CHAPTER 4 NUMERICAL EXAMPLE

4.1. VP EWMA Control Chart

4.1.1 Numerical Example

This is an example of foundry operations. In the study, periodic samples of molten iron were taken to monitor the carbon-silicate content of the casting. High carbon-silicate content results in low tensile strength. The value of the input variables is:
$G = t_4 = t_5 = \frac{5}{60} hours, \quad t_0 = \frac{45}{60} hours, \quad \frac{1}{\lambda} = 50, \quad c_1 = \$114.24 / hour$
$c_2 = \$949.2 / hour, \quad c_3 = c_4 = \$114.24; \quad a = 0; \quad b = \$4.22; \quad \gamma_1 = 1, \quad \gamma_2 = 0$

In order to accomplish the optimization of the unit cost function, the following constraints were considered:

$n_1 \le n_2; \quad n_2 \ge 5; \quad n_1 \ge 1; \; 0.1 \le h_2 \le h_1; \quad h_1 \ge 1; \quad w_2 \le w_1 \; and \; k_2 \le k_1; \quad k_1 \; and \; k_2 \ge 1$.

A nonlinear constrained optimization algorithm was applied to the cost function. We considered several shifts of the mean;

$\delta = 0.5; 0.75; 1; 1.25; 1.5; 1.75; 2; 2.5; 3$ and $r = 0.05(0.05)0.95$.

Table 4.1 The economic performance of VP EWMA control chart for $r = 0.05, 0.1, 0.15, 0.2, 0.25, 0.3$, and 0.35.

hift δ	**Optimum parameters for variable parameters** $(n_1, n_2, h_1, h_2, w_1, w_2, k_1, k_2)$								**Optimum** *ECTU*						
									Value of r						
									$r=.05$	$r=.1$	$r=.15$	$r=.2$	$r=.25$	$r=.3$	$r=.35$
delta	n_1	n_2	h_1	h_2	w_1	w_2	k_1	k_2	*ECTU*	*ECTU*	*ECTU*	*ECTU*	*ECTU*	*ECTU*	*ECTU*
0	12	17	2.21	0.1	1.19	1.11	2.71	1.9	212.398	210.726	211.195	213.197	216.607	221.474	220.769
0.5	11	15	2.15	0.1	1.15	1.08	2.62	1.97	227.573	219.239	213.437	208.952	205.328	195.709	191.931
0.75	7	9	1.7	0.1	1.23	1.18	3.03	2.22	205.248	196.687	190.745	186.159	182.452	171.854	168.045
1	5	6	1.43	0.1	1.3	1.26	3.26	2.38	196.033	187.038	180.807	175.999	172.108	160.708	156.791
1.25	3	5	1.25	0.1	1.43	1.39	3.44	2.47	183.716	175.780	170.333	166.158	162.795	151.368	147.852
1.5	3	5	1.11	0.1	1.71	1.6	3.62	2.44	168.444	162.679	158.818	155.914	153.617	141.049	138.005
1.75	2	5	1	0.1	1.9	1.8	3.65	2.42	156.738	152.497	149.671	147.547	145.865	134.891	132.409
2	2	5	1	0.1	2.06	1.9	3.56	2.42	160.003	155.213	151.994	149.551	147.593	134.848	131.919
2.5	2	5	1	0.1	2.07	2	3.5	2.41	153.302	148.667	146.817	144.810	143.183	133.497	131.119
3	2	5	1	0.1	2.08	2.01	3.49	2.39	152.272	148.417	146.239	144.387	142.888	133.452	131.165

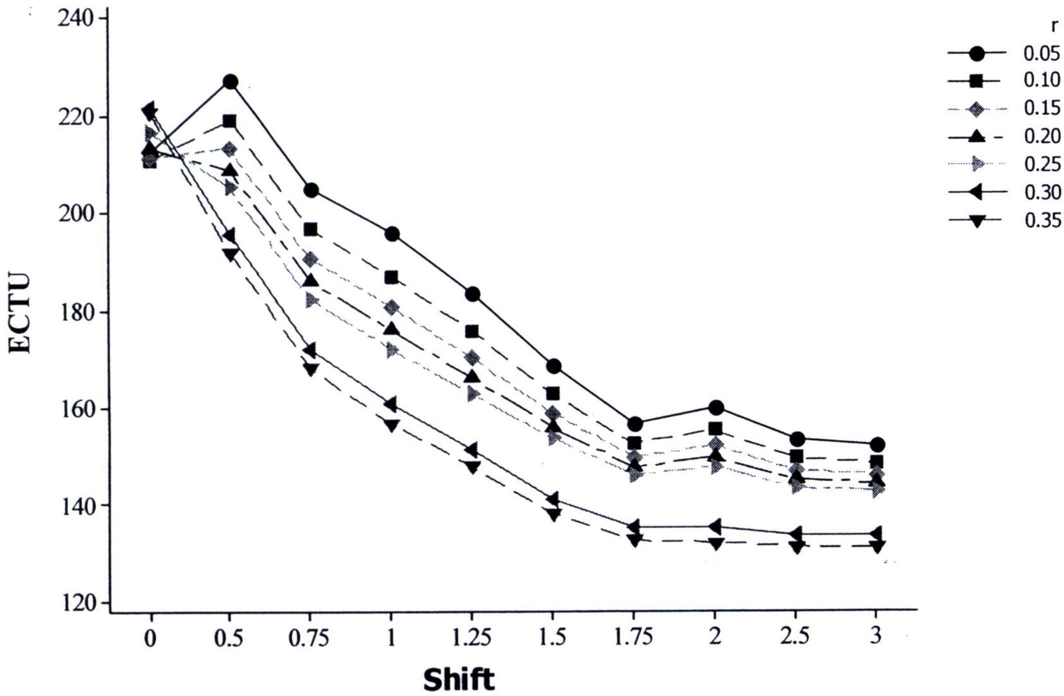
Table 4.2 The economic performance of VP EWMA control chart for $r = 0.4, 0.45, 0.5, 0.55, 0.6, 0.65$, and 0.7.

shift δ	**Optimum parameters for variable parameters** $(n_1, n_2, h_1, h_2, w_1, w_2, k_1, k_2)$								**Optimum** *ECTU* **Value of** r						
									$r=.4$	$r=.45$	$r=.5$	$r=.55$	$r=.6$	$\lambda=.65$	$\lambda=.7$
delta	n_1	n_2	h_1	h_2	w_1	w_2	k_1	k_2	*ECTU*	*ECTU*	*ECTU*	*ECTU*	*ECTU*	*ECTU*	*ECTU*
0	12	17	2.21	0.1	1.19	1.11	2.71	1.9	236.282	246.792	259.905	276.150	296.167	320.709	350.618
0.5	11	15	2.15	0.1	1.15	1.08	2.62	1.97	197.835	196.201	195.754	194.064	193.569	193.484	193.850
0.75	7	9	1.7	0.1	1.23	1.18	3.03	2.22	174.701	172.951	172.299	170.497	169.785	169.433	169.468
1	5	6	1.43	0.1	1.3	1.26	3.26	2.38	163.900	162.003	161.142	159.226	158.326	157.760	157.549
1.25	3	5	1.25	0.1	1.43	1.39	3.44	2.47	155.749	154.128	153.477	151.749	150.969	150.464	150.244
1.5	3	5	1.11	0.1	1.71	1.6	3.62	2.44	149.011	148.044	147.889	146.857	146.656	146.756	147.207
1.75	2	5	1	0.1	1.9	1.8	3.65	2.42	142.475	141.752	141.749	140.820	140.611	140.583	140.754
2	2	5	1	0.1	2.06	1.9	3.56	2.42	143.527	142.612	142.370	141.336	140.978	140.820	140.881
2.5	2	5	1	0.1	2.07	2	3.5	2.41	139.674	138.827	138.545	137.523	137.059	136.723	136.523
3	2	5	1	0.1	2.08	2.01	3.49	2.39	139.644	138.851	136.459	137.602	137.143	136.791	136.555

Table 4.3 The economic performance of VP EWMA control chart for $r = 0.75, 0.8, 0.85, 0.9$, and 0.95.

shift δ	**Optimum parameters for variable parameters** $(n_1, n_2, h_1, h_2, w_1, w_2, k_1, k_2)$								**Optimum** *ECTU* **Value of** r				
									$r=.75$	$r=.8$	$r=.85$	$r=.9$	$r=.95$
delta	n_1	n_2	h_1	h_2	w_1	w_2	k_1	k_2	*ECTU*	*ECTU*	*ECTU*	*ECTU*	*ECTU*
0	12	17	2.21	0.1	1.19	1.11	2.71	1.9	386.756	429.878	480.411	538.137	601.834
0.5	11	15	2.15	0.1	1.15	1.08	2.62	1.97	194.724	196.182	198.324	201.278	205.202
0.75	7	9	1.7	0.1	1.23	1.18	3.03	2.22	169.932	170.880	172.383	174.518	177.368
1	5	6	1.43	0.1	1.3	1.26	3.26	2.38	157.722	158.321	159.392	160.980	163.118
1.25	3	5	1.25	0.1	1.43	1.39	3.44	2.47	150.332	150.751	151.529	152.687	154.231
1.5	3	5	1.11	0.1	1.71	1.6	3.62	2.44	148.084	149.484	151.516	154.260	157.648
1.75	2	5	1	0.1	1.9	1.8	3.65	2.42	141.145	141.782	142.692	143.889	145.364
2	2	5	1	0.1	2.06	1.9	3.56	2.42	141.188	141.767	142.638	143.792	145.166
2.5	2	5	1	0.1	2.07	2	3.5	2.41	136.468	136.571	136.841	137.283	137.891
3	2	5	1	0.1	2.08	2.01	3.5	2.39	136.444	136.636	136.636	136.952	137.409

In Table 4.1, 4.2, and 4.3, the results of the economic performance of VP EWMA control chart at different value of r are present. At the same δ, the values of $ECTU$ are decrease. From these tables, it can conclude that the minimum value of the $ECTU$ is 131.119 at $r = 0.35$ and $\delta = 2.5$.



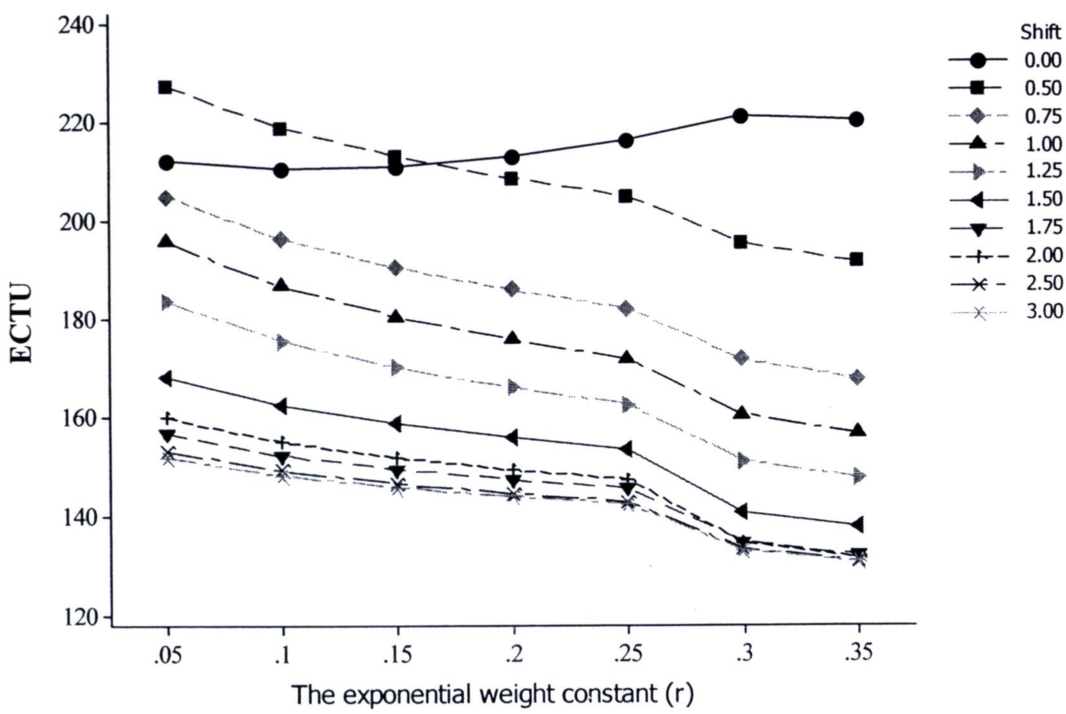


Figure 4.1 $ECTU$ of VP EWMA control chart: $r = 0.05$, 0.1, 0.15, 0.2, 0.25, 0.3 and 0.35.

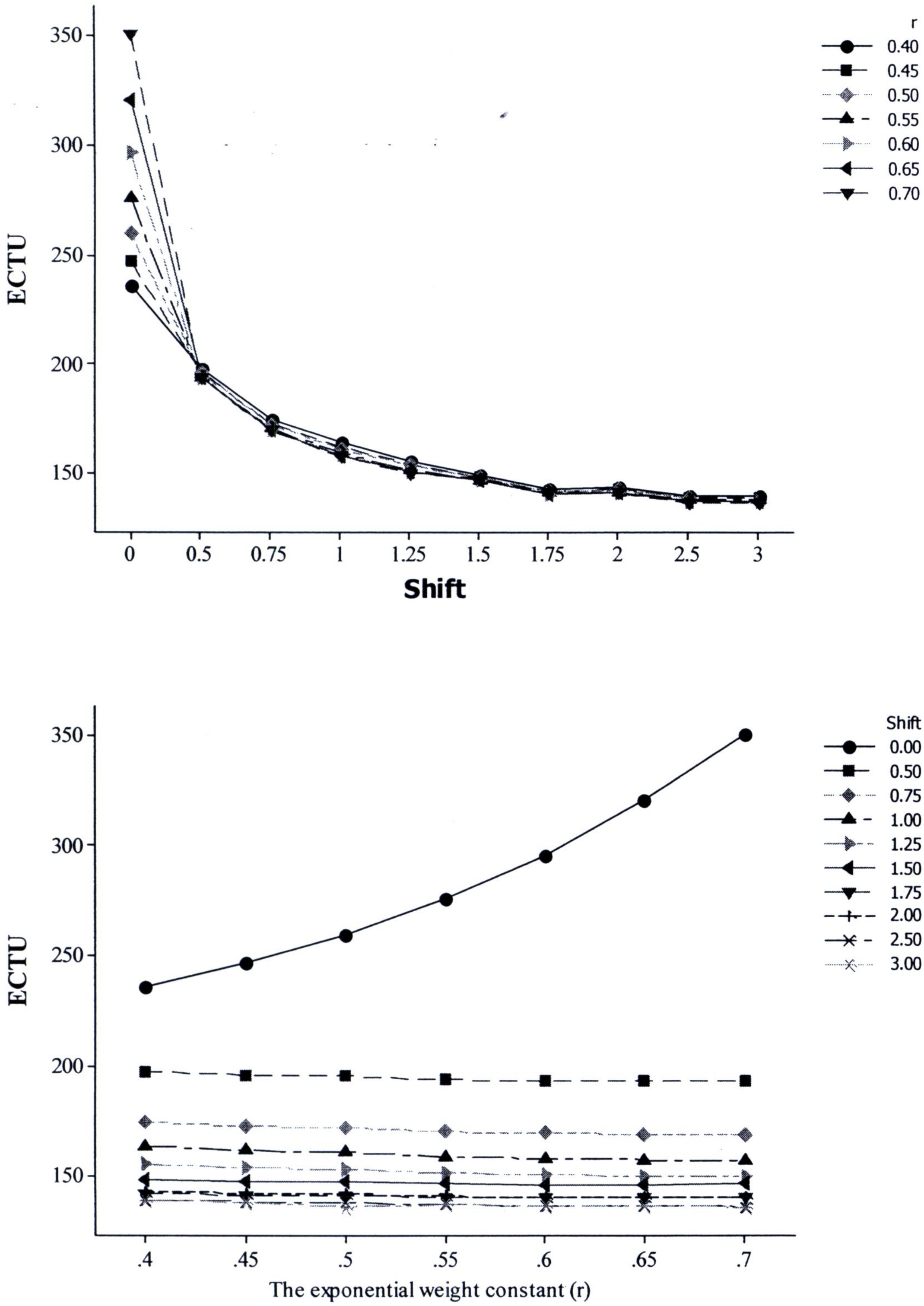
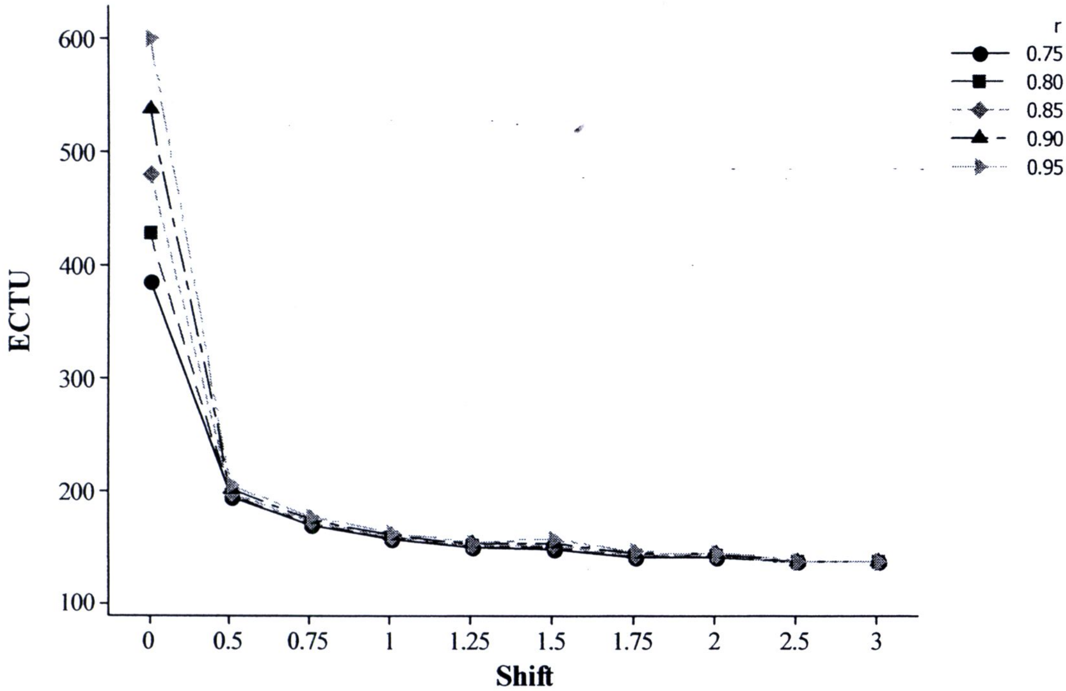


Figure 4.2 *ECTU* of VP EWMA control chart: $r = 0.4, 0.45, 0.5, 0.55, 0.6, 0.65$ and 0.7.



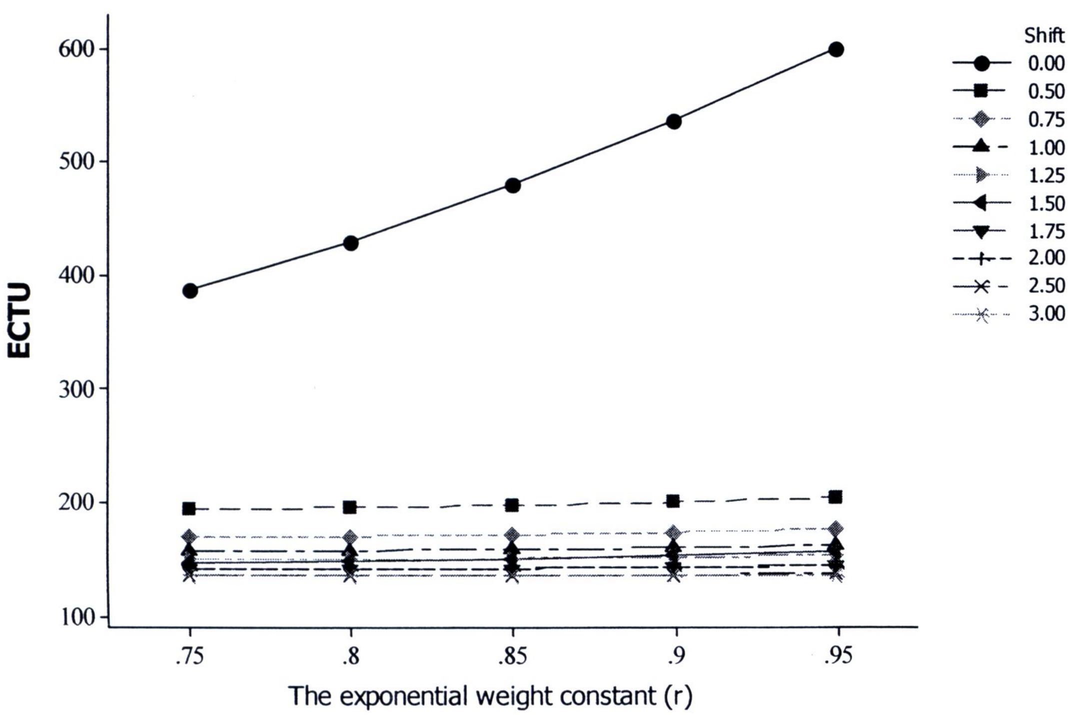
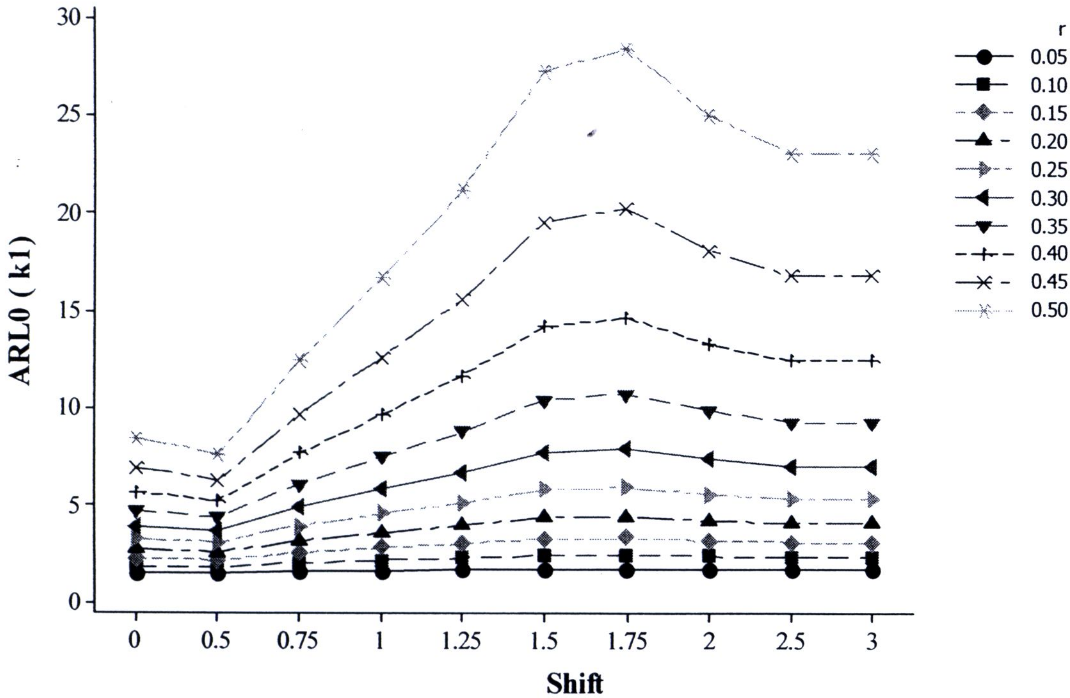


Figure 4.3 *ECTU* of VP EWMA control chart: $r = 0.75, 0.8, 0.85, 0.9$ and 0.95.

Average run length $\left(ARL_0^1\right)$

Table 4.4 The ARL_0^1 for k_1 of VP EWMA control chart: r = 0.5, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 and 0.5.

Shift δ	ARL_0^1 for value of r										
		$r=.05$	$r=.1$	$r=.15$	$r=.2$	$r=.25$	$r=.3$	$r=.35$	$r=.4$	$r=.45$	$r=.5$
delta	k_1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1
0	2.71	1.51	1.87	2.27	2.73	3.27	3.92	4.72	5.70	6.93	8.50
0.5	2.62	1.48	1.83	2.19	2.61	3.11	3.69	4.39	5.26	6.33	7.67
0.75	3.03	1.59	2.05	2.58	3.20	3.97	4.92	6.14	7.71	9.75	12.46
1	3.26	1.66	2.20	2.83	3.61	4.59	5.85	7.51	9.70	12.66	16.72
1.25	3.44	1.72	2.33	3.06	3.98	5.17	6.74	8.84	11.71	15.67	21.27
1.5	3.62	1.78	2.46	3.30	4.39	5.84	7.79	10.48	14.23	19.56	27.31
1.75	3.65	1.79	2.49	3.35	4.47	5.96	7.99	10.78	14.71	20.32	28.50
2	3.56	1.76	2.41	3.22	4.25	5.60	7.42	9.89	13.32	18.15	25.10
2.5	3.5	1.74	2.37	3.14	4.11	5.38	7.07	9.35	12.48	16.86	23.09
3	3.49	1.74	2.36	3.12	4.09	5.34	7.01	9.26	12.35	16.65	22.77



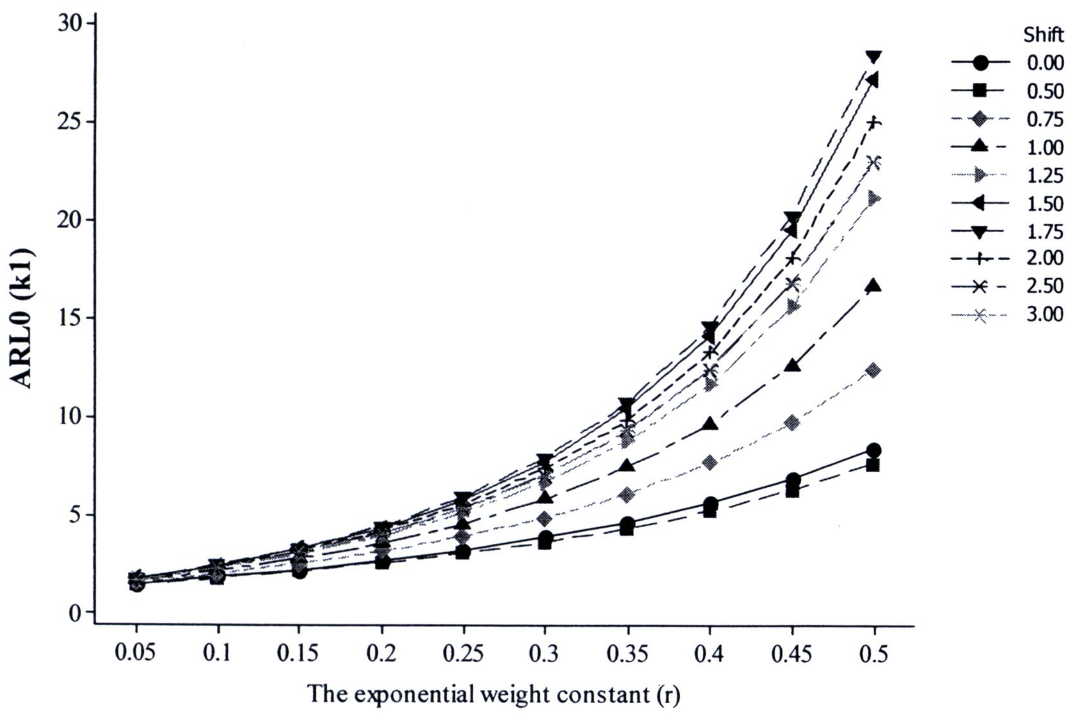
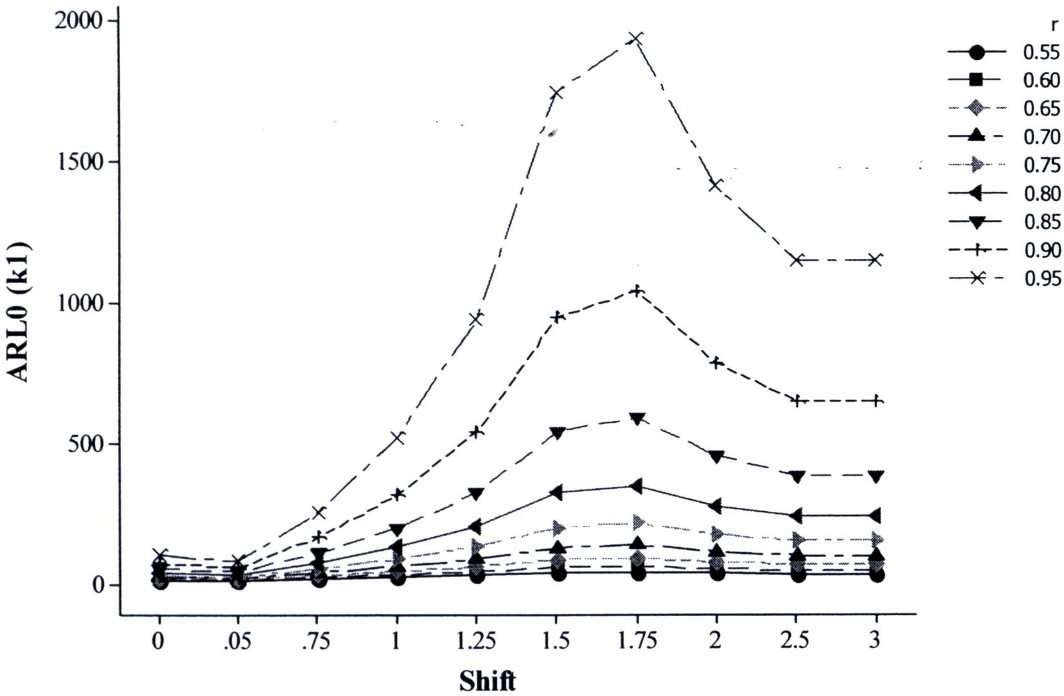


Figure 4.4 The ARL_0^1 for k_1 of VP EWMA control chart: $r = 0.05$, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 and 0.5.

Table 4.5 The ARL_0^1 for k_1 of VP EWMA control chart: $r = 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9$ and 0.95

Shift δ	ARL_0^1 for value of r								
	$r=.55$	$r=.6$	$r=.65$	$r=.7$	$r=.75$	$r=.8$	$r=.85$	$r=.9$	$r=.95$
delta	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1	ARL_0^1
0	10.51	13.15	16.65	21.39	27.93	37.15	50.47	70.25	100.55
0.5	9.38	11.59	14.48	18.34	23.58	30.85	41.17	56.20	78.75
0.75	16.12	21.14	28.16	38.19	52.84	74.84	108.84	163.13	253.15
1	22.39	30.46	42.21	59.71	86.48	128.65	197.34	313.45	518.28
1.25	29.31	41.12	58.87	86.25	129.74	201.07	322.39	537.41	936.73
1.5	38.79	56.19	83.27	126.60	198.15	320.57	538.53	944.45	1740.20
1.75	40.69	59.27	88.35	135.17	213.01	347.16	587.88	1040.01	1934.61
2	35.29	50.57	74.06	111.20	171.72	273.80	452.75	780.47	1411.26
2.5	32.14	45.56	65.98	97.85	149.11	234.37	381.58	646.75	1148.01
3	32.65	44.79	64.73	95.80	145.68	228.43	370.94	626.97	1109.51



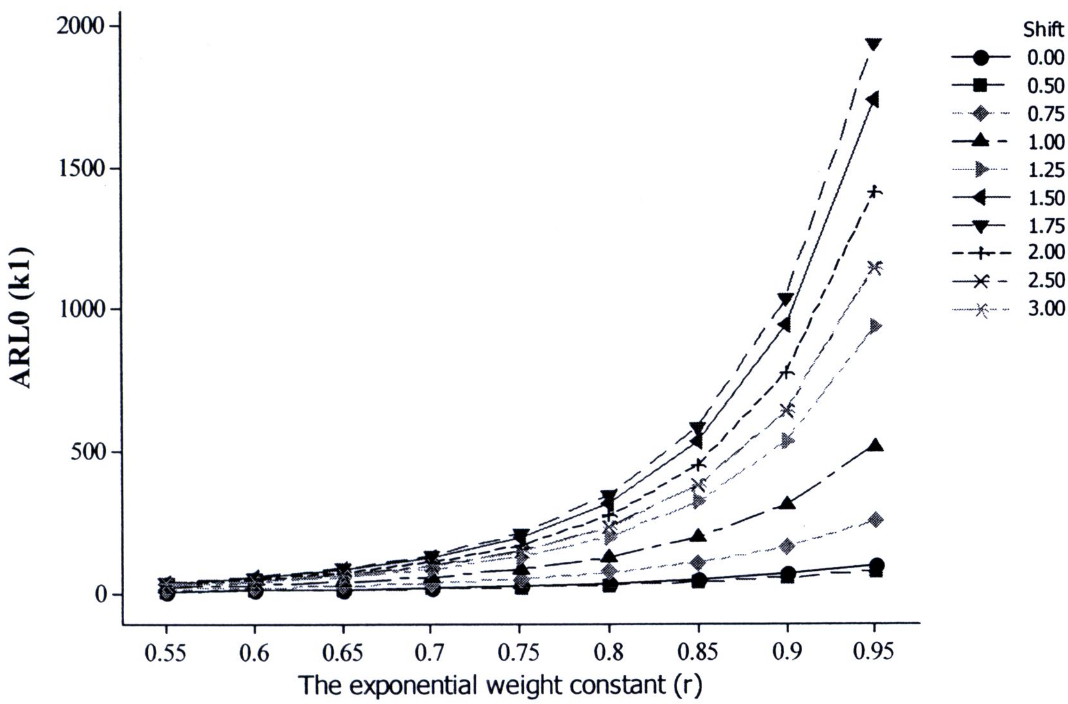


Figure 4.5 The ARL_0^1 for k_1 of VP EWMA control chart: r = 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9 and 0.95.

Table 4.6 The ARL_0^2 of k_2 of VP EWMA control chart: $r =$ 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 and 0.5.

Shift δ		**ARL_0^2 for value of r**									
		$r=.05$	$r=.1$	$r=.15$	$r=.2$	$r=.25$	$r=.3$	$r=.35$	$r=.4$	$r=.45$	$r=.5$
delta	k_2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2
0	1.9	1.31	1.51	1.70	1.90	2.12	2.35	2.62	2.92	3.27	3.67
0.5	1.97	1.33	1.54	1.74	1.96	2.19	2.45	2.75	3.08	3.47	3.92
0.75	2.22	1.38	1.64	1.90	2.18	2.49	2.85	3.26	3.75	4.32	5.00
1	2.38	1.42	1.71	2.01	2.34	2.71	3.15	3.66	4.27	5.01	5.90
1.25	2.47	1.44	1.75	2.08	2.44	2.85	3.34	3.92	4.61	5.46	6.50
1.5	2.44	1.44	1.74	2.05	2.40	2.81	3.27	3.83	4.50	5.30	6.29
1.75	2.42	1.43	1.73	2.04	2.38	2.77	3.23	3.77	4.42	5.20	6.16
2	2.42	1.43	1.73	2.04	2.38	2.77	3.23	3.77	4.42	5.20	6.16
2.5	2.41	1.43	1.72	2.03	2.37	2.76	3.21	3.75	4.38	5.15	6.09
3	2.39	1.43	1.71	2.02	2.35	2.73	3.17	3.69	4.31	5.05	5.97

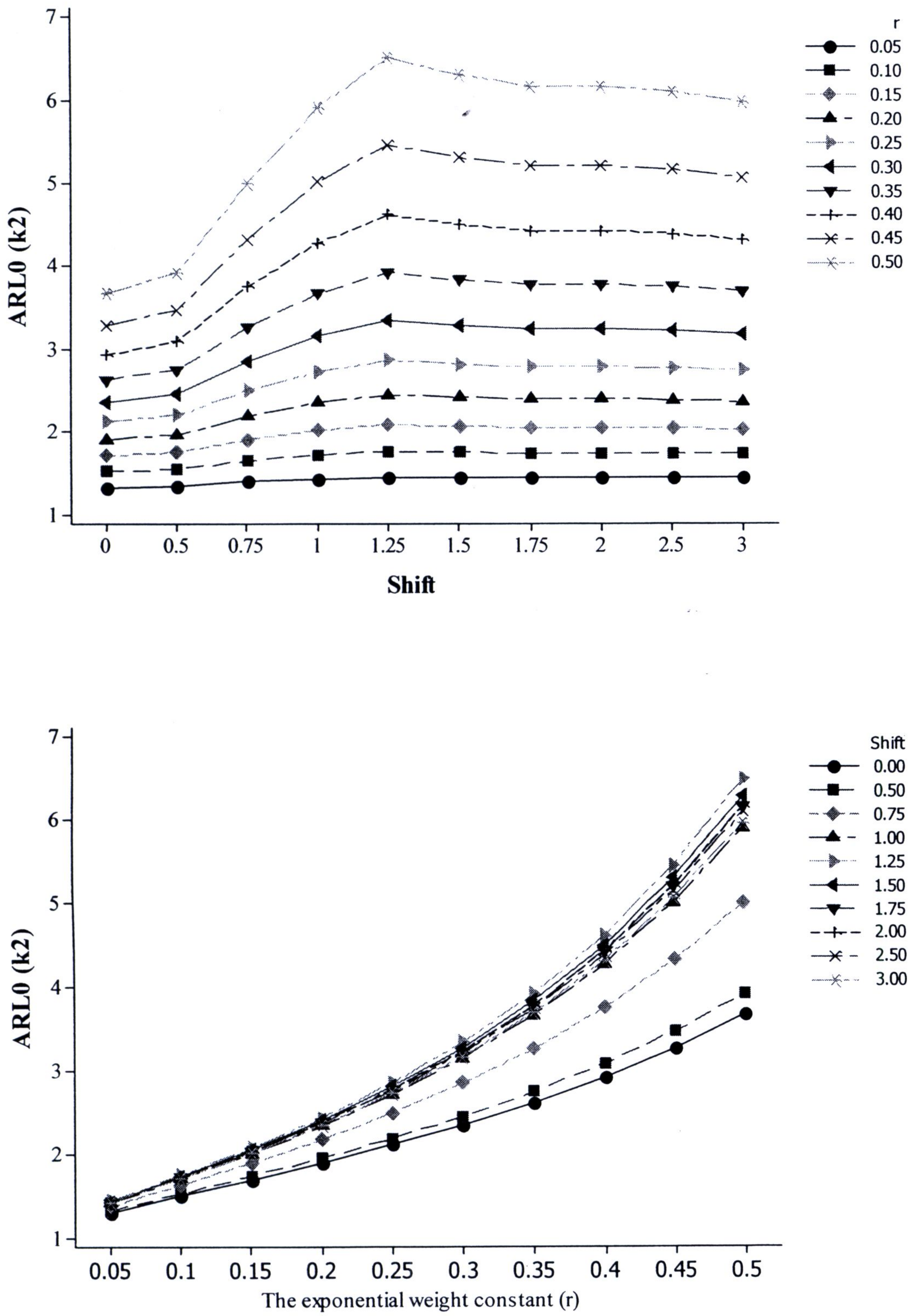
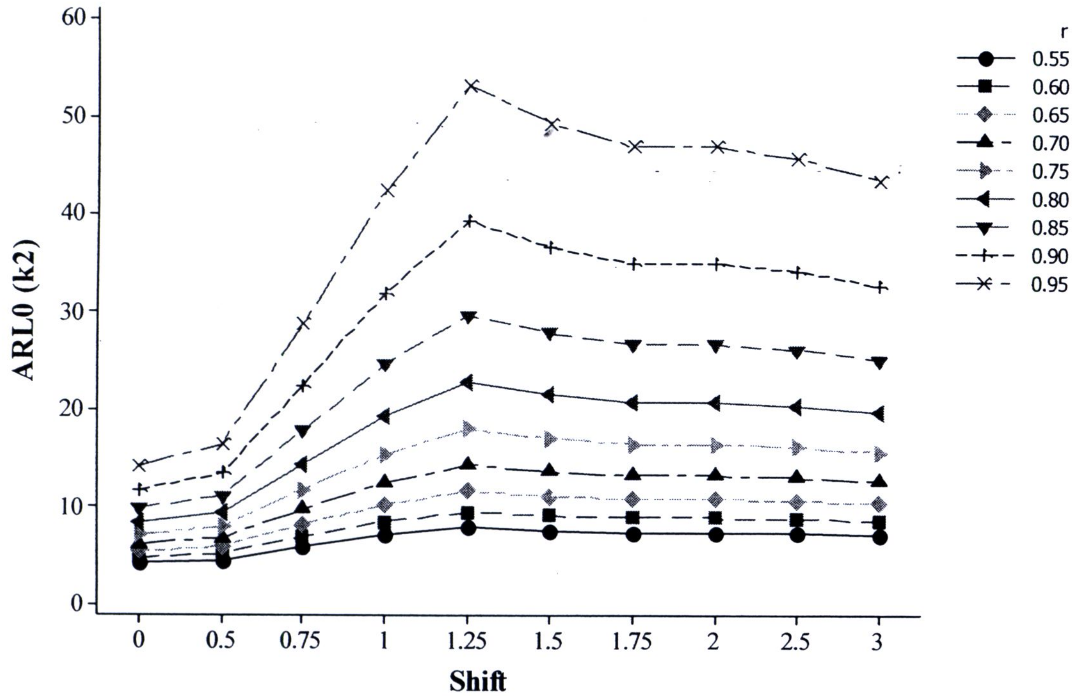


Figure 4.6 The ARL_0^2 of k_2 of VP EWMA control chart: $r =$ 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 and 0.5.

Table 4.7 The ARL_0^2 of k_2 of VP EWMA control chart : $r = 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9$ and 0.95

Shift δ	ARL_0^2 for value of r								
	$r=.55$	$r=.6$	$r=.65$	$r=.7$	$r=.75$	$r=.8$	$r=.85$	$r=.9$	$r=.95$
delta	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2	ARL_0^2
0	4.13	4.68	5.34	6.13	7.09	8.28	9.77	11.67	14.14
0.5	4.44	5.07	5.83	6.74	7.87	9.28	11.07	13.38	16.41
0.75	5.83	6.84	8.10	9.68	11.70	14.31	17.76	22.40	28.80
1	7.01	8.39	10.14	12.39	15.33	19.24	24.54	31.91	42.40
1.25	7.80	9.44	11.55	14.30	17.95	22.87	29.66	39.26	53.19
1.5	7.52	9.08	11.06	13.63	17.02	21.58	27.83	36.62	49.28
1.75	7.35	8.84	10.74	13.20	16.43	20.76	26.68	34.97	46.86
2	7.35	8.84	10.74	13.20	16.43	20.76	26.68	34.97	46.86
2.5	7.26	8.72	10.59	12.99	16.15	20.37	26.13	34.17	45.69
3	7.09	8.50	10.28	12.58	15.59	19.61	25.06	32.65	43.47



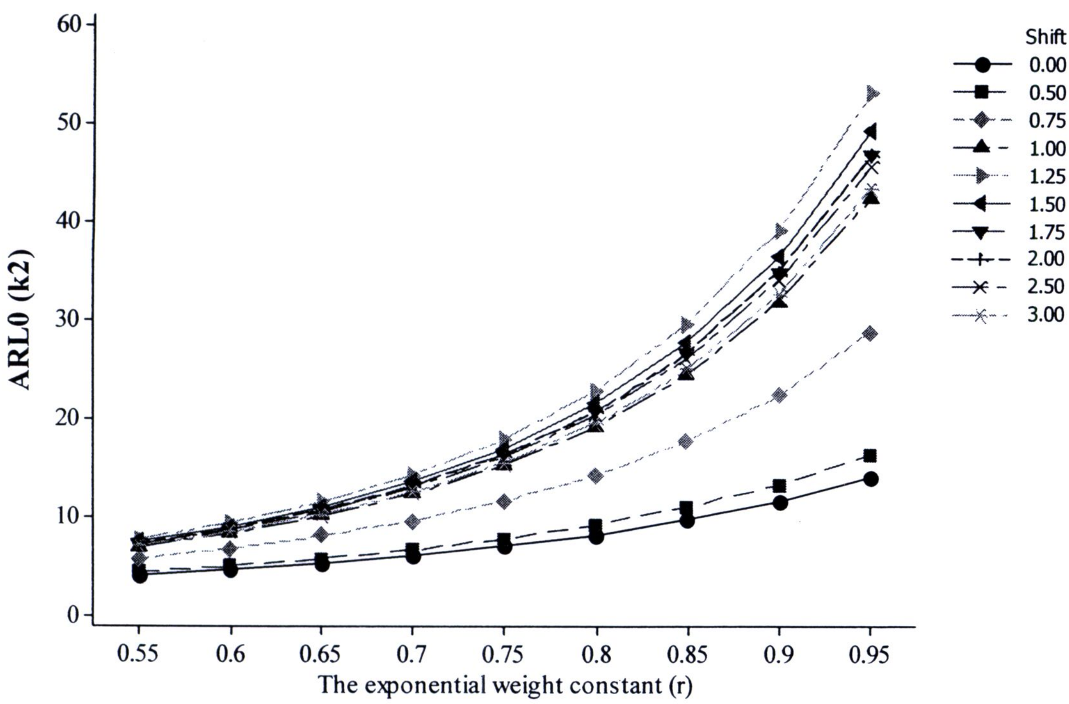


Figure 4.7 The ARL_0^2 of k_2 of VP EWMA control chart: $r = 0.55, 0.6, 0.65, 0.7,$ $0.75, 0.8, 0.85, 0.9$ and 0.95.

4.2 VP MEWMA Control Chart

4.2.1 Numerical Example and Sensitivity Analysis

In this section, numerical example and sensitivity analysis are conducted to study the effect of model parameters on the solution of economic design of the VP MEWMA control chart. Then, using economic model of VP MEWMA control chart and minimizing the hourly loss of MEWMA control chart with the variable parameter, by using Genetic algorithm. The sensitivity analysis for economic model of VP MEWMA control chart and minimizing the hourly loss of VP MEWMA control chart is carried out using orthogonal-array experimental design and multiple regressions. Here, the model parameters are considered as the independent variables and the test parameters (i.e., n_1, n_2, h_1, h_2, k_1, k_2, w_1, w_2, and r), as well as the average cost per unit time $(ECTU)$ of VP MEWMA control charts and average hourly loss $(E(L))$ of VP MEWMA control chart are treated as the dependent variables. We set warning limit and control limit from performance of the Max MEWMA chart by Yeh, et al. (2003) which are shown in Table 4.8 and eight independent parameter (i.e., the model parameters) considered in the sensitivity analysis and their corresponding level planning, which are shown in Table 4.9.

Table 4.8 Warning limit and control limit depend on r and p (Yeh, et al., 2003)

	$p=2$		$p=3$	
r	w	k	w	k
0.05	7.689	9.729	9.773	11.997
0.1	8.786	10.827	10.96	13.165
0.15	9.358	11.366	11.57	13.718
0.2	9.717	11.688	11.93	14.055

The value of warning limit and control limit depend on r and p show that Table 4.8

Table 4.9 Eleven model parameters and their level planning of VP MEWMA control chart.

Model parameter	Level 1	Level 2	Level 3	Level 4
r	0.5	0.1	0.15	0.2
d	0.5	1	1.5	2
s	5	10		
C_0	250	500		
C_1	50	500		
V_0	250	500		
V_1	50	100		
t_0	2.5	5		
t_1	1	10		
λ	0.01	0.05		
p	2	3		

Eleven independent parameters considered in the sensitivity analysis and their corresponding level planning is shown in Table 4.9. The $L_{16}(2^9 4^2)$ orthogonal array is employed and the eleven independent parameters are then assigned to columns of the $L_{16}(2^9 4^2)$ array , as shown in Table 2.7 and Table 2.8. In the $L_{16}(2^9 4^2)$ orthogonal array experiment design, there are 16 trials (i.e., 16 different level combinations of the independent variables). For each trial, the Genetic Algorithm is applied to produce the optimal solution of the economic design.

Table 4.10 Model parameter assignment in the L16 orthogonal array and the corresponding solution of VP MEWMA control chart.

Trail	Model parameter										
	r	d	s	C_0	C_1	V_0	V_1	t_0	t_1	λ	p
1	0.5	0.5	5	250	50	250	50	2.5	1	0.01	2
2	0.5	1	5	250	50	500	100	5	10	0.05	3
3	0.1	0.5	5	500	500	250	100	5	10	0.05	3
4	0.1	1	5	500	500	500	50	2.5	1	0.01	2
5	0.1	1.5	10	250	50	250	50	2.5	1	0.05	3
6	0.1	2	10	250	50	500	100	5	10	0.01	2
7	0.5	1.5	10	500	500	250	100	5	10	0.01	2
8	0.5	2	10	500	500	500	50	2.5	1	0.05	3
9	0.15	0.5	10	250	500	500	50	2.5	10	0.01	3
10	0.15	1	10	250	500	250	100	5	1	0.05	2
11	0.2	0.5	10	500	50	500	100	5	1	0.05	2
12	0.2	1	10	500	50	250	50	2.5	10	0.01	3
13	0.2	1.5	5	250	500	500	50	2.5	10	0.05	2
14	0.2	2	5	250	500	250	100	5	1	0.01	3
15	0.15	1.5	5	500	50	500	100	5	1	0.01	3
16	0.15	2	5	500	50	250	50	2.5	10	0.05	2

Table 4.11 The Optimal solution to the economic design of VP MEWMA control chart

Trial no.	Solution					
	n_1	n_2	h_1	h_2	$E(L)$	$ECTU$
1	32	50	1	0.5	0.118	247.928
2	57	69	1	0.5	0.174	497.891
3	31	48	1	0.5	0.038	249.962
4	38	64	1	0.5	0.150	499.850
5	6	21	1	0.5	0.096	249.904
6	27	33	2	1	0.018	499.982
7	17	37	1	0.5	0.138	249.862
8	11	25	1	0.5	0.411	499.589
9	20	49	1	0.5	0.129	499.871
10	6	11	1	0.5	0.254	249.746
11	26	41	2	1	0.360	499.400
12	9	34	2	1	0.043	249.957
13	57	60	1	0.5	0.019	499.981
14	12	15	2	1	0.538	247.745
15	29	45	1	0.5	0.299	499.701
16	25	42	1	0.5	0.267	249.590

The best value variable by genetic algorithm show that Table 4.11

Table 4.12 The Optimal value of model parameters of VP MEWMA control chart

Parameter	Value	Parameter	Value	Parameter	Value
r	0.1	C_1	50	t_1	10
d	2	V_0	500	λ	0.01
s	10	V_1	100	p	2
C_0	250	t_0	5		

The best value variable by genetic algorithm show that Table 4.12

Table 4.13 The Optimal values for four variables and the optimal value of the total hourly loss costs and total cost of VP MEWMA control chart.

Variable	**Integrate model of VP MEWMA control chart**
n_1	27
n_2	33
h_1	2
h_2	1
$E(L)$	0.018
$ECTU$	499.892

We found that the optimal values of the policy variables those minimize $E(L)$ are $n_1 = 27$, $n_2 = 33$, $h_1 = 2$, $h_2 = 1$ and corresponding hourly loss $E(L)$ and average cost per time unit $ECTU$ are 0.018 and 499.892 respectively.

4.2.2 Data Analysis

The output of the GA for each trial is also recorded in Table 4.12 and 4.13

To study the effect of model parameters on the solution of economic design of VP MEWMA control chart, based on the data in Table 4.12 and 4.13, the statistical software SPSS 15.0 is used to run the regression analysis for each dependent variable.

For each dependent variable, the output of SPSS includes an ANOVA table for regression and a table of regression coefficients, showing the corresponding information about statistical hypothesis testing.

For finding appropriated small sample size (n_1), it will be on the basis that the small sample size (n_1) is depended on the following: magnitude of shift (d) ,the past observations exponential weighted (r) ,the parameter of exponential distribution (λ) ,the quality characteristics (p) ,the cost for each inspected item (s) , the average amount of time exhausted searching for the assignable cause when the process is in-control(t_0),the time to identify and correct the assignable cause (t_1),the average search cost if the given signal is false (C_0),the average cost to discover the assignable cause and adjust the process to in-control state (C_1),the hourly profit earned when the process is operating in control state(V_0), the hourly profit earned when the process is operating in out-of-control state(V_1). When studying the relationships from all values using Stepwise regression, it was found that the small sample size (n_1) is depending on the cost for each inspected item (s), the hourly profit earned when the process is operating in control state (V_0) the time to identify and correct the assignable cause(t_1). They will result to the change of the sample size (n_1)at 80.4%. Therefore, if the hourly profit earned when the process is operating in control state(V_0), changes 1 unit while the time to identify and correct the assignable cause(t_1) and the cost for each inspected item (s) are zero, the small sample size (n_1) will increase 0.064.If the time to identify and correct the assignable cause(t_1) change 1 unit while the hourly profit earned when the process is operating in control state $(V_0)$and the cost for each inspected item $(s)$are zero, the small sample size (n_1) will increase 1.153. If the cost for each inspected item (s) changes 1 unit while the hourly profit earned when the process is operating in control state(V_0) and the time to identify and correct the assignable cause $(t_1)$are zero, the small sample size (n_1) will decrease 3.975.The deviation of using this model is 7.830 as shown in Table 4.14.

$$n_1 = 24.847 - 3.975\,s + 0.064\,V_0 + 1.153\,t_1$$

$$(2.804^*)\ (-5.076^*)\ \ (4.055^*)\ \ (2.650^*)$$

$R^2 = 0.084$ S.E. = 7.830 F = 16.411

Note * Significance level < 0.05

where n_1 is the small sample size

V_0 is the hourly profit earned when the process is operating in control state

s is the cost for each inspected item
t_1 is the time to identify and correct the assignable cause

Table 4.14 SPSS output for the small sample size (n_1) of VP MEWMA control chart

Model Summary Table

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.897(a)	.804	.755	7.830

(*) Predictors: (Constant), s, V_0, t_1

ANOVA Table

Model	Sum of Squares	df	Mean Square	F	P-Value
Regression	3018.688	3	1006.229	16.411	.000
Residual	735.750	12	61.313		
Total	3754.438	15			

Predictors: (Constant), s, V_0, t_1

Table of regression coefficients

Independent Variable	Coefficient	Std. error	t	P-Value
(Constant)	24.847	8.862	2.804*	.016
s	-3.975	.783	-5.076*	.000
V_0	.064	.016	4.055*	.002
t_0	1.153	.435	2.650*	.021

(a) Dependent Variable: n_1

For finding appropriated large sample size (n_2), it will be on the basis that the large sample size (n_2) is depended on the following: magnitude of shift (d) ,the past observations exponential weighted (r) ,the parameter of exponential distribution (λ) ,the quality characteristics (p) ,the cost for each inspected item (s) , the average amount of time exhausted searching for the assignable cause when the process is in-control (t_0),the time to identify and correct the assignable cause(t_1),the average search cost if the given signal is false (C_0) ,the average cost to discover the assignable cause and adjust the process to in-control state (C_1),the hourly profit earned when the process is operating in control state(V_0), the hourly profit earned when the process is operating in out-of-control state (V_1). When studying the relationships from all values using Stepwise regression, it was found that the large sample size (n_2) is depending on the magnitude of shift (d), the cost for each inspected item (s), the hourly profit earned when the process is operating in control state (V_0), the time to identify and correct the assignable cause (t_1). They will result to the change of the large sample size (n_2) at 85.1%. Therefore, if the hourly profit earned when the process is operating in control state (V_0),changes 1 unit while the time to identify and correct the assignable cause (t_1), the magnitude of shift (d) and the cost for each inspected item (s) are zero, the large sample size (n_2)will increase 0.065.If the time to identify and correct the assignable cause (t_1) changes 1 unit while the hourly profit earned when the process is operating in control state (V_0), the magnitude of shift (d) and the cost for each inspected item (s) are zero, the large sample size (n_2) will increase 1.417. If the cost for each inspected item (s) changes 1 unit while the hourly profit earned when the process is operating in control state (V_0), the magnitude of shift (d) and the time to identify and correct the assignable cause (t_1) are zero, the large sample size (n_2) will decrease 3.600. If the magnitude of shift (d) changes 1 unit while the hourly profit earned when the process is operating in control state (V_0), the cost for each inspected item (s) and the time to identify and correct the assignable cause (t_1) are zero, the large sample size (n_2) will decrease 11.600.The deviation of using this model is 7.654 as shown in Table 4.15.

$$n_2 = 49.708 - 3.600\, s + 0.065\, V_0 - 11.600 d + 1.147\, t_1$$
$$(5.145^{*})\ (-4.703^{*})\ \ (4.246^{*})\ \ \left(-3.389^{*}\right)\ \left(3.332^{*}\right)$$

R^2 = 0.085 S.E. = 7.765 F = 15.683

Note * Significance level < 0.05

where n_1 is the small sample size

V_0 is the hourly profit earned when the process is operating in control state

s is the cost for each inspected item

d is the magnitude of shift

t_1 is the time to identify and correct the assignable cause

Table 4.15 SPSS output for the large sample size (n_2) of VP MEWMA control chart

Model Summary Table

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.922(a)	.851	.797	7.654

(a)Predictors: (Constant), s, V_0 ,d ,t_1

ANOVA Table

Model	Sum of Squares	df	Mean Square	F	P-Value
Regression	3675.300	4	918.825	15.683	0.000 (*)
Residual	644.450	11	58.586		
Total	4319.750	15			

(*) Predictors: (Constant), s, V_0 ,d ,t_1

Table of regression coefficients

Independent Variable	Coefficient	Std. error	t	P-Value
(Constant)	49.708	9.662	5.145*	0.000
s	-3.600	.765	-4.703*	0.001
V_0	.065	.015	4.246*	0.001
d	-11.600	3.423	-3.389*	0.006
t_1	1.417	.425	3.332*	0.007

(a) Dependent Variable: n_2

For finding appropriated long sampling interval(h_1), it will be on the basis that long sampling interval$(h_1)$is not depended on the following: magnitude of shift(d) ,the past observations exponential weighted(r), the parameter of exponential distribution(λ), the quality characteristics (p),the cost for each inspected item(s) , the average amount of time exhausted searching for the assignable cause when the process is in-control(t_0),the time to identify and correct the assignable cause (t_1),the average search cost if the given signal is false (C_0),the average cost to discover the assignable cause and adjust the process to in-control state (C_1),the hourly profit earned when the process is operating in control state(V_0) and the hourly profit earned when the process is operating in out-of-control state(V_1). When studying the relationships from all values using Stepwise regression, it was found that no model parameter significantly affect the long sampling interval (h_1) as shown in Table 4.16

Table 4.16 SPSS output for long sampling interval (h_1) of VP MEWMA control chart

ANOVA Table

Model	Sum of Squares	df	Mean Square	F	P-Value
Regression	2.238	11	0.203	0.678	0.725
Residual	1.200	4	0.300		
Total	3.438	15			

For finding appropriated short sampling interval (h_2), it will be on the basis that short sampling interval (h_2) is not depended on the following: magnitude of shift(d), the past observations exponential weighted(r) , the parameter of exponential distribution(λ) , the quality characteristics (p), the cost for each inspected item(s) , the average amount of time exhausted searching for the assignable cause when the process is in-control(t_0),the time to identify and correct the assignable cause(t_1),the average search cost if the given signal is false(C_0),the average cost to discover the assignable cause and adjust the process to in-control state(C_1) ,the hourly profit earned when the process is operating in control state(V_0), the hourly profit earned when the process is operating in out-of-control state (V_1). When studying the relationships from all values using stepwise regression, it was found that no model parameter significantly affect the short sampling interval (h_2)as shown in Table 4.17.

Table 4.17 SPSS output for the short sampling interval (h_2) of VP MEWMA control chart

ANOVA Table

Model	Sum of Squares	df	Mean Square	F	P-Value
Regression	0.559	11	0.051	0.678	0.725
Residual	0.300	4	0.075		
Total	0.859	15			

For finding appropriated the hourly loss $(E(L))$, it will be on the basis that the hourly loss $(E(L))$ is depended on the following: magnitude of shift (d) ,the past observations exponential weighted(r), the parameter of exponential distribution(λ), the quality characteristics(p), the cost for each inspected item(s), the average amount of time exhausted searching for the assignable cause when the process is in-control (t_0),the time to identify and correct the assignable cause(t_1),the average search cost if the given signal is false (C_0),the average cost to discover the assignable cause and adjust the process to in-control state(C_1),the hourly profit earned when the process is operating in control state(V_0), the hourly profit earned when the process is operating in out-of-control state(V_1).When studying the relationships from all values using stepwise regression, it was found that the hourly loss $(E(L))$ depends on the time to identify and correct the assignable cause (t_1). They will result to the change of the hourly loss $(E(L))$ at 33.3%. Therefore, if the time to identify and correct the assignable cause(t_1)changes 1 unit, the hourly loss $(E(L))$will decrease 0.018.The deviation of using this model is 0.124632 as shown in Table 4.18.

$$E(L) = 0.297 - 0.018\,t_1$$
$$(6.027^{*}) \quad (-2.645^{*})$$

R^2 = 0.333 S.E. = 0.124632 F = 6.994

Note * Significance level < 0.05

where $E(L)$ is the hourly loss

t_1 is the time to identify and correct the assignable cause

Table 4.18 SPSS output for the hourly loss $(E(L))$ of VP MEWMA control chart

Model Summary Table

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.577(a)	.333	.286	.124631

(*)Predictors: (Constant), t_1

ANOVA Table

Model	Sum of Squares	df	Mean Square	F	P-Value
Regression	.109	1	.109	6.994	0.019 (*)
Residual	.217	14	.016		
Total	.326	15			

(*) Predictors: (Constant), t_1

Table of regression coefficients

Independent Variable	Coefficient	Std. error	t	P-Value
(Constant)	.297	.049	6.027*	0.000
t_1	-.018	.007	-2.645*	0.019

(*) Dependent Variable: $(E(L))$

4.3 VPSC MEWMA Control Chart

4.3.1 Numerical Example and Sensitivity Analysis

In this section, numerical example and sensitivity analysis are conducted to study the effect of model parameters on the solution of economic design of the VPSC MEWMA chart. Then, using the design economic model of VPSC MEWMA control chart and minimizing the hourly loss of VPSC MEWMA control chart by using Genetic algorithm. The sensitivity analysis for economic model of VPSC MEWMA control chart and minimizing the hourly loss of VPSC MEWMA control chart is carried out using orthogonal-array experimental design and multiple regressions. Here, the model parameters are considered as the independent variables and the three test parameters (i.e., n_2, h_1 *and* h_2), as well as the average cost per unit time $(ECTU)$ of VPSC MEWMA control chart and average hourly loss $(E(L))$ of VPSC MEWMA control chart are treated as the dependent variables. We set warning limit and control limit from performance of the VPSC MEWMA control chart, which depends on the number of sample as shown in Table 4.22 and eleven independent parameters (i.e., the model parameters) considered in the sensitivity analysis and their corresponding level planning are shown in Table 4.23.

4.3.1 Numerical Example and Sensitivity Analysis of VPSC MEWMA Control Chart

Table 4.19 The sample data of VPSC MEWMA control chart when n=8, $\mu_0 = (6.93, 3.86), \sum_0 = \begin{bmatrix} 0.6 & -0.04 \\ -0.04 & 0.8 \end{bmatrix}$

x_1								x_2							
3.44	3.85	4.07	4.37	2.69	4.35	4.31	4.84	6.58	7.45	6.89	5.66	6.35	6.24	7.44	6.44
4.55	4.09	3.18	3.21	4.70	2.95	2.95	4.29	7.90	7.45	7.55	6.87	6.08	4.97	8.11	7.24
3.58	4.32	3.81	3.38	5.03	4.35	4.99	2.49	8.30	7.43	6.76	8.47	5.94	7.01	5.10	6.94
3.53	3.53	3.96	3.03	2.01	4.17	5.57	3.83	7.83	6.25	6.94	6.69	6.60	6.95	7.49	5.99
2.67	4.70	1.83	4.34	4.19	3.20	2.61	4.13	7.64	6.70	5.90	6.59	8.70	6.32	6.60	4.84
5.12	2.58	4.19	3.46	5.29	5.42	5.80	4.28	7.29	8.49	6.29	6.71	7.02	6.82	6.79	7.60
4.59	5.39	4.12	4.77	4.95	3.54	3.91	4.67	5.90	6.66	6.22	5.37	6.66	8.05	6.91	5.95
4.42	2.57	3.52	3.93	4.16	4.76	3.48	3.23	8.03	7.84	6.93	6.56	6.71	4.85	6.29	7.50
3.01	3.94	3.82	3.18	3.29	4.58	4.89	4.67	6.52	6.04	7.62	7.09	6.43	6.85	5.39	7.42
3.60	3.63	3.76	4.22	2.77	4.44	3.30	2.47	7.99	7.55	7.18	6.12	7.00	5.51	5.07	7.56
3.35	4.00	5.83	3.20	2.82	2.72	2.56	2.35	5.70	7.21	7.13	6.05	6.85	7.66	5.93	7.98
3.33	3.42	3.45	4.93	3.65	1.76	4.19	4.23	8.59	7.03	8.57	5.99	8.04	7.25	7.86	7.80
3.91	3.60	3.22	4.69	6.52	5.24	3.39	4.01	8.02	6.15	6.89	8.18	7.66	5.69	6.91	6.68
1.58	2.69	3.13	5.29	3.08	2.89	2.72	4.40	7.21	7.47	7.39	7.00	6.79	6.90	6.53	6.49
4.88	4.95	3.85	4.22	4.91	4.20	3.12	4.54	6.63	6.40	7.44	7.15	5.83	7.04	5.33	6.78

Table 4.20 The VPSC MEWMA value of data when $n = 8, r = 0.2$

z_1								z_2								$T_{\bar{Z}}$	T_s	T_p
3.78	3.79	3.85	3.95	3.70	3.83	3.92	4.11	6.86	6.98	6.96	6.70	6.63	6.55	6.73	6.67	0.0053	0.0058	0.0112
4.00	4.02	3.85	3.72	3.92	3.72	3.57	3.71	7.12	7.19	7.26	7.18	6.96	6.56	6.87	6.95	0.0015	0.0117	0.0132
3.80	3.91	3.89	3.79	4.04	4.10	4.28	3.92	7.20	7.25	7.15	7.42	7.12	7.10	6.70	6.75	0.0063	0.0127	0.0189
3.79	3.74	3.78	3.63	3.31	3.48	3.90	3.89	7.11	6.94	6.94	6.89	6.83	6.85	6.98	6.78	0.0041	0.0070	0.0111
3.62	3.84	3.44	3.62	3.73	3.62	3.42	3.56	7.07	7.00	6.78	6.74	7.13	6.97	6.90	6.48	0.0096	0.0155	0.0251
4.11	3.81	3.88	3.80	4.10	4.36	4.65	4.57	7.00	7.30	7.10	7.02	7.02	6.98	6.94	7.07	0.0161	0.0058	0.0219
4.01	4.28	4.25	4.36	4.47	4.29	4.21	4.30	6.72	6.71	6.61	6.36	6.42	6.75	6.78	6.61	0.0388	0.0097	0.0486
3.97	3.69	3.66	3.71	3.80	3.99	3.89	3.76	7.15	7.29	7.22	7.09	7.01	6.58	6.52	6.72	0.0004	0.0162	0.0166
3.69	3.74	3.75	3.64	3.57	3.77	4.00	4.13	6.85	6.69	6.87	6.92	6.82	6.82	6.54	6.71	0.0053	0.0065	0.0118
3.81	3.77	3.77	3.86	3.64	3.80	3.70	3.45	7.14	7.22	7.21	7.00	7.00	6.70	6.37	6.61	0.0027	0.0181	0.0208
3.76	3.81	4.21	4.01	3.77	3.56	3.36	3.16	6.68	6.79	6.86	6.69	6.73	6.91	6.71	6.97	0.0073	0.0156	0.0229
3.75	3.69	3.64	3.90	3.85	3.43	3.58	3.71	7.26	7.22	7.49	7.19	7.36	7.34	7.44	7.51	0.0353	0.0056	0.0409
3.87	3.82	3.70	3.89	4.42	4.58	4.34	4.28	7.15	6.95	6.94	7.19	7.28	6.96	6.95	6.90	0.0116	0.0167	0.0283
3.40	3.26	3.23	3.65	3.53	3.40	3.27	3.49	6.99	7.08	7.14	7.12	7.05	7.02	6.92	6.84	0.0295	0.0043	0.0339
4.06	4.24	4.16	4.18	4.32	4.30	4.06	4.16	6.87	6.78	6.91	6.96	6.73	6.79	6.50	6.56	0.0187	0.0055	0.0242

Table 4.21 Example value of VPSC MEWMA from the collect data when $n = 4$

Z_1				Z_2				$D_{\bar{Z}}$	D_s	T_p
6.8809	7.3321	5.6634	8.1333	4.5901	4.5754	4.5361	4.518	0.0116	0.0036	0.0152
7.833	6.4566	7.8539	7.2899	4.5458	4.5931	4.5893	4.3618	0.0178	0.0024	0.0202
9.3118	7.2477	6.9828	5.9994	2.846	4.3236	4.1813	3.611	0.0229	0.0047	0.0275
6.4645	6.0404	7.3147	8.4399	4.0785	3.3154	4.8228	3.3444	0.0009	0.006	0.0069
5.99	7.7679	6.2177	6.9949	3.7673	4.4899	3.7700	4.753	0.003	0.0023	0.0052
6.0013	6.8569	6.6404	6.9163	3.801	3.5673	2.1741	2.0827	0.0178	0.0098	0.0276
8.3848	5.4447	7.2096	7.269	4.3412	2.0869	3.1984	4.0555	0.0061	0.0079	0.014
8.1876	7.2474	6.7472	5.7371	3.808	4.3297	5.1301	2.7634	0.006	0.0063	0.0123
6.9466	6.4658	6.0395	6.236	3.5203	3.3519	2.1709	3.1477	0.0188	0.0089	0.0277
6.8982	5.3727	6.2157	7.7271	2.7082	4.427	3.3251	3.4327	0.0137	0.0046	0.0183
6.0444	6.4471	6.8841	6.4611	4.3259	4.0026	3.5327	2.7396	0.0088	0.0024	0.0112
6.8623	7.4504	7.1351	6.834	2.7518	4.8483	3.5052	5.0355	0.0009	0.0036	0.0044
7.0043	4.7891	6.911	6.7909	3.6031	3.2169	4.1167	3.5512	0.0146	0.0054	0.02
8.5787	7.4971	7.7083	7.178	4.042	3.0671	3.3973	4.0215	0.0297	0.0014	0.0311
7.5849	7.8938	7.7739	6.8764	4.2404	4.0877	2.8351	2.938	0.0155	0.0051	0.0206

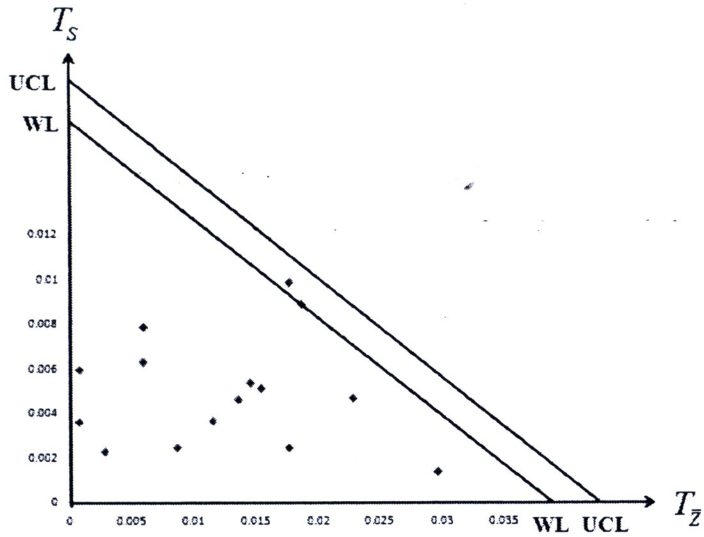


Figure 4.8 VPSC MEWMA control chart: $n = 4, WL = 3.947, UCL = 5.8936$

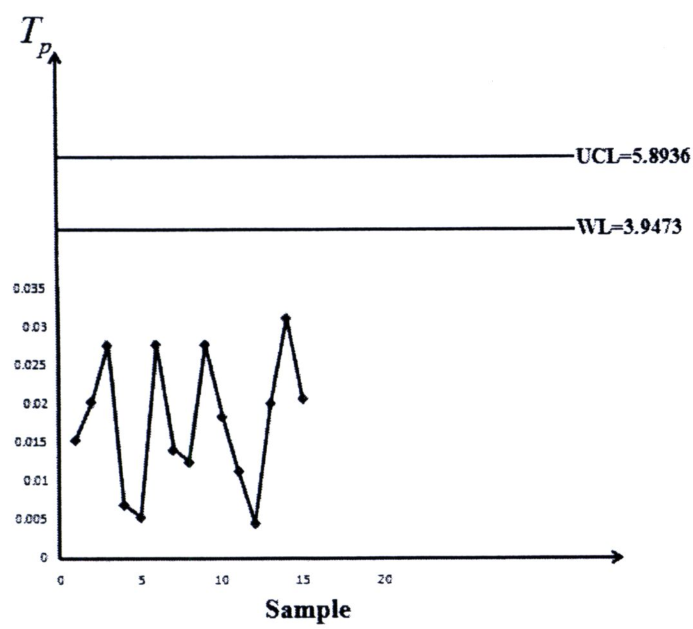


Figure 4.9 VPSC MEWMA value with respect to time series

Table 4.22 Warning limit and control limit depend on r and p of VPSC MEWMA control chart

Value of p	Control limit 2	3	4	5	Warning limit 2	3	4	5
$n=2$	8.126	10.031	11.787	13.45	4.86	6.427	7.898	9.309
$n=3$	6.687	8.419	10.032	11.571	5.265	5.74	7.119	8.451
$n=4$	5.894	7.524	9.054	10.52	3.214	5.339	6.665	7.952
$n=5$	5.38	6.943	8.416	9.832	3.723	5.071	6.361	7.617
$n=6$	5.016	6.529	7.961	9.34	3.559	4.875	6.14	7.373
$n=7$	4.742	6.217	7.616	8.967	3.433	4.725	5.97	7.185
$n=8$	4.527	5.97	7.344	8.672	3.333	4.605	5.834	7.035
$n=9$	4.353	5.771	7.122	8.432	3.25	4.506	5.722	6.911
$n=10$	4.208	5.604	6.938	8.232	3.181	4.424	5.628	6.807

Table 4.23 Eleven model parameters and their level planning of VPSC MEWMA control chart.

Model parameter	Level 1	Level 2	Level 3	Level 4
n_1	2	3	4	5
d	0.5	1	1.5	2
s	5	10		
C_0	250	500		
C_1	50	500		
V_0	250	500		
V_1	50	100		
t_0	2.5	5		
t_1	1	10		
λ	0.01	0.05		
p	2	3		

Eleven independent parameters considered in the sensitivity analysis and their corresponding level planning is shown in Table 4.23 The $L_{16}(2^9 4^2)$ orthogonal array is employed and the eleven independent parameters are then assigned to columns of the $L_{16}(2^9 4^2)$ array , as shown in Table 4.24. In the $L_{16}(2^9 4^2)$ orthogonal array experiment design, there are 16 trials (i.e., 16 different level combinations of the independent variable). For each trial, the Genetic Algorithm is applied to produce the optimal solution of the economic design.

Table 4.24 Model parameter assignment in the L_{16} orthogonal array and the corresponding solution of VPSC MEWMA control chart.

Trail	Model parameter										
	n_1	d	s	C_0	C_1	V_0	V_1	t_0	t_1	λ	p
1	2	0.5	5	250	50	250	50	2.5	1	.01	2
2	2	1	5	250	50	500	100	5	10	.05	3
3	3	0.5	5	500	500	250	100	5	10	.05	3
4	3	1	5	500	500	500	50	2.5	1	.01	2
5	3	1.5	10	250	50	250	50	2.5	1	.05	3
6	3	2	10	250	50	500	100	5	10	.01	2
7	2	1.5	10	500	500	250	100	5	10	.01	2
8	2	2	10	500	500	500	50	2.5	1	.05	3
9	4	0.5	10	250	500	500	50	2.5	10	.01	3
10	4	1	10	250	500	250	100	5	1	.05	2
11	5	0.5	10	500	50	500	100	5	1	.05	2
12	5	1	10	500	50	250	50	2.5	10	.01	3
13	5	1.5	5	250	500	500	50	2.5	10	.05	2
14	5	2	5	250	500	250	100	5	1	.01	3
15	4	1.5	5	500	50	500	100	5	1	.01	3
16	4	2	5	500	50	250	50	2.5	10	.05	2

Table 4.25 The Optimal solution to the economic design of VPSC MEWMA control chart

NO.	Solution					
	n_1	n_2	h_1	h_2	$E(L)$	$ECTU$
1	2	3	5.139	4.5	146.146	103.854
2	2	3	1.675	1	280.719	219.281
3	3	4	2.46	2	164.714	85.286
4	3	4	15	14	200.193	299.807
5	3	4	4.627	4.043	77.656	172.344
6	3	4	28.08	27.5	54.797	445.203
7	2	3	12.522	1	83.987	166.013
8	2	3	3.435	1.037	145.123	354.877
9	4	5	16.298	16	324.614	175.386
10	4	5	5.539	4.65	85.707	164.293
11	5	6	4.305	4	302.481	197.519
12	5	6	32.276	32	79.309	170.691
13	5	6	8.568	8	250.897	249.103
14	5	6	46.317	46	53.748	196.252
15	4	5	34.753	34	162.513	337.487
16	4	5	8.691	8	100.075	149.925

We found that the optimal values of the policy variables those minimize $(E(L))$ are $n_1 = 5,\ n_2 = 6,\ h_1 = 46.317,\ h_2 = 46$ and corresponding hourly loss $(E(L))$ and average cost per time unit $ECTU$ are 53.748 and 196.252 respectively.

Table 4.26 The Optimal value of model parameters of VPSC MEWMA control chart.

Parameter	Value	Parameter	Value	Parameter	Value
n_1	5	C_1	500	t_1	1
d	2	V_0	250	λ	0.01
s	5	V_1	100	p	3
C_0	250	t_0	5		

The best value variable by genetic algorithm show that table 4.26

Table 4.27 The Optimal values for three parameter, the optimal value of the total hourly loss of VPSC MEWMA control chart.

Variable	Integrate model of VPSC MEWMA control chart
n_2	6
h_1	46.317
h_2	46
$E(L)$	53.748

We found that the optimal values of the policy variables those minimize $E(L)$ are $n_2 = 6$, $h_1 = 46.317, h_2 = 56$ and the corresponding hourly loss $E(L) = 53.748$.

4.3.2 Data Analysis

The output of the GA for each trial is also recorded in Table 4.26 and 4.27

To study the effect of model parameters on the solution of economic design of VPSC MEWMA control chart, based on the data in Table 4.23 and Table 4.24, the statistical software SPSS 15.0 is used to run the regression analysis for each dependent variable. For each dependent variable, the output of SPSS includes an ANOVA table for regression and a table of regression coefficients, showing the corresponding information about statistical hypothesis testing.

For finding appropriated the long sampling interval (h_1), it will be on the basis that the long sampling interval (h_1) is depended on the following: small sample size (n_1) ,the magnitude of shift (d), the parameter of exponential distribution (λ) ,the quality characteristics(p) ,the cost for each inspected item (s), the average amount of time exhausted searching for the assignable cause when the process is in-control (t_0),the time to identify and correct the assignable cause (t_1),the average search cost if the given signal is false (C_0),the average cost to discover the assignable cause and adjust the process to in-control state(C_1),the hourly profit earned when the process is operating in control state (V_0), the hourly profit earned when the process is operating in out-of-control state (V_1). When studying the relationships from all values using Stepwise regression, it was found that the long sampling interval (h_1) depends on the parameter of exponential distribution (λ), the small sample size (n_1) ,the magnitude of shift (d),the quality characteristics $(p)$and the average amount of time exhausted searching for the assignable cause when the process is in-control(t_0). They will result to the change of the long sampling interval (h_1) at 97.8%.Therefore, if the parameter of exponential distribution (λ) changes 1 unit while the small sample size (n_1) ,the magnitude of shift (d),the quality characteristics (p) and the average amount of time exhausted searching for the assignable cause when the process is in-control (t_0) are zero ,the long sampling interval (h_1) will decrease 472.141.If the small sample size (n_1) changes 1 unit while the parameter of exponential distribution (λ), the magnitude of shift (d),the quality characteristics (p), the average amount of time exhausted searching for the assignable cause when the process is in-control (t_0) are zero, the long sampling interval (h_1) will increase 5.530. If the magnitude of shift (d) changes 1 unit while the small sample size (n_1),the parameter of exponential distribution (λ),the quality characteristics (p) and the average amount of time exhausted searching for the assignable cause when the process is in-control (t_0) are zero, the long sampling interval (h_1) will increase 9.047. If the quality characteristics (p) changes 1 unit while the parameter of exponential distribution (λ), the magnitude of shift (d), the small sample size (n_1) and the average amount of time exhausted searching for the assignable cause when the process is in-control (t_0) are zero, the long sampling interval (h_1) will increase 6.750. If the average amount of time exhausted searching for the assignable cause when the process is in-control (t_0) changes 1 unit while the magnitude of shift (d) the small sample size (n_1),the parameter of exponential distribution (λ) and the quality characteristics (p) are zero, the long sampling interval (h_1) will increase 2.081.The deviation of using this model is 2.492 as shown in Table 4.28.

$$h_1 = -26.822 - 472.141\,\lambda + 9.047\,d + 5.530\,n_1 + 6.750\,p + 2.081\,t_0$$
$$(-5.967^*)\ (-15.156^*)\ \ (8.118^*)\ \ (9.924^*)\ \ (5.417)\ \ (4.175)$$

$R^2 = 0.978$ S.E. = 2.492 F = 88.170

Note * Significance level < 0.05

where λ is the parameter of exponential distribution
d is the magnitude of shift
n_1 is the small sample size
t_0 is the average amount of time exhausted searching for the assignable cause when the process is in-control
p is the quality characteristics

Table 4.28 SPSS output for long sampling interval (h_1) of VPSC MEWMA control chart R^2=.978, R^2adjust=.967

Model Summary Table

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.989(a)	.978	.967	2.492

(*)Predictors: (Constant), λ, d, n_1, p, t_0

ANOVA Table

Model	Sum of Squares	df	Mean Square	F	P-Value
Regression	2738.013	5	547.603	88.170	0.000 (*)
Residual	62.107	10	6.211		
Total	2800.120	15			

(*) Predictors: (Constant), λ, d, n_1, p, t_0

Table of regression coefficients

Independent Variable	Coefficient	Std. error	t	P-Value
(Constant)	-26.822	4.495	-5.967*	0.000
λ	-472.141	31.152	-15.156*	0.000
d	9.047	1.115	8.118*	0.000
n_1	5.530	0.557	9.924*	0.000
p	6.750	1.246	5.417*	0.000
t_0	2.081	0.498	4.175*	0.002

(a) Dependent Variable: h_1

For finding appropriated the short sampling interval (h_2), it will be on the basis that the short sampling interval (h_2) is depended on the following: small sample size (n_1),the magnitude of shift (d) ,the parameter of exponential distribution (λ),the quality characteristics (p) ,the cost for each inspected item (s) , the average amount of time exhausted searching for the assignable cause when the process is in-control (t_0),the time to identify and correct the assignable cause(t_1),the average search cost if the given signal is false (C_0),the average cost to discover the assignable cause and adjust the process to in-control state (C_1),the hourly profit earned when the process is operating in control state(V_0), the hourly profit earned when the process is operating in out-of-control state (V_1). When studying the relationships from all values using Stepwise regression, it was found that the short sampling interval(h_2)depends on the parameter of exponential distribution(λ), the small sample size(n_1) , the magnitude of shift(d), the quality characteristics(p). They will result to the change of the short sampling interval(h_2) at 90.2%.Therefore, if the parameter of exponential distribution (λ) changes 1 unit while the small sample size (n_1), the magnitude of shift (d) and the quality characteristics(p) are zero , the short sampling interval (h_2) will decrease 444.594. If the small sampling size (n_1)changes 1 unit while the parameter of exponential distribution(λ), the magnitude of shift $(d)$and the quality characteristics $(p)$are zero, the short sampling interval (h_2) will increase 6.562. If the magnitude of shift (d) changes 1 unit while the small sample size(n_1), the parameter of exponential distribution$(\lambda)$and the quality characteristics(p) are zero, the short sampling interval (h_2) will increase 8.175. If the quality characteristics(p)changes 1 unit while the parameter of exponential distribution(λ), the magnitude of shift $(d)$and the small sample size (n_1) are zero, the short sampling interval (h_1)will increase 8.054.The deviation of using this model is 5.193 as shown in Table 4.29.

$$h_2 = -27.001 - 444.594\,\lambda + 8.175\,d + 6.652\,n_1 + 8.054\,p$$
$$(-3.170^*)\quad(-6.850^*)\quad(3.520^*)\quad(5.652^*)\quad(3.102^*)$$

R^2 = 0.866 S.E. = 5.193 F = 25.220

Note * Significance level < 0.05

where λ is the parameter of exponential distribution
d is the magnitude of shift
n_1 is the small sample size
p is the quality characteristics

Table 4.29 SPSS output for long sampling interval (h_2) of VPSC MEWMA control chart R^2=.902, R^2adjust=.902

Model Summary Table

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.950(a)	.902	.866	5.193

(*) Predictors: (Constant), λ, n_1, d, p

ANOVA Table

Model	Sum of Squares	df	Mean Square	F	P-Value
Regression	2719.970	4	679.992	25.220	0.000 (*)
Residual	296.589	11	26.963		
Total	3016.559	15			

(*) Predictors: (Constant), λ, n_1, d, p

Table of regression coefficients

Independent Variable	Coefficient	Std. error	t	P-Value
(Constant)	-27.001	8.517	-3.170*	0.009
λ	-444.594	64.907	-6.850*	0.000
n_1	6.562	1.161	5.652*	0.000
d	8.175	2.322	3.520*	0.005
p	8.054	2.596	3.102*	0.010

(*) Dependent Variable: h_2

For finding appropriated the hourly loss $(E(L))$, it will be on the basis that the hourly loss $(E(L))$,is depended on the following: small sample size (n_1) , the magnitude of shift(d),the parameter of exponential distribution(λ), the quality characteristics(p) ,the cost for each inspected item(s) , the average amount of time exhausted searching for the assignable cause when the process is in-control (t_0),the time to identify and correct the assignable cause (t_1),the average search cost if the given signal is false(C_0),the average cost to discover the assignable cause and adjust the process to in-control state (C_1),the hourly profit earned when the process is operating in control state (V_0), the hourly profit earned when the process is operating in out-of-control state (V_1).

When studying the relationships from all values using Stepwise regression, it was found that the hourly loss $(E(L))$ depends on the time to identify and correct the hourly profit earned when the process is operating in control state (V_0) and the magnitude of shift (d). They will result to the change of the hourly loss $(E(L))$ at 77.9%. Therefore, if the hourly profit earned when the process is operating in control state (V_0) changes 1 unit while the magnitude of shift (d) is zero, the hourly loss $(E(L))$ is increase 0.465. If the magnitude of shift (d) changes 1 unit while the hourly profit earned when the process is operating in control state (V_0) is zero, the hourly loss $(E(L))$ will decrease 91.176. The deviation of using this model is 45.631 as shown in Table 4.30.

$$E(L) = 96.638 + 0.465\ V_0 - 91.176\ d$$
$$(2.187^*)\quad (5.095^*)\quad (-4.468^*)$$

R^2 = 0.779 S.E. = 45.631 F = 22.962

Note * Significance level < 0.05

where V_0 is the hourly profit earned when the process is operating in control state
d is the magnitude of shift

Table 4.30 SPSS output for hourly loss $(E(L))$ of VPSC MEWMA control chart
R^2=.779, R^2adjust=.745

Model Summary Table

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.883(a)	.0.779	.745	45.631

(a) Predictors: (Constant), V_0, d

ANOVA Table

Model	Sum of Squares	df	Mean Square	F	P-Value
Regression	95620.573	2	47810.287	22.962	0.000 (a)
Residual	27067.853	13	2082.143		
Total	122688.4	15			

(a) Predictors: (Constant), V_0, d

Table of regression coefficients

Independent Variable	Coefficient	Std. error	t	P-Value
(Constant)	96.638	44.182	2.187*	0.048
V_0	0.465	0.091	5.095*	0.000
d	-91.176	20.407	-4.468*	0.001

(a) Dependent Variable: $E(L)$