CHAPTER CASE

DataStor Company

INTRODUCTION

"Another rejected shipment! That makes four in the past 20 days!" Tony Escalera knew that his boss, Bill Roberts, wouldn't be happy. Something was wrong, and things were going to be uncomfortable for everybody at DataStor until the problem was solved.

A few years ago, DataStor, a producer of magnetic data storage devices and media for the computer industry, began selling its new DataStor DS100, a compact hard drive, exclusively to Four-D Office Products, a national retailer. This arrangement with Four-D has been very profitable for DataStor.

Bill Roberts, vice president in charge of Sales at DataStor, rose rapidly up the management ladder due in large part to his role in developing the account with Four-D. Four-D had been impressed with Roberts and DataStor's commitment to quality.

In the manufacturing process, each of the three 8-hour shifts produces approximately 1200 DS100 drives per day. Once an hour as part of the quality inspection process, one drive is subjected to the PDQ (Performance and Drive Quality) test, originally developed by DataStor. The PDQ, a stiff test, measures the performance of the drive in a variety of conditions, checks accuracy and speed, and tests for defects in the drive's mechanism and storage media. The PDQ, a relatively expensive test that takes up to 20 minutes to do, computes an overall test score. The scores have historically followed a normal distribution with a mean value of 7.0 and a standard deviation of .30 when the process has been in control. Each hour, the new PDQ value is added to a control chart. Test scores below the lower control limit (LCL) may indicate a drop in quality, while scores above the upper control limit (UCL) may indicate a potential improvement in the process.

Shipments are made to Four-D once each day. Before Four-D accepts a shipment, it runs a random sample of 10 drives through the PDQ test as a final inspection. At Four-D, a drive is judged to be nonconforming if its score falls below 6.2. If one or more drives in the sample of 10 are found to be nonconforming, the entire shipment is judged to be "unacceptable" and returned to DataStor, which must pay a penalty to Four-D and replace the unacceptable shipment within 24 hours. Further penalties are assessed for each additional day that passes before the shipment is replaced.

The production engineers at DataStor have told Bill Roberts that "zero-defect" production is just about impossible, but that the percentage of defects has been reduced to the point that only rarely will a shipment be judged unacceptable. But in recent weeks, the frequency of returned shipments has noticeably increased. It was Tony's job as chief production engineer to bring the bad news of the latest returned shipment to Bill Roberts.

Roberts: Another rejected shipment! That makes four in the past 20 days! What's going on, Tony?

Escalera: Right now, I don't know any more than you do, Mr. Roberts. To borrow some statistical terminology, it's possible that we've just got a few "false rejections." After all, there's variability in any process. Even if the actual quality levels are on target, we expect a few inspections to indicate otherwise.

Roberts: But the number of rejections seems much higher than usual. Has Four-D changed their quality standards?

Escalera: Possibly, but I'm sure they would have told us about it. Maybe they're making mistakes when they do the PDQ tests or interpret the results.

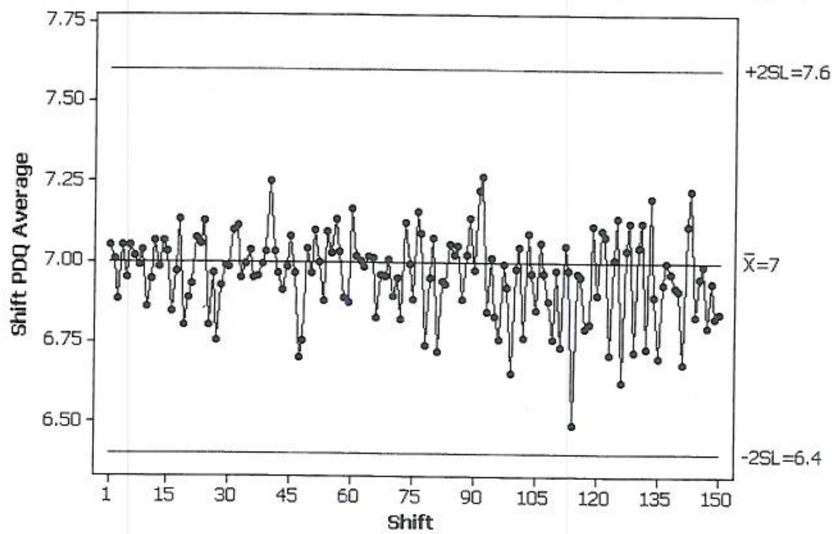
Roberts: Or maybe we're the ones making the mistakes. Is there any sign of quality problems here?

Escalera: You know we sample one drive each hour in each shift and run the test. We used to plot the PDQ value on the control chart each hour, too, but the new quality-control guy told us to plot the average of the eight values at the end of each shift.

Roberts: So what are the control charts saying?

Escalera: No signs of trouble on the latest two-sigma control chart—no out-of-control signals in the past 150 shifts. That's actually a surprise—normally we'd expect about 7 or 8 values out of 150 to fall outside the two-sigma limits. If anything, it looks like the variability in process quality is much lower now than in the past.

FIGURE 6.1 **Two-Sigma Control Chart for 150 Shift PDQ Averages at DataStor**



Roberts: But if the variability has actually gone down, why haven't we seen *fewer* returned shipments? Are we interpreting these charts correctly?

Escalera: I think so. I'll go back and check with the quality-control engineer.

Roberts: Maybe the problem really is at Four-D. Wait a minute! We're forgetting something. If everything looks good on our end, but Four-D is finding nonconformances, could damage in shipment be it?

Escalera: Someone else came up with that, but it's pretty unlikely given our protective packaging.

Roberts: We need to get to the bottom of this, Tony—and I mean ASAP! Check out our side first. If you can't turn up anything here, ask around at Four-D.

Tony collected the data from the tests over the past 150 shifts, which are contained in the file DataStor on the CD that came with your book. A partial listing of the data is shown in Figure 6.2.

FIGURE 6.2 **Partial Listing of the DataStor Company Data**

	A	B	C	D	E	F
1	Week	Day	Shift	WorkerHours	Drives	Shift PDQ
2	1	M	1	91.75	1115	7.052
3	1	M	2	91.25	1154	7.010
4	1	M	3	103.75	1275	6.884
5	1	T	1	96.75	1231	7.051
6	1	T	2	103.25	1280	6.952
7	1	T	3	91.50	1141	7.049
8	1	W	1	97.00	1173	7.018
9	1	W	2	99.25	1217	6.991
10	1	W	3	98.00	1148	7.035
11	1	R	1	95.50	1224	6.858
12	1	R	2	90.25	1156	6.944
13	1	R	3	89.75	1167	7.066
14	1	F	1	102.75	1285	6.984
15	1	F	2	91.25	1116	7.065

These data are coded as follows:

Week:	Week (1–10)
Day:	Day of the week (M, T, W, R, F)
Shift:	Shift (1, 2, 3)
WorkerHours:	Total number of hours worked by production employees during the shift
Drives:	Number of DataStor DS100 hard drives produced during the shift
Shift PDQ:	The average PDQ test score recorded for the eight drives tested during the shift. One randomly selected drive is tested each hour of every shift.

At the end of this chapter, we will help Bill Roberts and Tony Escalera solve the quality problem they are experiencing at DataStor by analyzing these data using statistical tools learned in this and earlier chapters of this book. ■

cross-sectional

time series

enumerative studies

analytic studies

IT'S USEFUL TO DISTINGUISH two kinds of samples. **Cross-sectional** samples are taken from an underlying population at a particular time. As the name implies, the idea is to obtain a reasonably accurate cross section of the relevant population at a particular time. **Time series** samples are taken over time from a random process. A closely related distinction is between **enumerative studies** and **analytic studies.** Enumerative studies involve sampling from a reasonably well-defined population; the purpose is usually to describe the nature of the population. Enumerative studies usually use cross-sectional samples. Analytic studies typically look at the results of a random process; the purpose is often to predict the future behavior of the process. Analytic studies usually involve time series samples.

6.25 As a real estate agent, one of your career goals is to make the Five-Million Dollar Club by selling at least $5,000,000 of residential properties within a one-year time period. From recent data, it is known that the average residential sales price in your area is $104,000 and the standard deviation is $25,000. If you sell 45 residential properties next year, what is the probability that you will make the Five-Million Dollar Club?

BUSINESS DECISION-MAKING IN ACTION

CHAPTER CASE ANALYSIS

DataStor Company

Recall that DataStor Company produces the DataStor DS100, a compact hard drive, and DataStor's main customer is the national retailer Four-D Office Products.

As part of DataStor's quality inspection process, one drive is subjected to the PDQ (Performance and Drive Quality) test hourly. The scores have historically followed a normal distribution with a mean value of 7.0 and a standard deviation of .30 when the process has been in control.

Before Four-D accepts a DS100 shipment, it subjects a random sample of 10 drives to the PDQ test as a final inspection. If one or more drives in the sample are found to be nonconforming (that is, PDQ < 6.2), the entire shipment is judged to be "unacceptable" and returned to DataStor.

The two-sigma control chart for the past 150 shifts, shown in Figure 6.1, does not indicate any problems to DataStor management that would explain the recent noticeable increase in the frequency of returned shipments from Four-D (4 out of the past 20 daily shipments). If anything, it appears that the variation in PDQ scores is actually lower than in the past, indicating higher consistency in drive quality.

We've been asked to examine the situation, using the data from the past 150 shifts recorded in the file DataStor on the CD that came with your book, to determine whether there's a problem and to find its source, if possible. The data for each of the past 150 shifts includes the week (1–10), the day of the week (M, T, W, R, F), the shift number (1, 2, or 3), the number of worker-hours recorded during the shift, the number of hard drives produced during the shift, and the average PDQ test score for the eight drives sampled and tested during the shift.

As a first step in the analysis, we can summarize the individual variables with the graphical and numerical tools described in Chapter 2.

```
Variable        N    Mean   SE Mean   StDev  Minimum       Q1   Median
WorkerHours   150  96.187     0.396   4.852   83.000   93.000   96.250
Drives        150  1204.0       4.2    51.1   1081.0   1171.5   1207.0
Shift PDQ     150  6.9614    0.0109  0.1334   6.4900   6.8840   6.9745

Variable           Q3   Maximum
WorkerHours    98.813   110.499
Drives         1237.3    1339.0
Shift PDQ      7.0492    7.2670
```

Figures 6.9, 6.10, and 6.11 are histograms of the WorkerHours, Drives, and Shift PDQ variables, respectively. The summary statistics and the histograms do not contain any serious outliers or unusual features that would suggest a quality problem at DataStor.

FIGURE 6.9

Histogram of WorkerHours in the DataStor Case

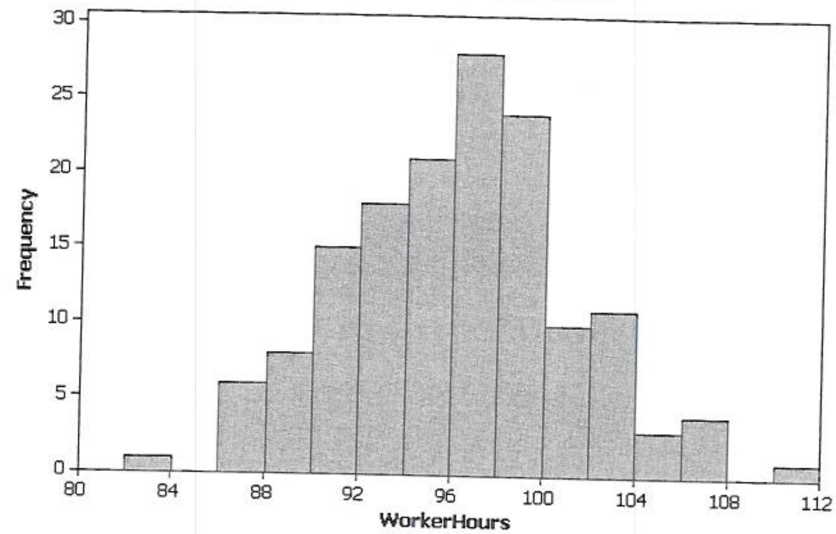
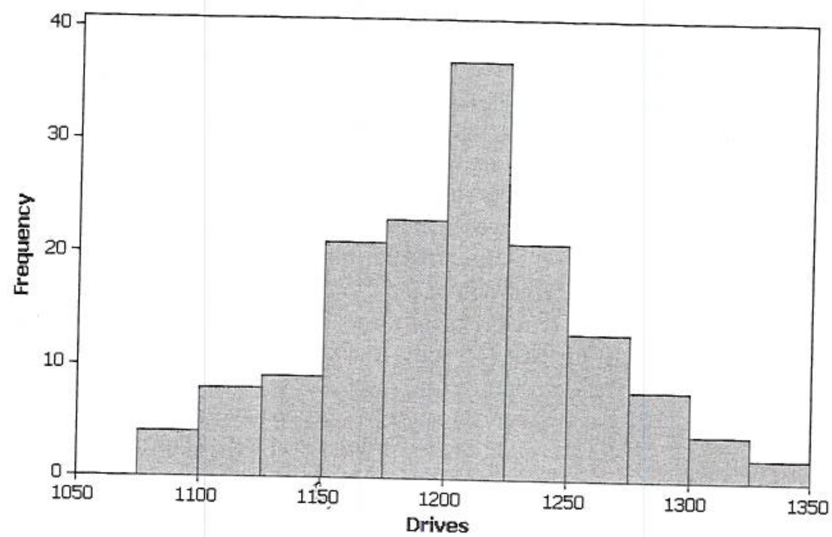


FIGURE 6.10

Histogram of Drives in the DataStor Case

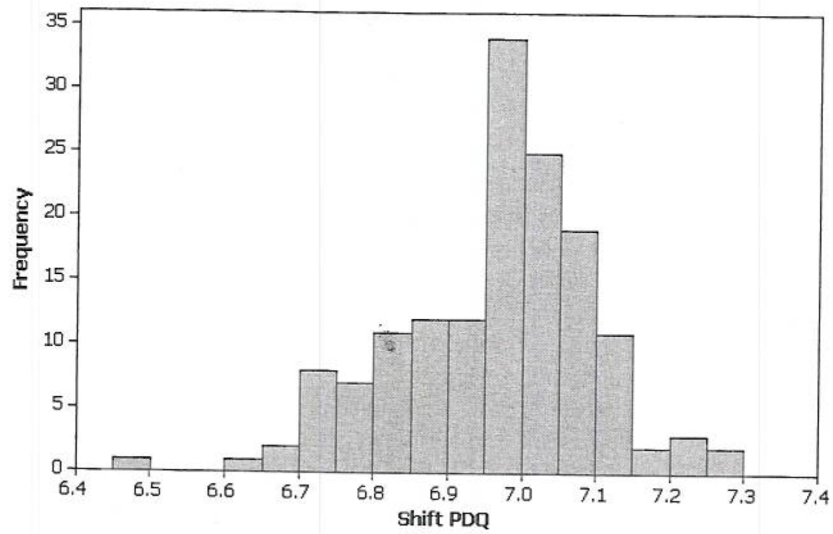


We next check to see if the number of rejected shipments seen recently could have been due to chance. Four-D declares a drive defective if its PDQ test score falls below 6.2. Let's first determine the probability of an individual drive having a score below 6.2. Recall that when the production process is in control, the distribution of scores follows a normal distribution with a mean of 7.0 and a standard deviation of .30, based on historical data. If we let Y denote the score of an individual drive, the probability of its having a score below 6.2 is given by

$$P(Y < 6.2) = P\left(\frac{Y - \mu}{\sigma} < \frac{6.2 - 7.0}{.30}\right) = P(Z < -2.67) = .0038$$

Therefore, Four-D would consider approximately 4 in every 1000 drives to be nonconforming when the production process is in control.

FIGURE 6.11 Histogram of Shift PDQ Averages in the DataStor Case



Assuming the PDQ scores in Four-D's daily sample of the 10 drives are independent and the process is in control, the number of drives in the 10 that fail the test, denoted X, follows a binomial distribution with parameters $n = 10$ and $\pi = .0038$. The probability that one or more drives in the sample of 10 fail the test and the shipment is returned to DataStor is given by

$$P(X \geq 1) = 1 - P(X = 0) = 1 - (1 - .0038)^{10} = .0374$$

If the production process is in control with respect to drive performance and quality, we expect Four-D to reject approximately 1 shipment in 27 (since $1/27 \approx .0374$).

What about the chance of 4 or more rejected shipments in the past 20 days? Is this an unusual event as Bill Roberts suggests? If we let W represent the number of rejected shipments in the past 20 days, then W follows a binomial distribution with $n = 20$ and $\pi = .0374$. The probability distribution for W is easily calculated in Minitab or Excel. (*Note:* Minitab does not show values of W for which the probability is .0000 to four decimals.)

```
MTB > PDF;
SUBC> Binomial 20 .0374.

    Binomial with n = 20 and p = 0.0374

       w          P( W = w )
       0             0.4666
       1             0.3626
       2             0.1338
       3             0.0312
       4             0.0052
       5             0.0006
       6             0.0001
       7             0.0000

MTB > CDF 3;
SUBC> Binomial 20 .0374.

    Binomial with n = 20 and p = 0.0374000

       w          P( W <= w )
    3.00              0.9941
```

From this table, we see that the chance of 4 or more rejected shipments in the past 20 days is

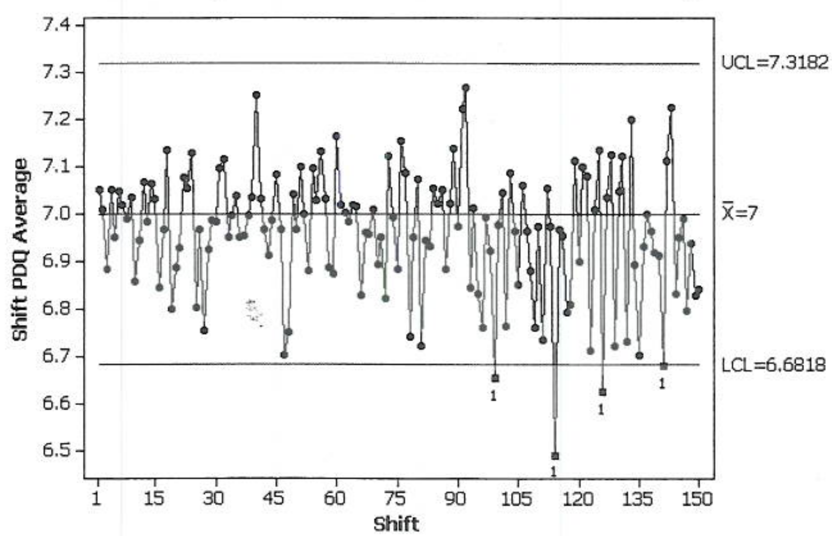
$$\begin{aligned} P(W \geq 4) &= 1 - [P(W = 0) + P(W = 1) + P(W = 2) + P(W = 3)] \\ &= 1 - [.4666 + .3626 + .1338 + .0312] \\ &= 1 - .9942 = .0058 \end{aligned}$$

This is indeed unusual under our assumption that the process is in control. It is highly unlikely that this many rejected shipments could have been due to chance alone.

Since we can rule out chance variation, we might next check the possibility of a quality problem at DataStor by reexamining the control chart in Figure 6.1. Tony Escalera noted that there were no out-of-control signals from the process in the two-sigma control chart over the past 150 shifts and took this as a sign of less variation and improved quality. This is a clue to the problem. In a two-sigma control chart, we expect to have a 5% false alarm rate. Assuming the process is in control, over the course of 150 shifts, we should have seen about seven or eight values beyond the control limits! In fact, the variation of the points in the plot does not even come close to the control limits.

Recall that DataStor recently switched from plotting individual PDQ test scores to plotting shift average PDQ test scores based on eight individual test scores. It simply forgot to adjust the control limits to account for this change. (Obviously, averages have less variation than individual values, so DataStor should have tightened up the control limits on its chart.) Figure 6.12 shows a correct control chart for the 150 shift averages.

FIGURE 6.12 **Correct Three-Sigma Control Chart for Shift PDQ Averages**



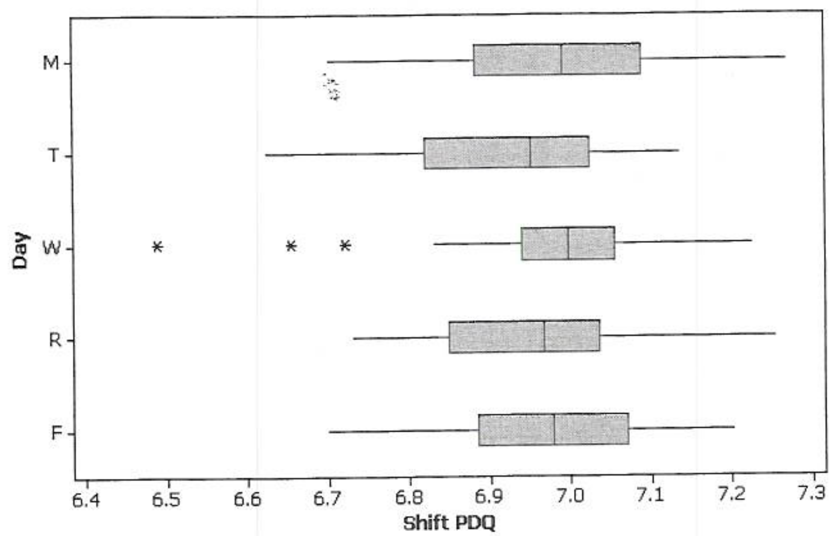
In this control chart, the three-sigma upper and lower control limits are shown instead of two-sigma control limits. We used the historical mean of 7.0 and the standard error of the sample mean, $\sigma/\sqrt{n} = .30/\sqrt{8} = .106$, based on the historical standard deviation of .30 for individual PDQ test values. Several of the plotted values fall below the lower control limit in the most recent 60 shifts.

We are now fairly certain that there is a recent quality problem at DataStor, but what is the source of the problem? We can examine the relationship between the shift average PDQ variable and each of the other variables in the data set for clues.

Figure 6.13 is a box plot of the shift PDQ average versus day of the week. Although some variation exists among the days of the week, there's no strong evidence that the problem is linked to day of the week.

FIGURE 6.13

Box Plots of Shift PDQ Averages by Day of the Week



Figures and 6.14 and 6.15 are scatterplots of the shift PDQ average versus the-WorkerHours and Drives variables, respectively. If production levels had been increased recently, that might account for a decrease in quality. For example, at higher levels of WorkerHours (or Drives), we might have seen an overall decrease in the shift PDQ averages. The lack of an unusual pattern in these scatterplots, however, suggests that DataStor has been operating well within its range of production capability.

FIGURE 6.14

Scatterplot of Shift PDQ Average Versus WorkersHours

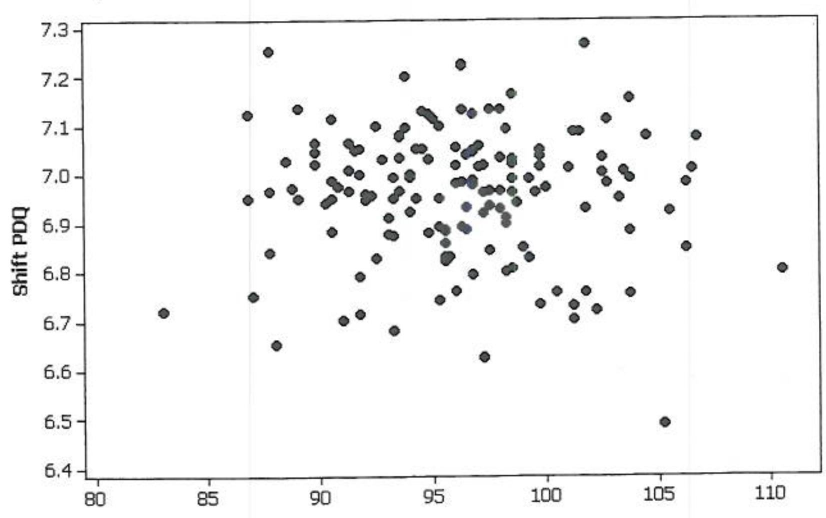


FIGURE 6.15 Scatterplot of Shift PDQ Average Versus Drives

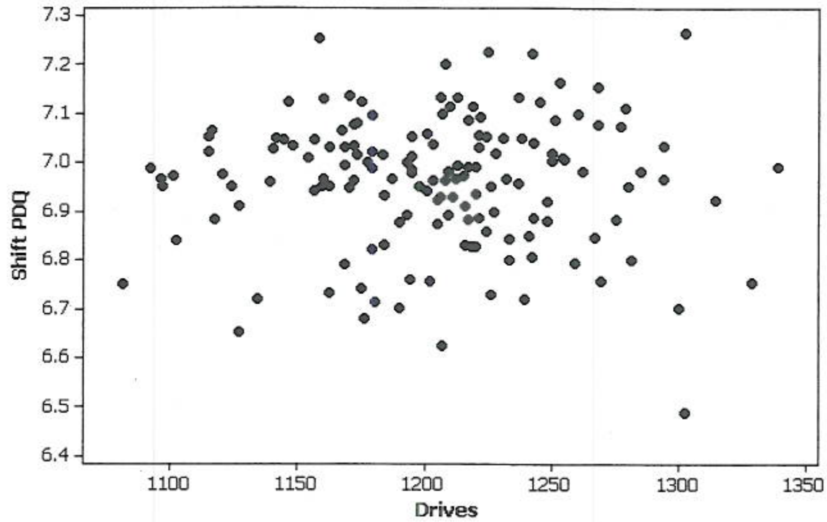
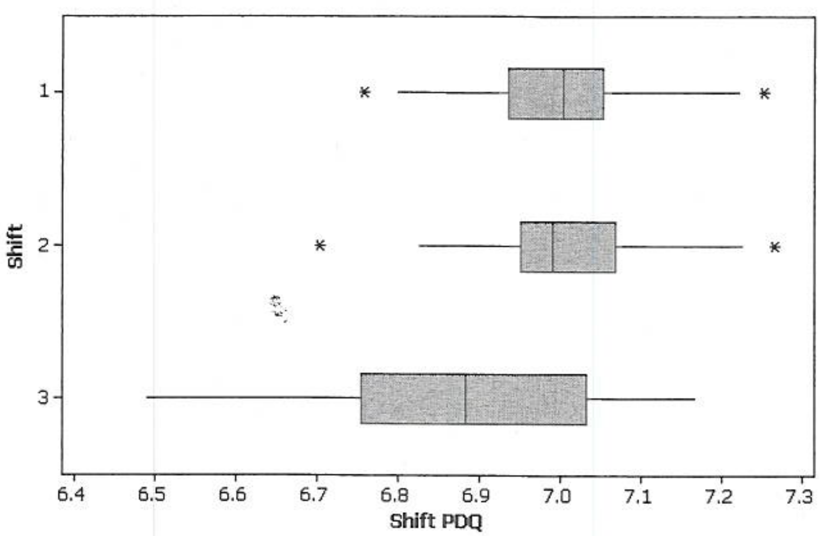


Figure 6.16 is a box plot of the shift PDQ average versus Shift. The graph shows clearly that the quality of drives produced in Shift 3 is worse on average and exhibits higher variation. Control charts for the three shifts, shown in Figure 6.17, indicate that Shifts 1 and 2 have not had any problems, but that Shift 3 has had declining quality in its drives over the past 60 days.

FIGURE 6.16 Box Plots of Shift PDQ Averages by Shift



The quality problem is therefore real and the source is the third shift at DataStor. Further investigation by DataStor is needed to pin down the actual source of the problem, but we can say that the problem seems to have started roughly 20–30 days ago based on our analysis of the data.

FIGURE 6.17 Three-Sigma Control Charts of Shift PDQ Averages for Each Shift