CHAPTER 9 EXERCISES

SS **9.1.** The data in Table 9E.1 represent individual observations on molecular weight taken hourly from a chemical process.

Table 9E.1 Molecular Weight

Observation Number	*x*	Observation Number	*x*
1	1,045	11	1,139
2	1,055	12	1,169
3	1,037	13	1,151
4	1,064	14	1,128
5	1,095	15	1,238
6	1,008	16	1,125
7	1,050	17	1,163
8	1,087	18	1,188
9	1,125	19	1,146
10	1,146	20	1,167

The target value of molecular weight is 1,050 and the process standard deviation is thought to be about $\sigma = 25$.

a. Set up a tabular CUSUM for the mean of this process. Design the CUSUM to quickly detect a shift of about 1.0σ in the process mean.

b. Is the estimate of σ used in part (a) of this problem reasonable?

9.2. Rework Exercise 9.1 using a standardized CUSUM.

SS **9.3.** **a.** Add a headstart feature to the CUSUM in Exercise 9.1.

b. Use a combined Shewhart–CUSUM scheme on the data in Exercise 9.1. Interpret the results of both charts.

9.4. The data in Table 9E.2 are temperature readings from a chemical process in °C, taken every two minutes. (Read the observations down, from left.)

The target value for the mean is $\mu_0 = 950$.

Table 9E.2 Chemical Process Temperature Data

953	985	949	937	959	948	958	952
945	973	941	946	939	937	955	931
972	955	966	954	948	955	947	928
945	950	966	935	958	927	941	937
975	948	934	941	963	940	938	950
970	957	937	933	973	962	945	970
959	940	946	960	949	963	963	933
973	933	952	968	942	943	967	960
940	965	935	959	965	950	969	934
936	973	941	956	962	938	981	927

a. Estimate the process standard deviation.

b. Set up and apply a tabular CUSUM for this process, using standardized values $h = 5$ and $k = \frac{1}{2}$. Interpret this chart.

9.5. Bath concentrations are measured hourly in a chemical process. Data (in ppm) for the last 32 hours are shown in Table 9E.3 (read down from left). SS

Table 9E.3 Bath Concentration

160	186	190	206
158	195	189	210
150	179	185	216
151	184	182	212
153	175	181	211
154	192	180	202
158	186	183	205
162	197	186	197

The process target is $\mu_0 = 175$ ppm.

a. Estimate the process standard deviation.

b. Construct a tabular CUSUM for this process using standardized values of $h = 5$ and $k = \frac{1}{2}$.

SS **9.6.** Viscosity measurements on a polymer are made every 10 minutes by an on-line viscometer. Thirty-six observations are shown in Table 9E.4 (read down from left). The target viscosity for this process is $\mu_0 = 3{,}200$.

Table 9E.4 Polymer Viscosity

3,169	3,205	3,185	3,188
3,173	3,203	3,187	3,183
3,162	3,209	3,192	3,175
3,154	3,208	3,199	3,174
3,139	3,211	3,197	3,171
3,145	3,214	3,193	3,180
3,160	3,215	3,190	3,179
3,172	3,209	3,183	3,175
3,175	3,203	3,197	3,174

a. Estimate the process standard deviation.
b. Construct a tabular CUSUM for this process using standardized values of $h = 8.01$ and $k = 0.25$.
c. Discuss the choice of h and k in part (b) of this problem on CUSUM performance.

9.7. Consider the loan processing cycle time data in Exercise 8.10. Set up a CUSUM chart for monitoring this process. Does the process seem to be in statistical control?

9.8. Consider the loan processing cycle time data in Exercise 8.10. Set up an EWMA control chart for monitoring this process using $\lambda = 0.1$. Does the process seem to be in statistical control?

9.9. Consider the "minute clinic" waiting time data in Exercise 6.41. These data may not be normally distributed. Set up a CUSUM chart for monitoring this process. Does the process seem to be in statistical control?

SS **9.10.** Consider the "minute clinic" waiting time data in Exercise 6.41. These data may not be normally distributed. Set up an EWMA control chart using $\lambda = 0.1$ for monitoring this process. Does the process seem to be in statistical control?

9.11. Consider the "minute clinic" waiting time data in Exercise 6.41. Set up an EWMA control chart using $\lambda = 0.4$ for monitoring this process. Compare this EWMA chart to the one from Exercise 9.10.

9.12. Apply the scale CUSUM discussed in Section 9.1.8 to the data in Exercise 9.1.

9.13. Apply the scale CUSUM discussed in Section 9.1.8 to the concentration data in Exercise 9.5.

9.14. Consider the viscosity data in Exercise 9.6. Suppose that the target value of viscosity is $\mu_0 = 3{,}150$ and that it is only important to detect disturbances in the process that result in increased viscosity. Set up and apply an appropriate one-sided CUSUM for this process.

9.15. Rework Exercise 9.1 using an EWMA control chart with $\lambda = 0.1$ and $L = 2.7$. Compare your results to those obtained with the CUSUM. SS

9.16. Consider a process with $\mu_0 = 10$ and $\sigma = 1$. Set up the following EWMA control charts:
a. $\lambda = 0.1,\ L = 3$
b. $\lambda = 0.2,\ L = 3$
c. $\lambda = 0.4,\ L = 3$

Discuss the effect of λ on the behavior of the control limits.

9.17. Reconsider the data in Exercise 9.4. Apply an EWMA control chart to these data using $\lambda = 0.1$ and $L = 2.7$.

9.18. Reconstruct the control chart in Exercise 9.17 using $\lambda = 0.4$ and $L = 3$. Compare this chart to the one constructed in Exercise 9.17.

9.19. Reconsider the data in Exercise 9.5. Set up and apply an EWMA control chart to these data using $\lambda = 0.05$ and $L = 2.6$.

9.20. Reconsider the homicide data in Exercise 7.52. Set up an EWMA control chart for this process with $\lambda = 0.1$ and $L = 2.7$. Does potential non-normality in the data pose a concern here? SS

9.21. Reconsider the data in Exercise 9.6. Set up and apply an EWMA control chart to these data using $\lambda = 0.1$ and $L = 2.7$.

9.22. Analyze the data in Exercise 9.1 using a moving average control chart with $w = 6$. Compare the results obtained with the cumulative sum control chart in Exercise 9.1.

9.23. Analyze the homicide data in Exercise 7.52 using a moving average control chart with $w = 5$. Does potential non-normality in the data pose a concern here? SS

9.24. Show that if the process is in control at the level μ, the exponentially weighted moving average is an unbiased estimator of the process mean.

9.25. Derive the variance of the exponentially weighted moving average z_i.

9.26. **Equivalence of moving average and exponentially weighted moving average control charts.** Show that

6.38. The viscosity of a polymer is measured hourly. Measurements for the last 20 hours are shown in Table 6E.12.

Table 6E.12 Viscosity Data for Exercise 6.38

Test	Viscosity	Test	Viscosity
1	2,838	11	3,174
2	2,785	12	3,102
3	3,058	13	2,762
4	3,064	14	2,975
5	2,996	15	2,719
6	2,882	16	2,861
7	2,878	17	2,797
8	2,920	18	3,078
9	3,050	19	2,964
10	2,870	20	2,805

a. Does viscosity follow a normal distribution?

b. Set up a control chart on viscosity and a moving range chart. Does the process exhibit statistical control?

c. Estimate the process mean and standard deviation.

6.39. Continuation of Exercise 6.38. The next five measurements on viscosity are 3,163, 3,199, 3,054, 3,147, and 3,156. Do these measurements indicate that the process is in statistical control?

6.40. a. Thirty observations on the oxide thickness of individual silicon wafers are shown in Table 6E.13. Use these data to set up a control chart on oxide thickness and a moving range chart. Does the process exhibit statistical control? Does oxide thickness follow a normal distribution?

Table 6E.13 Data for Exercise 6.40

Wafer	Oxide Thickness	Wafer	Oxide Thickness
1	45.4	16	58.4
2	48.6	17	51.0
3	49.5	18	41.2
4	44.0	19	47.1
5	50.9	20	45.7
6	55.2	21	60.6
7	45.5	22	51.0
8	52.8	23	53.0
9	45.3	24	56.0
10	46.3	25	47.2
11	53.9	26	48.0
12	49.8	27	55.9
13	46.9	28	50.0
14	49.8	29	47.9
15	45.1	30	53.4

b. Following the establishment of the control charts in part (a), 10 new wafers were observed. The oxide thickness measurements are as follows:

Wafer	Oxide Thickness
1	54.3
2	57.5
3	64.8
4	62.1
5	59.6
6	51.5
7	58.4
8	67.5
9	61.1
10	63.3

Plot these observations against the control limits determined in part (a). Is the process in control?

c. Suppose the assignable cause responsible for the out-of-control signal in part (b) is discovered and removed from the process. Twenty additional wafers are subsequently sampled. Plot the oxide thickness against the part (a) control limits. What conclusions can you draw? The new data are shown in Table 6E.15.

6.41. The waiting time for treatment in a "minute-clinic" located in a drugstore is monitored using control charts for individuals and the moving range. Table 6E.14 contains 30 successive measurements on waiting time.

Table 6E.14 Clinic Waiting Time for Exercise 6.41

Observation	Waiting Time	Observation	Waiting Time	Observation	Waiting Time
1	2.49	11	1.34	21	1.14
2	3.39	12	0.50	22	2.66
3	7.41	13	4.35	23	4.67
4	2.88	14	1.67	24	1.54
5	0.76	15	1.63	25	5.06
6	1.32	16	4.88	26	3.40
7	7.05	17	15.19	27	1.39
8	1.37	18	0.67	28	1.11
9	6.17	18	4.14	29	6.92
10	5.12	20	2.16	30	36.99

if $\lambda = 2/(w + 1)$ for the EWMA control chart, then this chart is equivalent to a w-period moving average control chart in the sense that the control limits are identical in the steady state.

9.27. **Continuation of Exercise 9.26.** Show that if $\lambda = 2/(w + 1)$, then the average "ages" of the data used in computing the statistics z_i and M_i are identical.

9.28. Show how to modify the control limits for the moving average control chart if rational subgroups of size $n > 1$ are observed every period, and the objective of the control chart is to monitor the process mean.

9.29. An EWMA control chart uses $\lambda = 0.4$. How wide will the limits be on the Shewhart control chart, expressed as a multiple of the width of the steady-state EWMA limits?

9.30. Consider the valve failure data in Example 7.6. Set up a CUSUM chart for monitoring the time between events using the transformed variable approach illustrated in that example. Use standardized values of $h = 5$ and $k = \frac{1}{2}$.

9.31. Consider the valve failure data in Example 7.6. Set up a one-sided CUSUM chart for monitoring and detecting an increase in failure rate of the valve. Assume that the target value of the mean time between failures is 700 hr.

9.32. Set up an appropriate EWMA control chart for the valve failure data in Example 7.6. Use the transformed variable approach illustrated in that example.

9.33. Discuss how you could set up one-sided EWMA control charts.

9.34. Consider the blood pressure and pulse data in Table 4E.8. Set up a cumulative sum control chart for the systolic blood pressure data. Does the blood pressure for this individual seem to be in a state of statistical control? What are some potential assignable causes for this process?

9.35. Consider the blood pressure and pulse data in Table 4E.8. Set up a scale CUSUM for the systolic blood pressure data. Does the variability in this blood pressure for this individual seem to be in a state of statistical control?

9.36. Consider the blood pressure and pulse data in Table 4E.8. Set up a cumulative sum control chart for the diastolic blood pressure data. Does the blood pressure for this individual seem to be in a state of statistical control? What are some potential assignable causes for this process?

9.37. Consider the blood pressure and pulse data in Table 4E.8. Set up a scale CUSUM for the diastolic blood pressure data. Does the variability in this blood pressure for this individual seem to be in a state of statistical control?

9.38. Consider the blood pressure and pulse data in Table 4E.8. Set up an EWMA control chart for the systolic blood pressure data using $\lambda = 0.2$. Does the blood pressure for this individual seem to be in a state of statistical control? What are some potential assignable causes for this process?

9.39. Consider the blood pressure and pulse data in Table 4E.8. Set up an EWMA control chart for the diastolic blood pressure data using $\lambda = 0.2$. Does the blood pressure for this individual seem to be in a state of statistical control? What are some potential assignable causes for this process?

9.40. Consider the blood pressure and pulse data in Table 4E.8. Set up an EWMA control chart for the pulse rate data using $\lambda = 0.2$. Does the blood pressure for this individual seem to be in a state of statistical control? What are some potential assignable causes for this process?

9.41. Consider the blood pressure and pulse data in Table 4E.8. Set up a cumulative sum control chart for the pulse rate data using $\lambda = 0.2$. Does the blood pressure for this individual seem to be in a state of statistical control? What are some potential assignable causes for this process?

9.42. Consider the blood pressure and pulse data in Table 4E.8. Set up a scale CUSUM for the pulse rate data. Does the variability in this blood pressure for this individual seem to be in a state of statistical control?

9.43. Rework Exercise 9.40 using $\lambda = 0.1$. Comment on any differences that you see in the two control charts.

9.44. Rework Exercise 9.38 using $\lambda = 0.1$. Comment on any differences that you see in the two control charts.

9.45. Consider the blood pressure and pulse data in Table 4E.8. Set up a moving average control chart with span w = 5 periods for the systolic blood pressure data. Compare this to the EWMA control chart in Exercise 9.38.

9.46. Consider the blood pressure and pulse data in Table 4E.8. Set up a moving average control chart with span w = 5 periods for the diastolic blood pressure data. Compare this to the EWMA control chart in Exercise 9.39.