850	2.4194	0.1159
4	MCB	0	3	7	98,557	1.9858	2.4384	0.1212
5	MCB	0	4	6	100,490	1.9832	2.4230	0.1258
6	MCB	0	5	5	100,463	1.9783	2.4915	0.1324
7	MCB	0	6	4	100,412	1.9674	2.4846	0.1423
8	MCB	0	7	3	100,379	1.9493	2.5390	0.1548
9	MCB	0	8	2	100,316	1.9156	2.5468	0.1685
10	MCB	0	9	1	100,233	1.8534	2.5457	0.1884
11	EDF	0	10	0	100,161	1.7522	2.5006	0.2050
12	MCB	1	0	9	100,016	1.0763	2.3747	0.4552
13	MCB	1	1	8	99,845	1.0741	2.3661	0.4516
14	MCB	1	2	7	98,572	1.0759	2.3615	0.4518
15	MCB	1	3	6	98,571	1.0742	2.3670	0.4512
16	MCB	1	4	5	98,568	1.0740	2.4201	0.4515
17	MCB	1	5	4	98,566	1.0708	2.3634	0.4494
18	MCB	1	6	3	98,564	1.0724	2.3643	0.4501
19	MCB	1	7	2	98,561	1.0688	2.3980	0.4476
20	MCB	1	8	1	98,558	1.0670	2.3707	0.4509
21	MCB	1	9	0	98,559	1.0698	2.4034	0.4471

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Table 4.4: (*continued*)

No	Policy	w_1	w_2	w_3	Rejected request	Avg wait	Max wait	Sd wait
22	MCB	2	0	8	98,555	1.0340	2.3112	0.4393
23	MCB	2	1	7	98,554	1.0356	2.3203	0.4431
24	MCB	2	2	6	98,561	1.0343	2.3448	0.4398
25	MCB	2	3	5	98,562	1.0367	2.3188	0.4418
26	MCB	2	4	4	98,561	1.0400	2.4207	0.4395
27	MCB	2	5	3	98,557	1.0363	2.3804	0.4390
28	MCB	2	6	2	98,556	1.0374	2.3557	0.4389
29	MCB	2	7	1	98,556	1.0358	2.3765	0.4403
30	MCB	2	8	0	98,555	1.0311	2.3730	0.4370
31	MCB	3	0	7	98,553	1.0225	2.2821	0.4356
32	MCB	3	1	6	98,555	1.0220	2.3161	0.4369
33	MCB	3	2	5	98,559	1.0196	2.3834	0.4443
34	MCB	3	3	4	98,559	1.0220	2.3102	0.4386
35	MCB	3	4	3	98,558	1.0217	2.3192	0.4344
36	MCB	3	5	2	98,556	1.0173	2.3275	0.4368
37	MCB	3	6	1	98,557	1.0166	2.2816	0.4367
38	MCB	3	7	0	98,556	1.0176	2.3185	0.4395
39	MCB-3	3.33	3.33	3.33	98,555	1.0217	2.3192	0.4370
40	MCB	4	0	6	98,553	1.0118	2.2842	0.4350
41	MCB	4	1	5	98,559	1.0140	2.2825	0.4364
42	MCB	4	2	4	98,558	1.0160	2.3100	0.4373

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Table 4.4: (*continued*)

No	Policy	w_1	w_2	w_3	Rejected request	Avg wait	Max wait	Sd wait
43	MCB	4	3	3	98,557	1.0160	2.3275	0.4410
44	MCB	4	4	2	98,557	1.0107	2.3275	0.4361
45	MCB	4	5	1	98,557	1.0116	2.3300	0.4325
46	MCB	4	6	0	98,554	1.0093	2.2986	0.4342
47	MCB	5	0	5	98,554	1.0099	2.3242	0.4352
48	MCB	5	1	4	98,557	1.0032	2.3200	0.4333
49	MCB	5	2	3	98,557	1.0073	2.3281	0.4331
50	MCB	5	3	2	98,556	1.0046	2.3275	0.4339
51	MCB	5	4	1	98,555	1.0073	2.3290	0.4339
52	MCB-2	5	5	0	98,555	1.0043	2.3263	0.4333
53	MCB	6	0	4	98,554	1.0011	2.3224	0.4329
54	MCB	6	1	3	98,557	1.0065	2.3145	0.4303
55	MCB	6	2	2	98,556	0.9999	2.3174	0.4318
56	MCB	6	3	1	98,554	1.0031	2.3231	0.4324
57	MCB	6	4	0	98,556	1.0010	2.2799	0.4315
58	MCB	7	0	3	98,555	1.0002	2.3281	0.4375
59	MCB	7	1	2	98,557	0.9963	2.3229	0.4308
60	MCB	7	2	1	98,555	0.9956	2.3171	0.4369
61	MCB	7	3	0	98,556	0.9944	2.3365	0.4374
62	MCB	8	0	2	98,555	0.9940	2.3215	0.4304
63	MCB	8	1	1	98,554	0.9979	2.3672	0.4332

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Table 4.4: (*continued*)

No	Policy	w_1	w_2	w_3	Rejected request	Avg wait	Max wait	Sd wait
64	MCB	8	2	0	98,556	0.9971	2.3221	0.4332
65	MCB	9	0	1	98,556	0.9914	2.1884	0.4330
66	MCB	9	1	0	98,556	0.9960	2.2027	0.4319
67	SPT	10	0	0	98,556	0.9924	2.1955	0.4308

The scheduling function refers to (3.8),$\sum w_i = 10$, w_1 is normalized processing time's weight,

w_2 is normalized deadline's weight, and w_3 is normalized arrival time's weight.

No	Policy	w_1	w_2	w_3	Rejected request	Avg wait	Max wait	Sd wait
1	FIFO	0	0	10	100,516	1.9791	2.4249	0.1105
11	EDF	0	10	0	100,161	1.7522	2.5006	0.2050
39	MCB-3	3.33	3.33	3.33	98,555	1.0217	2.3192	0.4370
52	MCB-2	5	5	0	98,555	1.0043	2.3263	0.4333
67	SPT	10	0	0	98,556	0.9924	2.1955	0.4308

Figure 4.12 and 4.13 show the density of successful data in histogram of the two data cases. Only FIFO, EDF, SPT, MCB-2, and MCB-3 are presented for comparative. MCB-3 is selected as an instance of MCB scheduling policies for fair weighting. MCB-2 ($w_1 = w_2 = 5,\ w_3 = 0$) is selected as an instance of bi-criteria policy. The probability density function (PDF) is used to measure the probability of various continuous outcomes. In the Figures, MCB-2 and MCB-3 have results nearly to SPT which has lower average waiting times than FIFO and EDF. It is recommended that FIFO and EDF have higher rejected requests than MCB-2, MCB-3, and SPT.

At scheduling level, Figure 4.14 to 4.16 present average waiting time, maximum waiting time, and Sd. waiting time of first data set of medium loaded and heavily

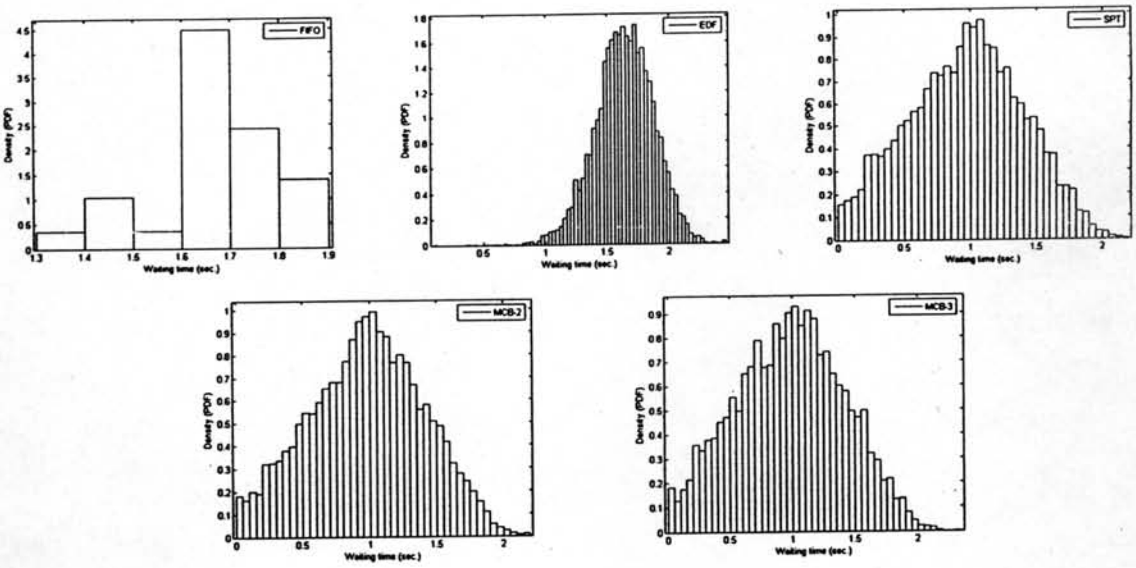

Figure 4.12: Density of successful data for medium loaded case with deadline's data histogram

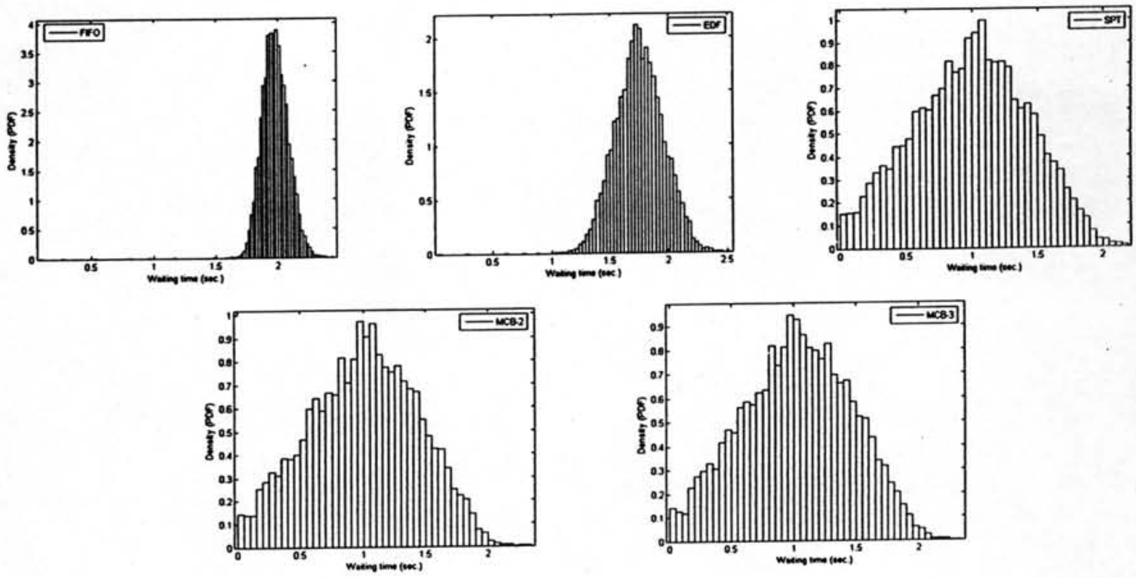

Figure 4.13: Density of successful data for heavily loaded case with deadline's data histogram

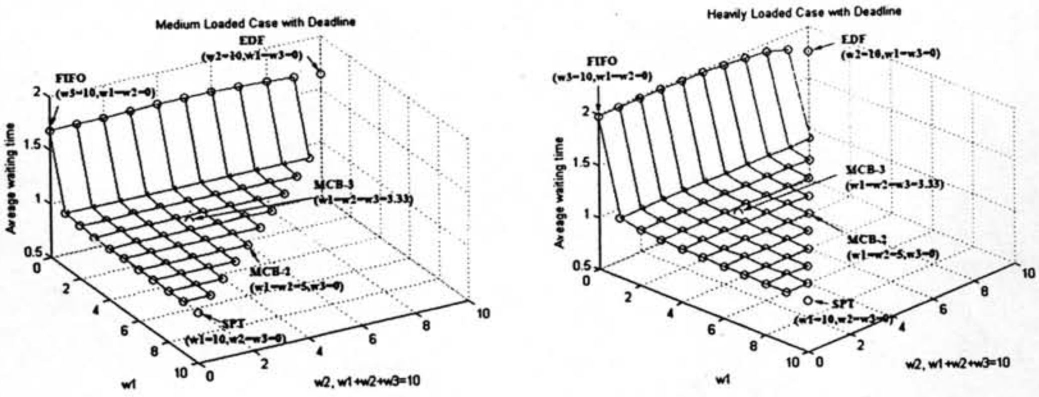

Figure 4.14: Average waiting time of medium and heavily loaded cases with deadline

loaded cases on deadline checking situation, respectively. Results of FIFO, EDF, and SPT are also represented in the Figures. For FIFO approach, w_3 equals to 10 while w_1 and w_2 equal to zero. For EDF approach, w_2 equals to 10 while w_1 and w_3 equal to zero. For SPT approach that has low average waiting time, w_1 equals to 10 while w_2 and w_3 equal to zero. In case of deadline checking, ignoring processing time by setting w_1 to zero leads high average waiting time with low standard deviation, whereas inconsistent results appear in maximum waiting time's graphs. If w_1 set to zero and w_2 has high value, this situation leads the highest maximum waiting time while varying w_2 and w_3 leads insignificant in maximum waiting time. In case w_1 set to zero and w_2, w_3 are varied, this leads insignificant in average and Sd. waiting times.

Figure 4.17 shows the request rejection's results which occur only in deadline checking case. Number of rejected request is decreased when w_1 fixed to zero, w_2 increases, and w_3 decreases. The highest rejection appears in FIFO, $w_1 = w_2 = 0,\ and\ w_3 = 10$.

Comparative waiting time consumption of each scheduling policy at scheduling level are presented in two dimensional graphs, Figure 4.18 to 4.19. In each graph, There are 67 scheduling policies, presented on X-axis, consist of FIFO at 1, EDF at 11, SPT at 67, MCB-2 at 52, MCB-3 at 39, and the remainders of MCBs. For deadline checking

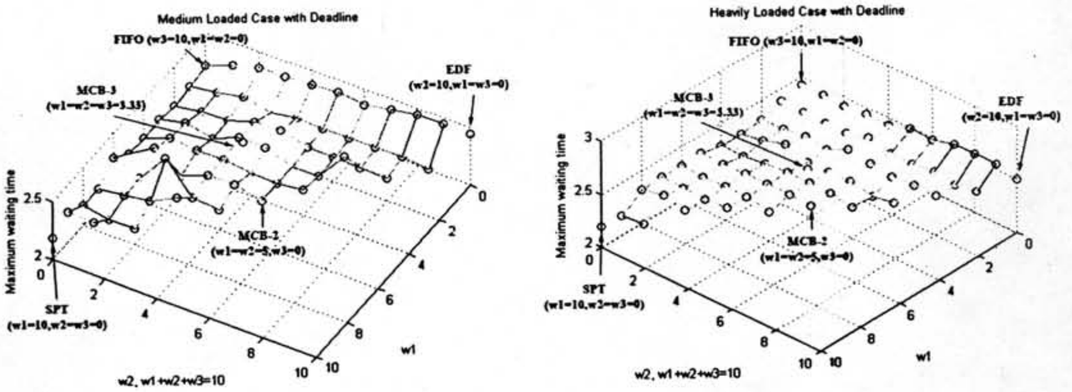

Figure 4.15: Maximum waiting time of medium and heavily loaded cases with deadline

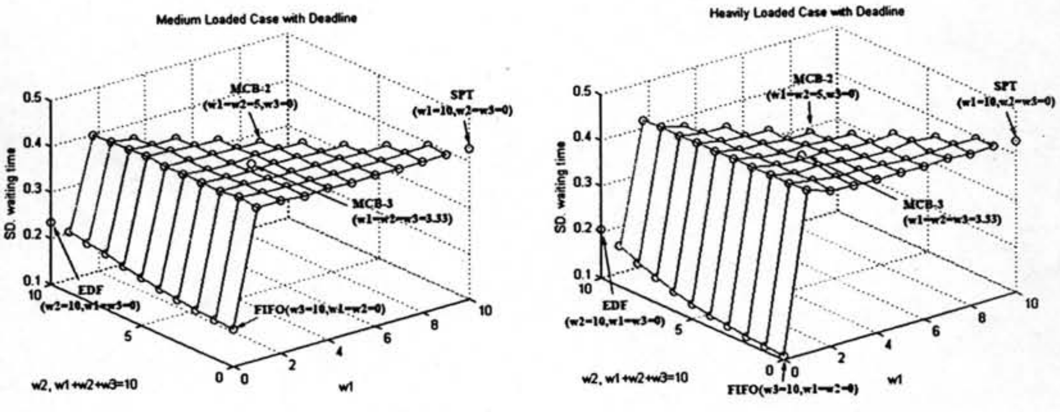

Figure 4.16: Standard deviation waiting time of medium and heavily loaded cases with deadline

case, FIFO and EDF still have the same direction with the lowest Sd. waiting time and high average waiting time. Average and Sd. waiting times of SPT, MCB-2, and MCB-3 have significant changes, lower maximum waiting time and higher Sd. waiting time, compared with FIFO and EDF.

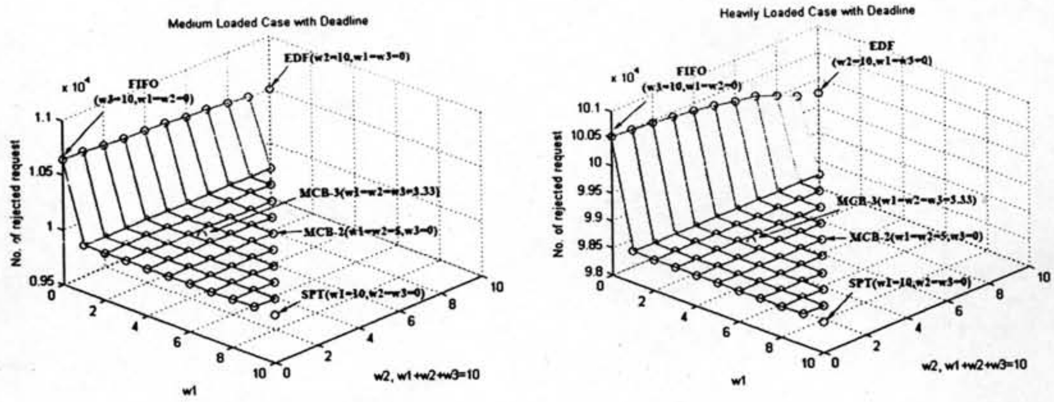

Figure 4.17: Number of rejected request of medium and heavily loaded cases with deadline

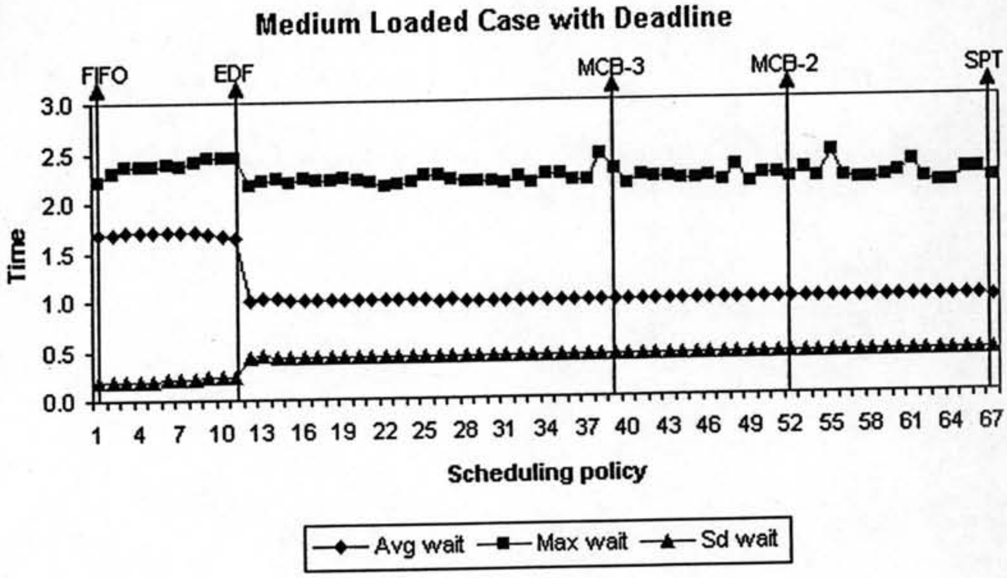

Figure 4.18: Medium loaded case with deadline checking's time consumed

4.3.2 At Performance Measurement Level

Non-deadline Checking Situation

From the scheduling level, the waiting time information are exploited as criteria of the performance measurement function, (3.9), of each scheduling policy. Weight aggregation

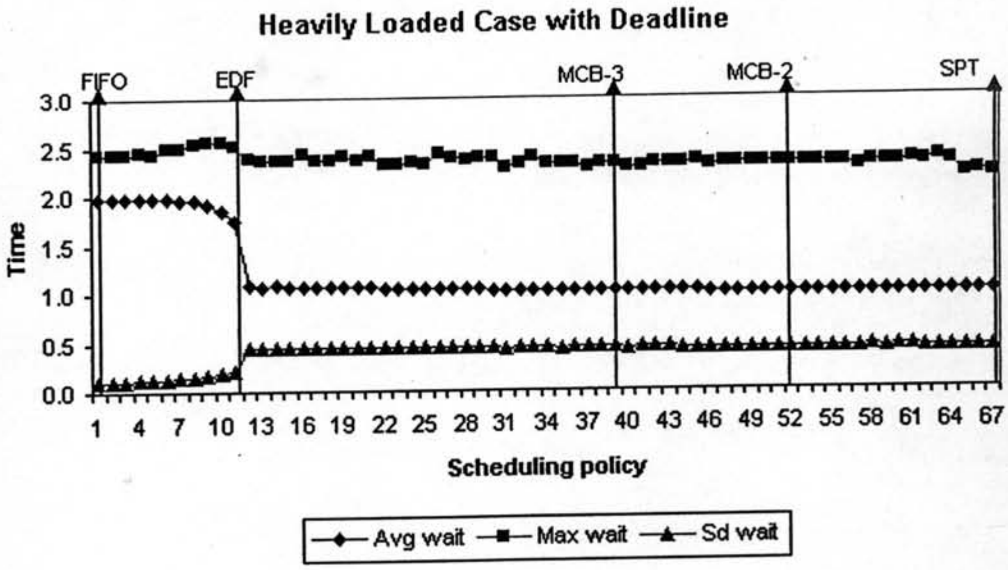

Figure 4.19: Heavily loaded case with deadline checking's time consumed

technique is applied to each policy to conduct the conflicting criteria into a scalar value, follows (3.9). Two MCB instances: MCB-2 and MCB-3; are also chosen to compare with FIFO, EDF, and SPT. By varying weight values, sixty-six results are calculated from the raw data and presented in Table 4.5 and 4.6 for medium loaded and heavily loaded cases, respectively. Some raw data of the performance measurement result of both cases are selected as examples. In this paper, we have the objective to minimize average, maximum, and Sd. waiting times, therefore the less summation is the optimal policy.

Table 4.5: Performance result of medium loaded case without deadline

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
1	0.0	0.0	1.0	0.6047	0.6047	1.0000	0.6180	0.6061
2	0.0	0.1	0.9	0.6045	0.6045	1.0000	0.6244	0.6101
3	0.0	0.2	0.8	0.6043	0.6043	1.0000	0.6309	0.6142
4	0.0	0.3	0.7	0.6040	0.6040	1.0000	0.6373	0.6183
5	0.0	0.4	0.6	0.6038	0.6038	1.0000	0.6437	0.6223
6	0.0	0.5	0.5	0.6036	0.6036	1.0000	0.6501	0.6264
7	0.0	0.6	0.4	0.6033	0.6033	1.0000	0.6566	0.6304
8	0.0	0.7	0.3	0.6031	0.6031	1.0000	0.6630	0.6345
9	0.0	0.8	0.2	0.6028	0.6028	1.0000	0.6694	0.6385
10	0.0	0.9	0.1	0.6026	0.6026	1.0000	0.6758	0.6426
11	0.0	1.0	0.0	0.6024	0.6024	1.0000	0.6822	0.6466
12	0.1	0.0	0.9	0.6443	0.6443	0.9891	0.6534	0.6426
13	0.1	0.1	0.8	0.6440	0.6440	0.9891	0.6598	0.6467
14	0.1	0.2	0.7	0.6438	0.6438	0.9891	0.6662	0.6507
15	0.1	0.3	0.6	0.6436	0.6436	0.9891	0.6726	0.6548
16	0.1	0.4	0.5	0.6433	0.6433	0.9891	0.6791	0.6588
17	0.1	0.5	0.4	0.6431	0.6431	0.9891	0.6855	0.6629
18	0.1	0.6	0.3	0.6428	0.6428	0.9891	0.6919	0.6669
19	0.1	0.7	0.2	0.6426	0.6426	0.9891	0.6983	0.6710
20	0.1	0.8	0.1	0.6424	0.6424	0.9891	0.7047	0.6751
21	0.1	0.9	0.0	0.6421	0.6421	0.9891	0.7112	0.6791

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Table 4.5: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
22	0.2	0.0	0.8	0.6838	0.6838	0.9782	0.6887	0.6792
23	0.2	0.1	0.7	0.6836	0.6836	0.9782	0.6951	0.6832
24	0.2	0.2	0.6	0.6833	0.6833	0.9782	0.7016	0.6873
25	0.2	0.3	0.5	0.6831	0.6831	0.9782	0.7080	0.6913
26	0.2	0.4	0.4	0.6828	0.6828	0.9782	0.7144	0.6954
27	0.2	0.5	0.3	0.6826	0.6826	0.9782	0.7208	0.6994
28	0.2	0.6	0.2	0.6824	0.6824	0.9782	0.7272	0.7035
29	0.2	0.7	0.1	0.6821	0.6821	0.9782	0.7337	0.7075
30	0.2	0.8	0.0	0.6819	0.6819	0.9782	0.7401	0.7116
31	0.3	0.0	0.7	0.7233	0.7233	0.9672	0.7241	0.7157
32	0.3	0.1	0.6	0.7231	0.7231	0.9672	0.7305	0.7198
33	0.3	0.2	0.5	0.7228	0.7228	0.9672	0.7369	0.7238
34	0.3	0.3	0.4	0.7226	0.7226	0.9672	0.7433	0.7279
35	0.3	0.4	0.3	0.7224	0.7224	0.9672	0.7497	0.7319
36	0.3	0.5	0.2	0.7221	0.7221	0.9672	0.7562	0.7360
37	0.3	0.6	0.1	0.7219	0.7219	0.9672	0.7626	0.7400
38	0.3	0.7	0.0	0.7217	0.7217	0.9672	0.7690	0.7441
39	0.4	0.0	0.6	0.7628	0.7628	0.9563	0.7594	0.7522
40	0.4	0.1	0.5	0.7626	0.7626	0.9563	0.7658	0.7563
41	0.4	0.2	0.4	0.7624	0.7624	0.9563	0.7722	0.7604
42	0.4	0.3	0.3	0.7621	0.7621	0.9563	0.7787	0.7644

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Table 4.5: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
43	0.4	0.4	0.2	0.7619	0.7619	0.9563	0.7851	0.7685
44	0.4	0.5	0.1	0.7617	0.7617	0.9563	0.7915	0.7725
45	0.4	0.6	0.0	0.7614	0.7614	0.9563	0.7979	0.7766
46	0.5	0.0	0.5	0.8024	0.8024	0.9454	0.7947	0.7888
47	0.5	0.1	0.4	0.8021	0.8021	0.9454	0.8012	0.7928
48	0.5	0.2	0.3	0.8019	0.8019	0.9454	0.8076	0.7969
49	0.5	0.3	0.2	0.8017	0.8017	0.9454	0.8140	0.8009
50	0.5	0.4	0.1	0.8014	0.8014	0.9454	0.8204	0.8050
51	0.5	0.5	0.0	0.8012	0.8012	0.9454	0.8269	0.8091
52	0.6	0.0	0.4	0.8419	0.8419	0.9345	0.8301	0.8253
53	0.6	0.1	0.3	0.8417	0.8417	0.9345	0.8365	0.8294
54	0.6	0.2	0.2	0.8414	0.8414	0.9345	0.8429	0.8334
55	0.6	0.3	0.1	0.8412	0.8412	0.9345	0.8494	0.8375
56	0.6	0.4	0.0	0.8409	0.8409	0.9345	0.8558	0.8415
57	0.7	0.0	0.3	0.8814	0.8814	0.9236	0.8654	0.8619
58	0.7	0.1	0.2	0.8812	0.8812	0.9236	0.8719	0.8659
59	0.7	0.2	0.1	0.8809	0.8809	0.9236	0.8783	0.8700
60	0.7	0.3	0.0	0.8807	0.8807	0.9236	0.8847	0.8740
61	0.8	0.0	0.2	0.9209	0.9209	0.9127	0.9008	0.8984
62	0.8	0.1	0.1	0.9207	0.9207	0.9127	0.9072	0.9025
63	0.8	0.2	0.0	0.9205	0.9205	0.9127	0.9136	0.9065

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Table 4.5: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
64	0.9	0.0	0.1	0.9605	0.9605	0.9017	0.9361	0.9349
65	0.9	0.1	0.0	0.9602	0.9602	0.9017	0.9426	0.9390
66	1.0	0.0	0.0	1.0000	1.0000	0.8908	0.9715	0.9715

The performance measurement function refers to (3.9), $\sum \lambda_i = 1$, λ_1 is normalized average waiting time's weight,

λ_2 is normalized maximum waiting time's weight, and λ_3 is normalized Sd. waiting time's weight.

Table 4.6: Performance result of heavily loaded case without deadline

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
1	0.0	0.0	1.0	0.9309	0.9309	1.0000	0.9331	0.9311
2	0.0	0.1	0.9	0.9313	0.9313	1.0000	0.9342	0.9318
3	0.0	0.2	0.8	0.9316	0.9316	1.0000	0.9353	0.9325
4	0.0	0.3	0.7	0.9320	0.9320	1.0000	0.9364	0.9333
5	0.0	0.4	0.6	0.9323	0.9323	1.0000	0.9375	0.9340
6	0.0	0.5	0.5	0.9327	0.9327	1.0000	0.9386	0.9347
7	0.0	0.6	0.4	0.9331	0.9331	1.0000	0.9397	0.9354
8	0.0	0.7	0.3	0.9334	0.9334	1.0000	0.9407	0.9361
9	0.0	0.8	0.2	0.9338	0.9338	1.0000	0.9418	0.9369
10	0.0	0.9	0.1	0.9341	0.9341	1.0000	0.9429	0.9376
11	0.0	1.0	0.0	0.9345	0.9345	1.0000	0.9440	0.9383
12	0.1	0.0	0.9	0.9378	0.9378	0.9919	0.9376	0.9368
13	0.1	0.1	0.8	0.9382	0.9382	0.9919	0.9387	0.9375

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Table 4.6: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
14	0.1	0.2	0.7	0.9385	0.9385	0.9919	0.9398	0.9383
15	0.1	0.3	0.6	0.9389	0.9389	0.9919	0.9409	0.9390
16	0.1	0.4	0.5	0.9392	0.9392	0.9919	0.9419	0.9397
17	0.1	0.5	0.4	0.9396	0.9396	0.9919	0.9430	0.9404
18	0.1	0.6	0.3	0.9400	0.9400	0.9919	0.9441	0.9411
19	0.1	0.7	0.2	0.9403	0.9403	0.9919	0.9452	0.9419
20	0.1	0.8	0.1	0.9407	0.9407	0.9919	0.9463	0.9426
21	0.1	0.9	0.0	0.9410	0.9411	0.9919	0.9474	0.9433
22	0.2	0.0	0.8	0.9447	0.9447	0.9839	0.9421	0.9426
23	0.2	0.1	0.7	0.9451	0.9451	0.9839	0.9432	0.9433
24	0.2	0.2	0.6	0.9454	0.9454	0.9839	0.9442	0.9440
25	0.2	0.3	0.5	0.9458	0.9458	0.9839	0.9453	0.9447
26	0.2	0.4	0.4	0.9462	0.9462	0.9839	0.9464	0.9454
27	0.2	0.5	0.3	0.9465	0.9465	0.9839	0.9475	0.9462
28	0.2	0.6	0.2	0.9469	0.9469	0.9839	0.9486	0.9469
29	0.2	0.7	0.1	0.9472	0.9472	0.9839	0.9497	0.9476
30	0.2	0.8	0.0	0.9476	0.9476	0.9839	0.9507	0.9483
31	0.3	0.0	0.7	0.9516	0.9516	0.9758	0.9465	0.9483
32	0.3	0.1	0.6	0.9520	0.9520	0.9758	0.9476	0.9490
33	0.3	0.2	0.5	0.9523	0.9523	0.9758	0.9487	0.9497
34	0.3	0.3	0.4	0.9527	0.9527	0.9758	0.9498	0.9504

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Table 4.6: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
35	0.3	0.4	0.3	0.9531	0.9531	0.9758	0.9509	0.9512
36	0.3	0.5	0.2	0.9534	0.9534	0.9758	0.9520	0.9519
37	0.3	0.6	0.1	0.9538	0.9538	0.9758	0.9530	0.9526
38	0.3	0.7	0.0	0.9541	0.9542	0.9758	0.9541	0.9533
39	0.4	0.0	0.6	0.9585	0.9585	0.9678	0.9510	0.9540
40	0.4	0.1	0.5	0.9589	0.9589	0.9678	0.9521	0.9547
41	0.4	0.2	0.4	0.9593	0.9593	0.9678	0.9532	0.9554
42	0.4	0.3	0.3	0.9596	0.9596	0.9678	0.9543	0.9562
43	0.4	0.4	0.2	0.9600	0.9600	0.9678	0.9553	0.9569
44	0.4	0.5	0.1	0.9603	0.9603	0.9678	0.9564	0.9576
45	0.4	0.6	0.0	0.9607	0.9607	0.9678	0.9575	0.9583
46	0.5	0.0	0.5	0.9654	0.9654	0.9597	0.9555	0.9597
47	0.5	0.1	0.4	0.9658	0.9658	0.9597	0.9565	0.9604
48	0.5	0.2	0.3	0.9662	0.9662	0.9597	0.9576	0.9612
49	0.5	0.3	0.2	0.9665	0.9665	0.9597	0.9587	0.9619
50	0.5	0.4	0.1	0.9669	0.9669	0.9597	0.9598	0.9626
51	0.5	0.5	0.0	0.9672	0.9673	0.9597	0.9609	0.9633
52	0.6	0.0	0.4	0.9724	0.9724	0.9516	0.9599	0.9655
53	0.6	0.1	0.3	0.9727	0.9727	0.9516	0.9610	0.9662
54	0.6	0.2	0.2	0.9731	0.9731	0.9516	0.9621	0.9669
55	0.6	0.3	0.1	0.9734	0.9734	0.9516	0.9632	0.9676

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Table 4.6: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
56	0.6	0.4	0.0	0.9738	0.9738	0.9516	0.9643	0.9683
57	0.7	0.0	0.3	0.9793	0.9793	0.9436	0.9644	0.9712
58	0.7	0.1	0.2	0.9796	0.9796	0.9436	0.9655	0.9719
59	0.7	0.2	0.1	0.9800	0.9800	0.9436	0.9666	0.9726
60	0.7	0.3	0.0	0.9803	0.9804	0.9436	0.9676	0.9733
61	0.8	0.0	0.2	0.9862	0.9862	0.9355	0.9689	0.9769
62	0.8	0.1	0.1	0.9865	0.9865	0.9355	0.9699	0.9776
63	0.8	0.2	0.0	0.9869	0.9869	0.9355	0.9710	0.9783
64	0.9	0.0	0.1	0.9931	0.9931	0.9274	0.9733	0.9826
65	0.9	0.1	0.0	0.9934	0.9935	0.9274	0.9744	0.9834
66	1.0	0.0	0.0	1.0000	1.0000	0.9194	0.9778	0.9884

The performance measurement function refers to (3.9), $\sum \lambda_i = 1$, λ_1 is normalized average waiting time's weight, λ_2 is normalized maximum waiting time's weight, and λ_3 is normalized Sd. waiting time's weight.

The performance measurement results of each running case are plotted in Figure 4.20 and 4.21 in order to distinct the preferred policy. On the Figures, the preferred policy is indicated on each range of the graph. For medium loaded case, Figure 4.20 shows that MCB-2 and MCB-3 have an advantage on the other policies in range 46 ($\lambda_1 = \lambda_3 = 0.5, \lambda_2 = 0$) to 62 ($\lambda_1 = 0.8, \lambda_2 = \lambda_3 = 0.1$), especially, MCB-3 is better than MCB-2. Table 4.7 summaries the preference policy of medium loaded case. Figure 4.21 shows that heavily loaded case has result in a same direction as medium loaded case, but in the lower range, 31 ($\lambda_1 = 0.3, \lambda_2 = 0, \lambda_3 = 0.7$) to 49 ($\lambda_1 = 0.5, \lambda_2 = 0.3, \lambda_3 = 0.2$) and MCB-2 has lower values than MCB-3 on their advantage range. Table 4.8 summaries the preference policy of heavily loaded case. Moreover, it can be observed, in Figure 4.20 and 4.21, that the result of MCB-3 is the most predictable among the comparative policies as shown as the smooth exponential curve.

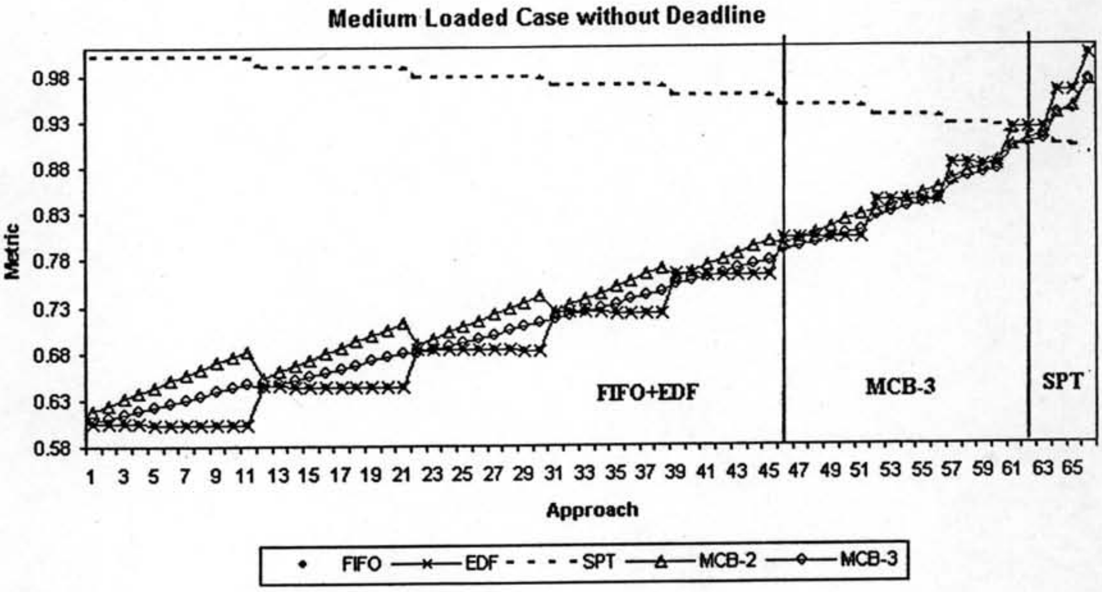

Figure 4.20: Performance measurement of medium loaded case without deadline

Comparing performance metrics of medium loaded (M) and heavily loaded (H) cases is presented in Figure 4.22. Varying weights in both cases make the graphs steepened. Especially, the graphs of medium loaded case are more steepened than the graphs of heavily loaded case. This indicates that varying weights in the heavily loaded situation has less effect than in medium loaded situation. Moreover, the figure shows that MCB-3 works better than MCB-2 in medium loaded case. On the other hand, MCB-2 works better than MCB-3 in heavily loaded case. Nevertheless, the different between MCB-2 and MCB-3 in heavily loaded case is less than medium loaded case.

Table 4.7: Preference policy of medium loaded case without deadline

Starting weights (λ_1,λ_2,λ_3)	Ending weights (λ_1,λ_2,λ_3)	Preference policy
(0.3,0.0,0.7)	(0.3,0.1,0.6)	MCB-3>(FIFO=EDF)>MCB-2>SPT
(0.3,0.2,0.5)	(0.3,0.7,0.0)	(FIFO=EDF)>MCB-3>MCB-2>SPT
(0.4,0.0,0.6)		MCB-3>MCB-2>(FIFO=EDF)>SPT
(0.4,0.1,0.5)	(0.4,0.2,0.4)	MCB-3>(FIFO=EDF)>MCB-2>SPT
(0.4,0.3,0.3)	(0.4,0.6,0.0)	(FIFO=EDF)>MCB-3>MCB-2>SPT
(0.5,0.0,0.5)	(0.5,0.1,0.4)	MCB-3>MCB-2>(FIFO=EDF)>SPT
(0.5,0.2,0.3)	(0.5,0.3,0.2)	MCB-3>(FIFO=EDF)>MCB-2>SPT
(0.5,0.4,0.1)	(0.5,0.5,0.0)	(FIFO=EDF)>MCB-3>MCB-2>SPT
(0.6,0.0,0.4)	(0.6,0.1,0.3)	MCB-3>MCB-2>(FIFO=EDF)>SPT
(0.6,0.2,0.2)	(0.6,0.4,0.0)	MCB-3>(FIFO=EDF)>MCB-2>SPT
(0.7,0.0,0.3)	(0.7,0.2,0.1)	MCB-3>MCB-2>(FIFO=EDF)>SPT
(0.7,0.3,0.0)		MCB-3>(FIFO=EDF)>MCB-2>SPT
(0.8,0.0,0.2)	(0.8,0.1,0.1)	MCB-3>MCB-2>SPT>(FIFO=EDF)
(0.8,0.2,0.0)		MCB-3>SPT>MCB-2>(FIFO=EDF)
(0.9,0.0,0.1)	(0.9,0.1,0.0)	SPT>MCB-3>MCB-2>(FIFO=EDF)
(1.0,0.0,0.0)		SPT>(MCB-3=MCB-2)>(FIFO=EDF)

Table 4.8: Preference policy of heavily loaded case without deadline

Starting weights (λ_1,λ_2,λ_3)	Ending weights (λ_1,λ_2,λ_3)	Preference policy
(0.0,0.0,1.0)	(0.0,1.0,0.0)	(FIFO=EDF)>MCB-3>MCB-2>SPT
(0.1,0.0,0.9)		MCB-3>MCB-2>(FIFO=EDF)>SPT
(0.1,0.1,0.8)	(0.1,0.2,0.7)	MCB-3>(FIFO=EDF)>MCB-2>SPT
(0.1,0.3,0.6)	(0.1,0.9,0.0)	(FIFO=EDF)>MCB-3> MCB-2>SPT
(0.2,0.0,0.8)	(0.2,0.1,0,7)	MCB-2>MCB-3>(FIFO=EDF)>SPT
(0.2,0.2,0.6)	(0.2,0.3,0.5)	MCB-3>MCB-2>(FIFO=EDF)>SPT
(0.2,0.4,0.4)	(0.2,0.5,0.3)	MCB-3>(FIFO=EDF)> MCB-2>SPT
(0.2,0.6,0.2)		(MCB-3=FIFO=EDF)>MCB-2> SPT
(0.2,0.7,0.1)	(0.2,0.8,0.1)	(FIFO=EDF)>MCB-3> MCB-2>SPT
(0.3,0.0,0.7)	(0.3,0.4,0.3)	MCB-2>MCB-3>(FIFO=EDF)>SPT
(0.3,0.5,0.2)	(0.3,0.7,0.0)	MCB-3>MCB-2>(FIFO=EDF)>SPT
(0.4,0.0,0.6)	(0.4,0.6,0.0)	MCB-2>MCB-3>(FIFO=EDF)>SPT
(0.5,0.0,0.5)		MCB-2>(MCB-3=SPT)>(FIFO=EDF)
(0.5,0.1,0.4)	(0.5,0.3,0.2)	MCB-2>SPT>MCB-3>(FIFO=EDF)
(0.5,0.4,0.1)	(1.0,0.0,0.0)	SPT>MCB-2>MCB-3>(FIFO=EDF)

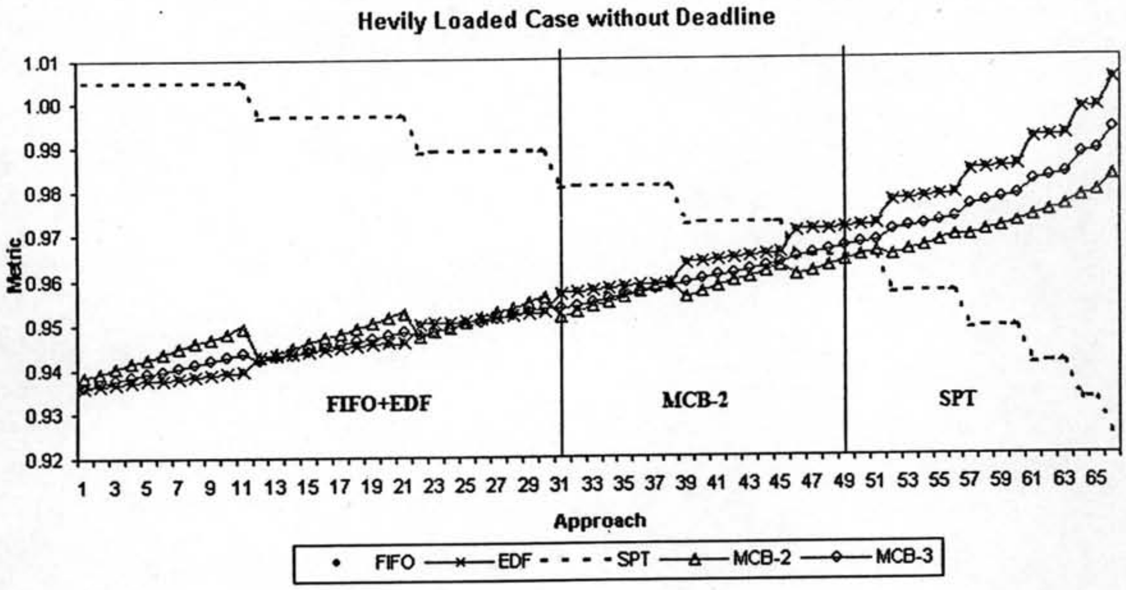

Figure 4.21: Performance measurement of heavily loaded case without deadline

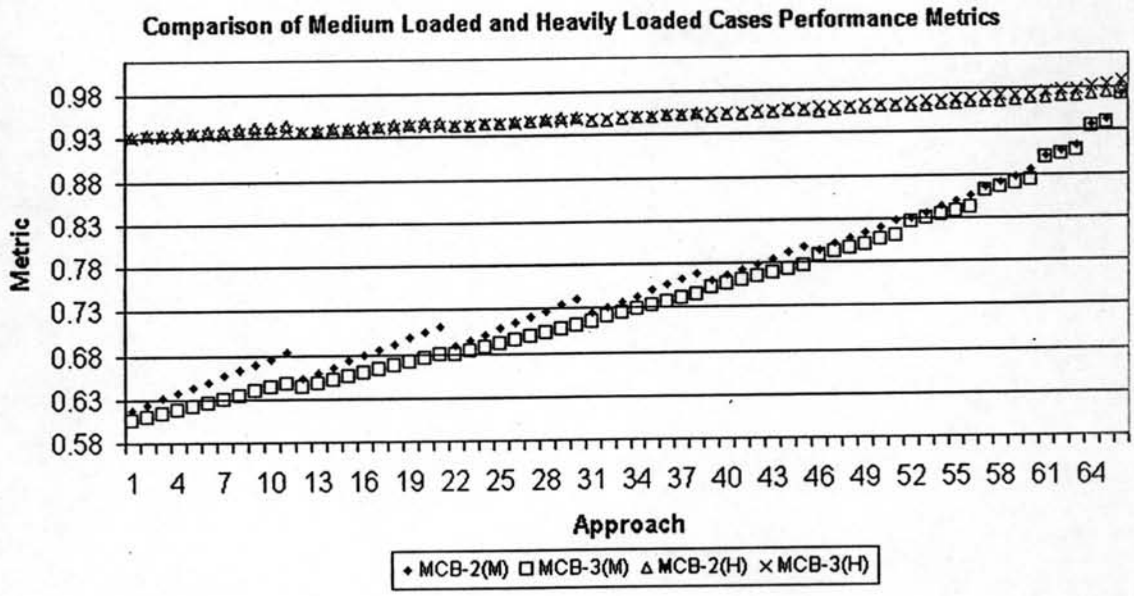

Figure 4.22: Comparison of medium loaded and heavily loaded cases without deadline's performance metrics

Deadline Checking Situation

In this dissertation, the waiting time information from the scheduling level are exploited as criteria of the performance measurement function, (3.9), of each scheduling policy, in order to compare the performance results with non-deadline checking cases by ignoring number of rejected request. To measure performance of each scheduling policy, weight aggregation technique is applied to each policy to conduct the conflicting criteria into a scalar value, follows (3.9). Two MCB instances: MCB-2 and MCB-3; are also chosen to compare with FIFO, EDF, and SPT. By varying weight values, sixty-six results are calculated from the raw data and presented in Table 4.9 and 4.10 for medium loaded and heavily loaded cases, respectively. Some raw data of the performance measurement result of both cases are selected as examples. In this paper, we have the objective to minimize average, maximum, and Sd. waiting times, therefore the less summation is the optimal policy.

Table 4.9: Performance result of medium loaded case with deadline

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
1	0.0	0.0	1.0	0.4184	0.5453	0.9917	0.9845	1.0000
2	0.0	0.1	0.9	0.4668	0.5908	0.9817	0.9756	0.9942
3	0.0	0.2	0.8	0.5152	0.6363	0.9717	0.9667	0.9884
4	0.0	0.3	0.7	0.5636	0.6817	0.9617	0.9578	0.9826
5	0.0	0.4	0.6	0.6120	0.7272	0.9517	0.9488	0.9768
6	0.0	0.5	0.5	0.6603	0.7727	0.9417	0.9399	0.9711
7	0.0	0.6	0.4	0.7087	0.8181	0.9317	0.9310	0.9653
8	0.0	0.7	0.3	0.7571	0.8636	0.9217	0.9221	0.9595

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Table 4.9: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
9	0.0	0.8	0.2	0.8055	0.9091	0.9118	0.9132	0.9537
10	0.0	0.9	0.1	0.8539	0.9545	0.9018	0.9043	0.9479
11	0.0	1.0	0.0	0.9023	1.0000	0.8918	0.8953	0.9421
12	0.1	0.0	0.9	0.4765	0.5884	0.9500	0.9441	0.9581
13	0.1	0.1	0.8	0.5249	0.6338	0.9401	0.9352	0.9523
14	0.1	0.2	0.7	0.5733	0.6793	0.9301	0.9263	0.9466
15	0.1	0.3	0.6	0.6217	0.7248	0.9201	0.9174	0.9408
16	0.1	0.4	0.5	0.6701	0.7702	0.9101	0.9085	0.9350
17	0.1	0.5	0.4	0.7185	0.8157	0.9001	0.8996	0.9292
18	0.1	0.6	0.3	0.7669	0.8612	0.8901	0.8906	0.9234
19	0.1	0.7	0.2	0.8153	0.9066	0.8801	0.8817	0.9176
20	0.1	0.8	0.1	0.8637	0.9521	0.8701	0.8728	0.9118
21	0.1	0.9	0.0	0.9121	0.9976	0.8601	0.8639	0.9060
22	0.2	0.0	0.8	0.5347	0.6314	0.9084	0.9038	0.9163
23	0.2	0.1	0.7	0.5831	0.6769	0.8984	0.8949	0.9105
24	0.2	0.2	0.6	0.6315	0.7224	0.8884	0.8859	0.9047
25	0.2	0.3	0.5	0.6799	0.7678	0.8785	0.8770	0.8989
26	0.2	0.4	0.4	0.7283	0.8133	0.8685	0.8681	0.8931
27	0.2	0.5	0.3	0.7767	0.8588	0.8585	0.8592	0.8873
28	0.2	0.6	0.2	0.8251	0.9042	0.8485	0.8503	0.8815
29	0.2	0.7	0.1	0.8735	0.9497	0.8385	0.8414	0.8757

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Table 4.9: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
30	0.2	0.8	0.0	0.9219	0.9952	0.8285	0.8324	0.8700
31	0.3	0.0	0.7	0.5929	0.6745	0.8668	0.8634	0.8744
32	0.3	0.1	0.6	0.6413	0.7199	0.8568	0.8545	0.8686
33	0.3	0.2	0.5	0.6896	0.7654	0.8468	0.8456	0.8628
34	0.3	0.3	0.4	0.7380	0.8109	0.8368	0.8367	0.8570
35	0.3	0.4	0.3	0.7864	0.8563	0.8268	0.8277	0.8513
36	0.3	0.5	0.2	0.8348	0.9018	0.8168	0.8188	0.8455
37	0.3	0.6	0.1	0.8832	0.9473	0.8069	0.8099	0.8397
38	0.3	0.7	0.0	0.9316	0.9927	0.7969	0.8010	0.8339
39	0.4	0.0	0.6	0.6510	0.7175	0.8252	0.8230	0.8325
40	0.4	0.1	0.5	0.6994	0.7630	0.8152	0.8141	0.8268
41	0.4	0.2	0.4	0.7478	0.8084	0.8052	0.8052	0.8210
42	0.4	0.3	0.3	0.7962	0.8539	0.7952	0.7963	0.8152
43	0.4	0.4	0.2	0.8446	0.8994	0.7852	0.7874	0.8094
44	0.4	0.5	0.1	0.8930	0.9448	0.7752	0.7785	0.8036
45	0.4	0.6	0.0	0.9414	0.9903	0.7652	0.7695	0.7978
46	0.5	0.0	0.5	0.7092	0.7605	0.7835	0.7827	0.7907
47	0.5	0.1	0.4	0.7576	0.8060	0.7736	0.7737	0.7849
48	0.5	0.2	0.3	0.8060	0.8515	0.7636	0.7648	0.7791
49	0.5	0.3	0.2	0.8544	0.8969	0.7536	0.7559	0.7733
50	0.5	0.4	0.1	0.9028	0.9424	0.7436	0.7470	0.7675

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Table 4.9: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
51	0.5	0.5	0.0	0.9512	0.9879	0.7336	0.7381	0.7617
52	0.6	0.0	0.4	0.7673	0.8036	0.7419	0.7423	0.7488
53	0.6	0.1	0.3	0.8157	0.8491	0.7319	0.7334	0.7430
54	0.6	0.2	0.2	0.8641	0.8945	0.7219	0.7245	0.7372
55	0.6	0.3	0.1	0.9125	0.9400	0.7119	0.7155	0.7314
56	0.6	0.4	0.0	0.9609	0.9855	0.7020	0.7066	0.7257
57	0.7	0.0	0.3	0.8255	0.8466	0.7003	0.7019	0.7070
58	0.7	0.1	0.2	0.8739	0.8921	0.6903	0.6930	0.7012
59	0.7	0.2	0.1	0.9223	0.9376	0.6803	0.6841	0.6954
60	0.7	0.3	0.0	0.9707	0.9830	0.6703	0.6752	0.6896
61	0.8	0.0	0.2	0.8837	0.8897	0.6587	0.6616	0.6651
62	0.8	0.1	0.1	0.9321	0.9351	0.6487	0.6526	0.6593
63	0.8	0.2	0.0	0.9805	0.9806	0.6387	0.6437	0.6535
64	0.9	0.0	0.1	0.9418	0.9327	0.6170	0.6212	0.6232
65	0.9	0.1	0.0	0.9902	0.9782	0.6070	0.6123	0.6174
66	1.0	0.0	0.0	1.0000	0.9758	0.5754	0.5808	0.5814

The performance measurement function refers to (3.9), $\sum \lambda_i = 1$, λ_1 is normalized average waiting time's weight, λ_2 is normalized maximum waiting time's weight, and λ_3 is normalized Sd. waiting time's weight.

Table 4.10: Performance result of heavily loaded case with deadline

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
1	0.0	0.0	1.0	0.2529	0.4691	0.9858	0.9915	1.0000
2	0.0	0.1	0.9	0.3245	0.5222	0.9750	0.9854	0.9927
3	0.0	0.2	0.8	0.3962	0.5753	0.9642	0.9793	0.9855
4	0.0	0.3	0.7	0.4679	0.6284	0.9535	0.9732	0.9782
5	0.0	0.4	0.6	0.5396	0.6815	0.9427	0.9670	0.9710
6	0.0	0.5	0.5	0.6113	0.7346	0.9319	0.9609	0.9637
7	0.0	0.6	0.4	0.6830	0.7876	0.9211	0.9548	0.9565
8	0.0	0.7	0.3	0.7547	0.8407	0.9103	0.9487	0.9492
9	0.0	0.8	0.2	0.8264	0.8938	0.8996	0.9425	0.9420
10	0.0	0.9	0.1	0.8980	0.9469	0.8888	0.9364	0.9347
11	0.0	1.0	0.0	0.9697	1.0000	0.8780	0.9303	0.9275
12	0.1	0.0	0.9	0.3276	0.5107	0.9374	0.9431	0.9516
13	0.1	0.1	0.8	0.3993	0.5638	0.9266	0.9370	0.9444
14	0.1	0.2	0.7	0.4709	0.6169	0.9158	0.9309	0.9371
15	0.1	0.3	0.6	0.5426	0.6700	0.9050	0.9248	0.9299
16	0.1	0.4	0.5	0.6143	0.7231	0.8942	0.9186	0.9226
17	0.1	0.5	0.4	0.6860	0.7762	0.8835	0.9125	0.9154
18	0.1	0.6	0.3	0.7577	0.8293	0.8727	0.9064	0.9081
19	0.1	0.7	0.2	0.8294	0.8824	0.8619	0.9003	0.9008
20	0.1	0.8	0.1	0.9011	0.9354	0.8511	0.8941	0.8936
21	0.1	0.9	0.0	0.9728	0.9885	0.8403	0.8880	0.8863

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Table 4.10: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
22	0.2	0.0	0.8	0.4023	0.5524	0.8889	0.8947	0.9032
23	0.2	0.1	0.7	0.4740	0.6054	0.8782	0.8886	0.8960
24	0.2	0.2	0.6	0.5457	0.6585	0.8674	0.8825	0.8887
25	0.2	0.3	0.5	0.6173	0.7116	0.8566	0.8763	0.8815
26	0.2	0.4	0.4	0.6890	0.7647	0.8458	0.8702	0.8742
27	0.2	0.5	0.3	0.7607	0.8178	0.8350	0.8641	0.8670
28	0.2	0.6	0.2	0.8324	0.8709	0.8242	0.8580	0.8597
29	0.2	0.7	0.1	0.9041	0.9240	0.8135	0.8519	0.8525
30	0.2	0.8	0.0	0.9758	0.9771	0.8027	0.8457	0.8452
31	0.3	0.0	0.7	0.4770	0.5940	0.8405	0.8463	0.8549
32	0.3	0.1	0.6	0.5487	0.6471	0.8297	0.8402	0.8476
33	0.3	0.2	0.5	0.6204	0.7002	0.8189	0.8341	0.8404
34	0.3	0.3	0.4	0.6921	0.7532	0.8082	0.8279	0.8331
35	0.3	0.4	0.3	0.7637	0.8063	0.7974	0.8218	0.8259
36	0.3	0.5	0.2	0.8354	0.8594	0.7866	0.8157	0.8186
37	0.3	0.6	0.1	0.9071	0.9125	0.7758	0.8096	0.8113
38	0.3	0.7	0.0	0.9788	0.9656	0.7650	0.8034	0.8041
39	0.4	0.0	0.6	0.5517	0.6356	0.7921	0.7979	0.8065
40	0.4	0.1	0.5	0.6234	0.6887	0.7813	0.7918	0.7992
41	0.4	0.2	0.4	0.6951	0.7418	0.7705	0.7857	0.7920
42	0.4	0.3	0.3	0.7668	0.7949	0.7597	0.7795	0.7847

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Table 4.10: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
43	0.4	0.4	0.2	0.8385	0.8480	0.7489	0.7734	0.7775
44	0.4	0.5	0.1	0.9101	0.9011	0.7382	0.7673	0.7702
45	0.4	0.6	0.0	0.9818	0.9541	0.7274	0.7612	0.7630
46	0.5	0.0	0.5	0.6264	0.6772	0.7436	0.7495	0.7581
47	0.5	0.1	0.4	0.6981	0.7303	0.7328	0.7434	0.7509
48	0.5	0.2	0.3	0.7698	0.7834	0.7221	0.7372	0.7436
49	0.5	0.3	0.2	0.8415	0.8365	0.7113	0.7311	0.7364
50	0.5	0.4	0.1	0.9132	0.8896	0.7005	0.7250	0.7291
51	0.5	0.5	0.0	0.9849	0.9427	0.6897	0.7189	0.7219
52	0.6	0.0	0.4	0.7011	0.7189	0.6952	0.7011	0.7097
53	0.6	0.1	0.3	0.7728	0.7719	0.6844	0.6950	0.7025
54	0.6	0.2	0.2	0.8445	0.8250	0.6736	0.6888	0.6952
55	0.6	0.3	0.1	0.9162	0.8781	0.6628	0.6827	0.6880
56	0.6	0.4	0.0	0.9879	0.9312	0.6521	0.6766	0.6807
57	0.7	0.0	0.3	0.7759	0.7605	0.6468	0.6527	0.6614
58	0.7	0.1	0.2	0.8475	0.8136	0.6360	0.6466	0.6541
59	0.7	0.2	0.1	0.9192	0.8667	0.6252	0.6404	0.6469
60	0.7	0.3	0.0	0.9909	0.9197	0.6144	0.6343	0.6396
61	0.8	0.0	0.2	0.8506	0.8021	0.5983	0.6043	0.6130
62	0.8	0.1	0.1	0.9223	0.8552	0.5875	0.5981	0.6057
63	0.8	0.2	0.0	0.9939	0.9083	0.5767	0.5920	0.5985

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Table 4.10: (*continued*)

No	λ_1	λ_2	λ_3	FIFO	EDF	SPT	MCB-2	MCB-3
64	0.9	0.0	0.1	0.9253	0.8437	0.5499	0.5559	0.5646
65	0.9	0.1	0.0	0.9970	0.8968	0.5391	0.5497	0.5574
66	1.0	0.0	0.0	1.0000	0.8854	0.5014	0.5075	0.5162

The performance measurement function refers to (3.9), $\sum \lambda_i = 1$, λ_1 is normalized average waiting time's weight, λ_2 is normalized maximum waiting time's weight, and λ_3 is normalized Sd. waiting time's weight.

The performance measurement results of each running case are plotted in Figure 4.23 and 4.24 in order to distinct the preferred policy. From the Figures, the preferred policy is indicated on each range of the graph. For deadline considering, MCB-2, MCB-3 and SPT have results in the same direction. In addition, MCB-2 is nearly to SPT and better than MCB-3. These three policies have advantages when λ_1, which considers average waiting time, is weighted with high value and λ_3, which considers Sd. waiting time, is weighted with low value. Figure 4.23 on X-axis's range 47 to 66, MCB-2, MCB-3, and SPT results are better than FIFO and EDF. The heavily loaded results, Figure 4.24 are similar to the medium loaded results. Table 4.11 and 4.12 show the preference policy of medium loaded and heavily loaded cases, respectively. Moreover, like non-deadline situation, it can be observed in Figure 4.23 and 4.24 that the result of MCB-3 is the most predictable among the comparative policies as shown as the smooth exponential curve.

Comparing performance metrics of medium loaded (M) and heavily loaded (H) cases is presented in Figure 4.25. Varying weights in both cases have the results in the same direction. As can be seen, MCB-2 has lower values than MCB-3 in deadline situation.

Table 4.11: Preference policy of medium loaded case with deadline

Starting weights (λ_1,λ_2,λ_3)	Ending weights (λ_1,λ_2,λ_3)	Preference policy
(0.0,0.0,1.0)	(0.0,0.6,0.4)	FIFO>EDF>MCB-2>SPT>MCB-3
(0.0,0.7,0.3)	(0.0,0.9,0.1)	FIFO>EDF>SPT>MCB-2>MCB-3
(0.0,1.0,0.0)	-	SPT>MCB-2>FIFO>MCB-3>EDF
(0.1,0.0,0.9)	(0.1,0.5,0.4)	FIFO>EDF>MCB-2>SPT>MCB-3
(0.1,0.6,0.3)	-	FIFO>EDF>SPT>MCB-2>MCB-3
(0.1,0.7,0.2)	-	FIFO>SPT>MCB-2>EDF>MCB-3
(0.1,0.8,0.1)	-	FIFO>SPT>MCB-2>MCB-3>EDF
(0.1,0.9,0.0)	-	SPT>MCB-2>MCB-3>FIFO>EDF
(0.2,0.0,0.8)	(0.2,0.4,0.4)	FIFO>EDF>MCB-2>SPT>MCB-3
(0.2,0.5,0.3)	-	FIFO>SPT>EDF>MCB-2>MCB-3
(0.2,0.6,0.2)	-	FIFO>SPT>MCB-2>MCB-3>EDF
(0.2,0.7,0.1)	-	SPT>MCB-2>FIFO>MCB-3>EDF
(0.2,0.8,0.0)	-	SPT>MCB-2>MCB-3>FIFO>EDF
(0.3,0.0,0.7)	(0.3,0.3,0.4)	FIFO>EDF>MCB-2>SPT>MCB-3
(0.3,0.4,0.3)	-	FIFO>SPT>MCB-2>MCB-3>EDF
(0.3,0.5,0.2)	-	SPT>MCB-2>FIFO>MCB-3>EDF
(0.3,0.6,0.1)	(0.3,0.7,0.0)	SPT>MCB-2>MCB-3>FIFO>EDF
(0.4,0.0,0.6)	(0.4,0.1,0.5)	FIFO>EDF>MCB-2>SPT>MCB-3
(0.4,0.2,0.4)	-	FIFO>(MCB-2=SPT)>EDF>MCB-3
(0.4,0.3,0.3)	-	SPT>FIFO>MCB-2>MCB-3>EDF
(0.4,0.4,0.2)	(0.4,0.6,0.0)	SPT>MCB-2>MCB-3>FIFO>EDF
(0.5,0.0,0.5)	-	FIFO>EDF>MCB-2>EDF>MCB-3
(0.5,0.1,0.4)	-	FIFO>SPT>MCB-2>MCB-3>EDF
(0.5,0.2,0.3)	(0.8,0.2,0.0)	SPT>MCB-2>MCB-3>FIFO>EDF
(0.9,0.0,0.1)	(1.0,0.0,0.0)	SPT>MCB-2>MCB-3>EDF>FIFO

Table 4.12: Preference policy of heavily loaded case with deadline

Starting weights $(\lambda_1,\lambda_2,\lambda_3)$	Ending weights $(\lambda_1,\lambda_2,\lambda_3)$	Preference policy
(0.0,0.0,1.0)	(0.0,0.7,0.3)	FIFO>EDF>SPT>MCB-2>MCB-3
(0.0,0.8,0.2)	-	FIFO>EDF>SPT>MCB-3>MCB-2
(0.0,0.9,0.1)	-	SPT>FIFO>MCB-3>MCB-2>SPT
(0.0,1.0,0.0)	-	SPT>MCB-3>MCB-2>FIFO>EDF
(0.1,0.0,0.9)	(0.1,0.6,0.3)	FIFO>EDF>SPT>MCB-2>MCB-3
(0.1,0.7,0.2)	-	FIFO>SPT>EDF>MCB-2>MCB-3
(0.1,0.8,0.1)	(0.1,0.9,0.0)	SPT>MCB-3>MCB-2>FIFO>EDF
(0.2,0.0,0.8)	(0.2,0.5,0.3)	FIFO>EDF>SPT>MCB-2>MCB-3
(0.2,0.6,0.2)	-	SPT>FIFO¿MCB-2>MCB-3>EDF
(0.2,0.7,0.1)	-	SPT>MCB-2>MCB-3>FIFO>EDF
(0.2,0.8,0.0)	-	SPT>MCB-3>MCB-2>FIFO>EDF
(0.3,0.0,0.7)	(0.3,0.3,0.4)	FIFO>EDF>SPT>MCB-2>MCB-3
(0.3,0.4,0.3)	-	FIFO>SPT>EDF>MCB-2>MCB-3
(0.3,0.5,0.2)	(0.3,0.6,0.1)	SPT>MCB-2>MCB-3>FIFO>EDF
(0.3,0.7,0.0)	-	SPT>MCB-2>MCB-3>EDF>FIFO
(0.4,0.0,0.6)	(0.4,0.2,0.4)	FIFO>EDF>SPT>MCB-2>MCB-3
(0.4,0.3,0.3)	-	SPT>FIFO>MCB-2>MCB-3>EDF
(0.4,0.4,0.2)	-	SPT>MCB-2>MCB-3>FIFO>EDF
(0.4,0.5,0.1)	(0.4,0.6,0.0)	SPT>MCB-2>MCB-3>EDF>FIFO
(0.5,0.0,0.5)	(0.5,0.1,0.4)	FIFO>EDF>SPT>MCB-2>MCB-3
(0.5,0.2,0.3)	-	SPT>MCB-2>MCB-3>FIFO>EDF
(0.5,0.3,0.2)	(0.5,0.5,0.0)	SPT>MCB-2>MCB-3>EDF>FIFO
(0.6,0.0,0.4)	-	SPT>(MCB-2=FIFO)>MCB-3>EDF
(0.6,0.1,0.3)	(1.0,0.0,0.0)	SPT>MCB-2>MCB-3>EDF>FIFO

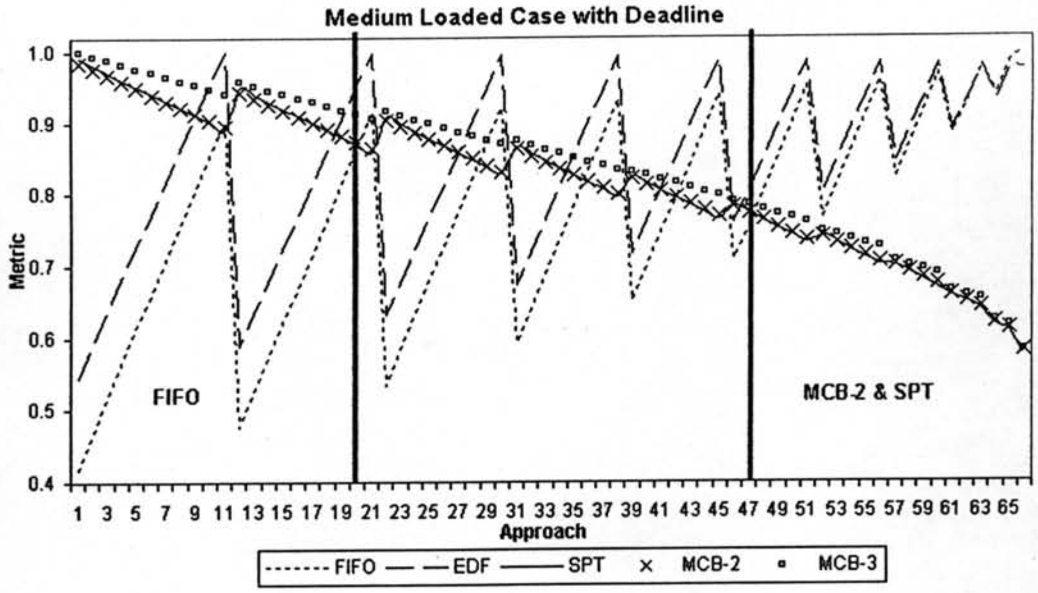

Figure 4.23: Performance measurement of medium loaded case with deadline

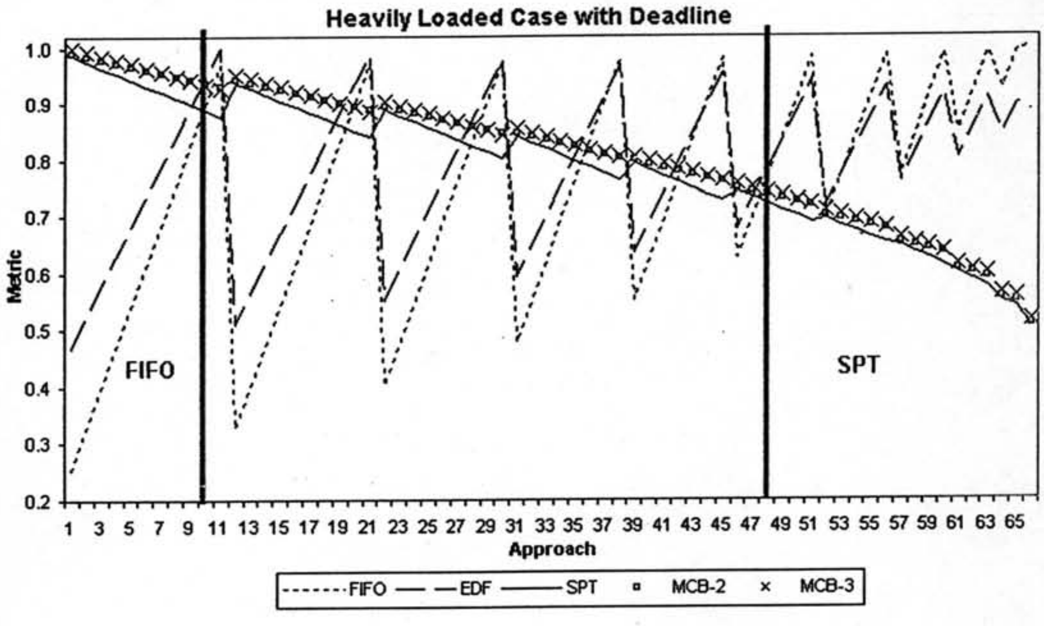

Figure 4.24: Performance measurement of heavily loaded case with deadline

4.3.3 Discussion

There are many researches on scheduling problem. Most of them are interested in job shop and flow shop problems. One main characteristic of the problems is that there is

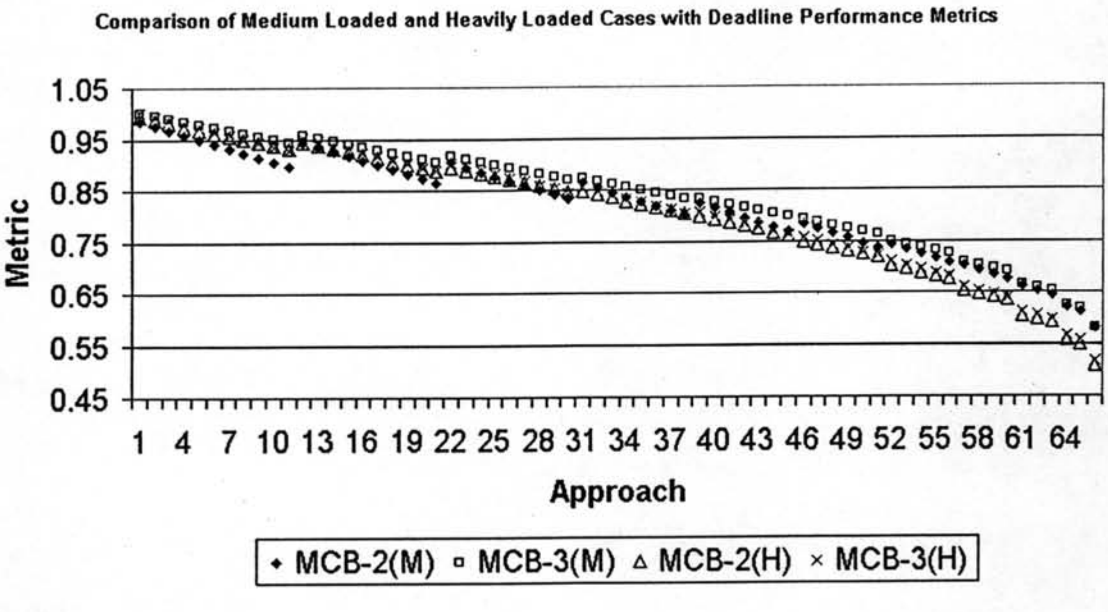

Figure 4.25: Comparison of medium loaded and heavily loaded cases without deadline's performance metrics

a set of n independent, single-operation jobs which is available for processing at time zero. As a result, EDF is optimal for this case [48]. FIFO is the policy of best effort service as it provides the fairness service for the users in term of minimizing variance of the waiting time. Lastly, SPT seems to be an effective policy because it can serve the users with minimum average waiting time.

In this paper, we study on incoming web request scheduling where the arrival time of the requests are difference. We are interested in the problem of the Poisson process, which is nearly to web traffic-liked characteristic than the system that the requests arrival time is Exponential distribution. We compare our proposed multicriteria scheduling policy, MCB, to the three traditions: FIFO, EDF, and SPT, which are single criterion policies. We consider two interesting situations where the system has medium loaded and heavily loaded services. First, non-deadline checking situation is concerned in order to measure the real performance of each policy. Second, deadline checking situation is focused to assess the deadline effect on each policy.

For both medium loaded and heavily loaded cases of non-deadline checking, all MCB method (MCBs) have average waiting times lower than FIFO and EDF but higher than SPT. For examples, average waiting time of MCB-2 is 2.9 and 2.3% lower than FIFO and EDF, and 8.3% and 6.0% higher than SPT in medium loaded case and heavily loaded case, respectively, while average waiting time of MCB-3 is 1.5% and 1.2% lower than FIFO and EDF, and 9.6% and 7.0% higher than SPT in medium loaded case and heavily loaded case, respectively. Furthermore, MCBs' maximum and Sd. waiting times are lower than SPT, but higher than FIFO and EDF. For examples, maximum waiting time of MCB-2 is 46.6% and 5.9% lower than SPT in medium loaded case and heavily loaded case, respectively, and 11.7% and 1.0% higher than FIFO and EDF in medium loaded case and heavily loaded case, respectively, while maximum waiting time of MCB-3 is 54.6% and 6.6% lower than SPT, and 6.8% and 0.4% higher than FIFO and EDF in medium loaded case and heavily loaded case, respectively. For Sd. waiting time examples, Sd. waiting time of MCB-2 is 61.8% and 7.2% lower than SPT in medium loaded case and heavily loaded case, respectively, and 2.1% and 0.2% higher than FIFO and EDF in medium loaded case and heavily loaded case, respectively, while Sd. waiting time of MCB-3 is 65.0% and 7.4% lower than SPT, 0.2% higher than FIFO and EDF in medium loaded case, and equals to FIFO and EDF in heavily loaded case. For coarse gain, the above results of the scheduling level indicate that MCB is an optimal policy among the comparative policies.

For fine gain, we use those three waiting times: average, maximum, and Sd.; as criteria to measure each comparative policy performance in the performance measurement level. The weight aggregation technique has been applied to determine weights of average, maximum, and Sd. waiting times according to its own role. The higher priority of each criterion is represented via the higher weight value. Average waiting time, which affects to the majority of users, should have high weight value. At the same time, maximum waiting time, which affects to the minority of users, should have low weight value, while the weight value of Sd. waiting time can be varied according to the web server's agreement policy. According to the above reasons and referring to the result in Table 4.5 and 4.6, the MCB approaches are more realistic to the dynamic situation of the web server because MCB is a preference approach in the interval of average waiting time 0.4-0.6 for medium loaded case without deadline checking.

For medium and heavily loaded cases with deadline checking, MCB policy did not show extremely advantage over other policies. This might be because of no consideration in main criterion of the deadline situation; number of rejected request. We ignore this criteria because we intend to compare the performance results with non-deadline checking cases on the three similar criteria. Consequently, FIFO and EDF have a good average waiting time because the rejected requests are not calculated. Comparing between medium loaded and heavily loaded cases, maximum and Sd. waiting times are unpredictable because the load of large data requests in both cases are differences. The further work shall cover this criterion. However, this indicates that selecting the proper criteria for each situation is the key success of MCB.

However, there are other concerning factors that should be studied before lauching the proposed policy to the real system. For example, the effect of multithread system, other HTTP capabilities such as TIMEOUT, inter-pages and inline-objects relations.

The proposed scheduling policy, MCB, can be applied to be a part of classification process in the QoS management cycle, Figure 3.3. To control the QoS of the system, the scheduling objectives; minimizing average, maximum, and Sd. waiting times, can be announced in the SLA as a service commitment of the system to all users. Under an uncertainty situation in web server, which has many requirements, applications, and various client and network environments, the adaptive system that concerns more criteria has an advantage over the traditional system as shown in the results at the scheduling level. MCB can be works as a single dynamically weighting policy. By varying weights of the scheduling criteria according to the system situation, the system can dynamically adjust their services to maximize user satisfaction as agreed in SLA.