Two large professional societies are engaged in the area of controls and control systems. These are as follows: (1) The Control Systems Society of IEEE (Institute of Electrical and Electronics Engineers) with website *www.ieeecss.org* and (2) IFAC (International Federation of Automatic Control) with website *www.ifac-control.org*. In addition, the American Society for Quality with website *www.asq.org* gives special attention to the dimension of control and related quality matters.

Study of much of the material presented in this chapter depends upon proficiency with probability theory and statistics. The material in Appendices C and D is intended to serve this purpose, but it may have to be augmented with prior knowledge and/or by reference to items cited in Appendix G.7.

Three fundamental topics from probability theory underpin Section 11.2 on statistical process control:

1. The Central Limit Theorem—A theorem stating that the distribution of sample means approaches normality as the sample size increases, provided that the sample values are independent. This provides the basis for control charts for variables.
2. The Binomial Distribution—A theoretical probability distribution providing the basis for control charts for attributes, where the sampled characteristic falls into one of two classes.
3. The Poisson Distribution—A theoretical probability distribution providing the basis for control charts for attributes, where the sampled characteristic is a numerical count. This distribution also underpins Section 11.3 on Optimum Policy Control.

A single comprehensive book, *Introduction to Statistical Quality Control*, 5th ed., by D. C. Montgomery, John Wiley & Sons, Inc., 2005, is recommended to those wishing to obtain greater understanding of statistical quality control. In addition, the website for the American Society for Quality at *http://www.asq.org* is an excellent source of information.

Project control is very important in systems engineering. Accordingly, this chapter developed the basic theory behind both CPM and PERT, including PERT-Cost. The relationship and importance of these control methods to systems engineering management is deferred until Part V.

The final section on total quality control revisits statistical process control from a historical and somewhat more basic perspective. It then touches on experimental design from a historical perspective and also from a modern view with a focus on life-cycle outcome predictability. Finally, parameter design and quality engineering are presented to close this chapter. These are topics closely related to the design-dependent parameter approach promulgated in this textbook.

QUESTIONS AND PROBLEMS

1. Speed is one characteristic or condition of an automobile that must be controlled. Discuss the role of each element of a control system for speed control.
2. Sketch a diagram such as Figure 11.1 that would apply to a thermostatically controlled heating system. Discuss each block.
3. Give an example of open-loop control and an example of closed-loop control.
4. What is the relationship among an unstable pattern of variation, control limits, and a Type I error? A Type II error?

5. Samples of $n = 10$ were taken from a process for a period of time. The process average was estimated to be $\overline{X} = 0.0250$ inch and the process range was estimated as $\overline{R} = 0.0020$ inch. Specify the control limits for an $\overline{X}$ chart and for an R chart.

6. Control charts by variables are to be established on the tensile strength in pounds of a yarn. Samples of five have been taken each hour for the past 20 hours. These were recorded as shown in the table.

Hour																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
50	44	44	48	47	47	44	52	44	13	47	49	47	43	44	45	45	50	46	48
51	46	44	52	46	44	46	46	46	44	44	48	51	46	43	47	45	49	47	44
49	50	44	49	46	43	46	45	46	49	44	41	50	46	40	51	47	45	48	49
42	47	47	49	48	40	48	42	46	47	42	46	48	48	40	48	47	49	46	50
43	48	48	46	50	45	46	55	43	45	50	46	42	46	46	46	46	48	45	46

(a) Construct an $\overline{X}$ chart based on these data.

(b) Construct an R chart based on these data.

7. A lower specification limit of 42 pounds is required for the condition of Problem 6. Sketch the relationship between the specification limit and the control limits. What proportion, if any, of the yarn will be defective?

8. The total number of accidents during the long weekends and the number of fatalities for a 10-year period are given in the table. Assuming that the process is in control with regard to the proportion of fatalities, construct a p chart and record the data of the last 8 weekends.

Weekend	Number of Accidents	Number of Fatalities	Weekend	Number of Accidents	Number of Fatalities
1	2,378	426	16	3,943	523
2	3,375	511	17	3,950	557
3	3,108	498	18	4,358	536
4	3,756	525	19	4,217	533
5	3,947	564	20	3,959	547
6	2,953	475	21	4,108	554
7	3,075	490	22	4,379	579
8	3,173	504	23	4,455	598
9	3,479	528	24	4,753	585
10	3,545	555	25	4,276	543
11	3,865	537	26	3,868	507
12	3,747	529	27	3,947	523
13	4,011	569	28	3,665	575
14	3,108	470	29	4,078	569
15	3,207	510	30	4,025	578

9. During a 4-week inspection period, the number of defects listed in the table were found in a sample of 400 electronic components. Construct a c chart for these data. Does it appear as though there existed an assignable cause of variation during the inspection period?