Exercise Manual for *Mastering Contact Center Metrics*

The Analyst's Math Exercises

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Introduction

This book is one part of the Walkabout® Series for managers of the future. Other books in the series include:

- The Executive Guide to Contact Center Excellence
- The Executive Guide to Contact Center Metrics
- Mastering Contact Center Metrics

This book, Exercise manual for the Mastering Contact Center, is an adjunct to Mastering Contact Center Metrics This book provides contact center concepts and supplementary contact center exercises and their solutions for added practice with statistics, statistical process control, and call center-specific metrics. The SPC book that this is designed to work with provides the math, formulas, and statistics thus providing a complete package for developing effective call center metrics.

How to Use This Book

This workbook was designed to work with Mastering Contact Center Metrics The chapters of this book and the Mastering Contact Center Metrics book cover identical material in the same sequence. The exercises in this book's modules will correspond to the material and pages covered in the Mastering Contact Center Metrics text. In this self-study guide, the modules are numbered sequentially. You will also see a note that tells you which chapter in the Mastering Contact Center Metrics book the workbook module corresponds to. The sample problems are numbered according to the chapter in the Mastering Contact Center Metrics book where those skills were taught, then the number exercise in the workbook. For example, in exercise 2-1 corresponds to material taught in Chapter 2 of the Mastering Contact Center Metrics book. The answers for each module's exercises are found at the end of that module. We recommend that you complete the lessons in this workbook in the order that they appearing the Mastering Contact Center Metrics. Some of the later lessons build on data from previous lessons.

There are two methods of completing the exercises. First, old school on paper. The second is downloading the exercise files and using your computer and Excel.

For the old school method, you will need a pad of paper, a pencil, an eraser, and graph paper. You will also want to get your calculator ready. If you have a computer, it will be a tremendous learning aid and will make the problems and work go much faster.

Using your computer, open the corresponding exercise spreadsheet and complete the problem in using the spreadsheet calculations.

Now let's get started.

Chapter Two:

Metric Monitors: Calculations and Fundamentals

Chapter Summary

The following table is a quick guide to what we have learned in Chapter 2 about how to describe our metrics. The following exercises will allow you to master the calculations.

Metric	Monitor	Population Symbol	Definition	Business USE
Central Tendency	Average	μ	Measures the center of data	Identifies typical performance
Variability	Standard Deviation	σ	Tracks the variability or spread around the average	Spots inconsistency in operations
Chaos Indicator	Coefficient of Variation		Compares variability as a percentage of the average	Benchmarks consistency across scales. Measure of Chaos in the center

Exercise 2-1

This first exercise analyzes phone pickup times. Compute the average, range, standard deviation, and coefficient of variation for the pickup times.

Pickup Time	
0.32	0.62
0.31	0.49
0.49	0.48
0.67	0.52
0.57	0.63

Exercise 2-2

Every workday our call center manager drives the same route to work. The following table shows the drive times that she has experienced recently. Compute the average, range, and standard deviation for drive time in minutes.

Call Center Manager's Drive Time to Work

Date	Day of Week	Time (Min)	Date	Day of Week	Time (Min)	Date	Day of Week	Time (Min)
5/22	Mon	40	6/27	Tue	34	8/7	Mon	36
5/23	Tue	44	6/28	Wed	34	8/8	Tue	37
5/24	Wed	46	6/29	Thr	36	8/9	Wed	37
5/25	Thr	39	6/30	Fri	36	8/10	Thr	34
5/26	Fri	45	7/6	Thr	35	8/11	Fri	35
6/5	Mon	34	7/7	Fri	37	8/14	Mon	39
6/6	Tue	37	7/10	Mon	36	8/15	Tue	43
6/7	Wed	39	7/11	Tue	33	8/16	Wed	40
6/8	Thr	39	7/12	Wed	34	8/17	Thr	43
6/9	Fri	34	7/13	Thr	38	8/18	Fri	44
6/12	Mon	36	7/14	Fri	36	8/21	Mon	46
6/13	Tue	35	7/17	Mon	38	8/22	Tue	44
6/14	Wed	35	7/18	Tue	35	8/23	Wed	45
6/15	Thr	34	7/19	Wed	36	8/24	Thr	43
6/16	Fri	37	7/20	Thr	32	8/25	Fri	39
6/19	Mon	34	7/21	Fri	33	8/28	Mon	47
6/20	Tue	37	7/24	Mon	39	8/29	Tue	43
6/21	Wed	32	7/25	Tue	32	8/30	Wed	43
6/22	Thr	39	7/26	Wed	38	8/31	Thr	44
6/23	Fri	35	7/27	Thr	38	9/1	Fri	42
6/26	Mon	36	7/28	Fri	34	9/5	Tue	44

Exercise 2-1 Solution

The following table shows the average, maximum, minimum, range and standard deviation point estimates for pickup time.

	Pickup Time
Average	0.51
Minimum, Maximum	0.31, 0.67
Range	0.36
Standard Deviation	0.12
Coefficient of Variation	24%

Exercise 2-2 Solution

The following table is the average, maximum, minimum, range and standard deviation for our production manager's drive time.

	Drive to Work
Average	38.1
Minimum, Maximum	32.0, 47.0
Range	15.0
Standard Deviation	4.1
Coefficient of Variation	11%

Chapter Ten

Building the Tactical alarm system

Chapter 10 provides the hands-on math playbook for constructing tactical alarm systems in contact centers, focusing on three key control charts:

- Individual/Moving Range
- X-bar/R
- P charts

Key takeaways:

- Chart calculation and construction
- Charts monitor central tendency and variability, detecting changes early.
- Lock limits once stable — automatic recalculation is a "fatal flaw."
- Between/within shifts reveal tampering or inconsistencies.

By building these alarms, analysts create surveillance tools for consistency. The next chapter explores interpreting alarms and hunting causes to drive proactive improvements. See Exercises.

Xbar and R Charts

The next exercises will Beto master Xbar and R charts.

Chapter Ten

Exercise 10-1

For this exercise we are monitoring the call processing duration from our Dallas call center. Our readings are taken every hour. The volume of calls is large, which allows us to sample five calls at the start of each hour. Each subgroup is made up of five consecutive calls. The measurements start at 1:00 am and continue every hour until 6:00 am of the next day. Using these measurements, complete the following three problems.

a. Take the raw individual readings for each subgroup and calculate the data to be posted on the chart.
b. Compute the control limits for the X-bar and the R control charts.
c. Build the control charts and post the data using graph paper.

	1:00	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**
1	134	137	113	134	113	138	117	116	112	122
2	130	116	114	107	109	103	126	131	117	122
3	113	123	123	121	133	128	122	125	136	120
4	122	106	137	103	117	119	120	121	120	123
5	124	120	110	115	128	114	128	102	135	129
$\overline{X}$										
R										

	11:00	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
1	126	106	113	133	130	116	137	106	138	131
2	110	114	113	133	121	132	137	117	124	135
3	116	126	137	117	103	102	117	132	120	125
4	118	126	109	120	117	112	124	109	119	134
5	133	124	120	121	104	124	121	109	116	109
$\overline{X}$										
R										

	21:00	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
1	122	116	108	120	113	118	116	114	120	109
2	110	114	104	120	108	135	117	127	115	121
3	123	122	104	105	113	116	121	127	135	122
4	105	135	133	110	104	119	105	117	117	107
5	112	131	116	112	106	129	129	115	121	133
$\overline{X}$										
R										

Exercise 10–2

Proper call pick up is a vital call center function. Our readings are taken every hour, with each of five consecutive calls being measured for pick up time. The call measurements start at 1:00 am and continue every hour until 6:00 am of the next day. Using these measurements, complete the following three problems.

a. Take the raw individual readings for each subgroup and calculate the data to be posted on the chart.

b. Compute the control limits for the X-bar and the R control charts.

a. Build the control charts and post the data using graph paper.

	1:00	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**
1	14.51	14.01	13.95	14.05	14.23	14.15	13.77	14.16	14.13	13.58
2	14.48	14.13	14.09	13.95	14.29	14.04	13.81	14.24	13.99	13.67
3	14.41	14.17	14.04	13.97	14.21	13.90	13.72	14.29	14.06	13.77
4	14.36	14.29	14.01	14.09	14.08	13.82	13.67	14.20	13.94	13.79
5	14.50	14.19	13.95	14.12	14.10	13.91	13.58	14.37	13.85	13.90
$\bar{X}$										
R										
	11:00	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
1	14.00	13.70	13.74	13.91	13.82	13.87	13.81	13.87	13.73	14.08
2	13.97	13.80	13.68	13.83	13.73	14.01	13.88	13.80	13.80	14.10
3	13.83	13.70	13.56	13.72	13.83	13.98	13.98	13.76	13.90	14.25
4	13.92	13.65	13.58	13.78	13.80	14.08	13.98	13.82	13.72	14.40
5	13.78	13.66	13.63	13.89	13.80	14.21	14.06	13.94	13.59	14.46
$\bar{X}$										
R										
	21:00	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
1	13.70	14.01	13.94	13.82	14.58	14.18	14.49	14.52	14.29	14.32
2	13.78	14.07	14.00	13.78	14.76	14.14	14.61	14.60	14.46	14.21
3	13.91	14.06	14.15	13.76	14.86	14.23	14.64	14.73	14.54	14.33
4	13.93	13.99	14.13	13.62	14.89	14.27	14.82	14.65	14.54	14.21
5	14.00	14.17	14.17	13.72	14.91	14.39	14.73	14.52	14.47	14.10
$\bar{X}$										
R										

Exercise 10-3

This is a continuation of exercise 7-1. The following call duration measurements are taken from the same center, starting after our last reading at 6:00 am. The first reading of this exercise is taken at 7:00 am and is shown on the table below. The duration measurements continue every hour until 9:00 am of the next day.

a. Compute and post these readings to the control chart from exercise 7-1.

b. A central tendency shift will be detected that will be permanent. Recalculate the control limits and extend the limits on the chart.

	7:00	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**
1	136	108	131	117	127	136	121	133	127	121
2	115	111	108	141	119	135	116	128	123	138
3	140	111	129	122	135	134	127	133	121	121
4	117	135	119	111	112	141	133	115	126	128
5	110	141	130	126	137	136	110	129	107	140
$\bar{x}$										
R										

	17:00	**18:00**	**19:00**	**20:00**	**21:00**
1	134	138	109	116	113
2	130	134	120	137	112
3	127	139	132	116	114
4	108	111	109	115	138
5	122	110	125	118	116
$\bar{x}$					
R					

Individual Charts

Exercise 10-4

The table below shows the number of orders processed by a retail store on Monday through Friday. Convert the data to values for plotting, compute the control limits, build the Individual control charts, and interpret any out-of-control conditions.

Mon	Tue	Wed	Thru	Fri	Mon	Tue	Wed	Thru	Fri
82	93	66	78	129	94	112	106	78	85

Mon	Tue	Wed	Thru	Fri	Mon	Tue	Wed	Thru	Fri
81	116	88	107	69	80	72	70	62	73

Mon	Tue	Wed	Thru	Fri	Mon	Tue	Wed	Thru	Fri
59	89	94	103	92	49	116	75	77	62

The data in this exercise could be the calls received for a time period or the calls completed per time period or the duration of the calls. As stated earlier, the Individual charts are extremely versatile and useful in a call center.

Chapter Ten

Exercise 10-5

The table below shows the number of calls requesting assistance received by an IT help desk call center. Can you identify any out-of-control conditions?

1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
515	451	518	477	502	541	454	530	460	492

11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
499	486	464	438	456	537	533	554	557	388

21:00	22:00	23:00	24:00	1:00	2:00	3:00	4:00	5:00	6:00
504	482	484	474	467	488	389	471	460	523

This is the tip of the iceberg for control charts. Now we must move on to study how to interpret and use these tactical metric tools.

P Control Charts

Exercise 10-6

Call centers (like 911 help desks, customer service centers, insurance claims centers, and order processing centers) must keep wait time to a minimum. Understanding utilization of the call center agents is key to queuing theory principles, which allows the manager to optimize the customer's wait time.

The following table is the daily agent hours utilized and total hours available for an insurance claims center. Use this table to compute the control chart data, the control limits, to build a control chart, and to check this center's utilization consistency.

	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
Hrs Utilized	45	42	37	47	40	46	42	35	46	48
Hrs Avail	64	63	64	66	65	64	66	63	64	64

	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
Hrs Utilized	49	44	43	44	46	47	40	46	47	43
Hrs Avail	64	63	66	61	66	62	64	66	64	63

	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
Hrs Utilized	42	35	40	44	45	46	47	48	44	42
Hrs Avail	61	62	64	66	62	64	65	63	65	64

Exercise 10-7

In many call centers the staffing during evening hours is lighter than during prime daytime hours. The following table is the daily agent hours utilized and available for an information technology (IT) help desk center. Use this table to compute the control chart data, the control limits, to build a control chart, and to check this center's utilization consistency.

Time of Day	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**
Hours Utilized	4.0	1.5	3.0	3.0	6.0	10.0	16.0	35.0	46.0	48.0
Hrs Available	8.0	8.0	8.0	8.0	8.0	16.0	24.0	63.0	64.0	64.0

Time of Day	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Hours Utilized	49.0	44.0	43.0	44.0	46.0	47.0	40.0	24.0	28.0	16.0
Hrs Available	64.0	63.0	66.0	61.0	66.0	62.0	64.0	36.0	36.0	24.0

Time of Day	**21:00**	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
Hours Utilized	12.0	5.0	3.0	5.0	2.0	2.0	3.0	2.0	8.0	15.0
Hrs Available	24.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	16.0	24.0

Exercise 10-8

Product defect rate is an important metric for any business. What designates a defect is important. In a call center, the customers who terminate their calls when they become frustrated waiting for an agent are designated as dropped calls. These dropped calls are defects and should be tracked.

The following table shows the calls dropped and the total number of calls received at this center. Use this table to compute the control chart data, compute the control limits, build a control chart, and check this center's utilization consistency.

	1:00	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**
Drop	2	1	1	0	1	1	1	3	4	10
Total	50	48	30	40	45	44	44	366	400	420

	11:00	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Drop	11	29	11	12	15	11	15	11	1	2
Total	420	450	455	437	401	380	360	200	150	120

	21:00	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
Drop	3	1	1	1	1	1	2	1	2	2
Total	100	50	40	45	30	45	40	45	100	175

Chapter Ten

Solution 10-1

The X-bar and R call duration time results are shown in the table below and will be used as the data on the control charts for determining consistency.

	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
$\bar{x}$	124.6	120.4	119.4	116.0	120.0	120.4	122.6	119.0	124.0	123.2
R	21.0	31.0	27.0	31.0	24.0	35.0	11.0	29.0	24.0	9.0

	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
$\bar{x}$	120.6	119.2	118.4	124.8	115.0	117.2	127.2	114.6	123.4	126.8
R	23.0	20.0	28.0	16.0	27.0	30.0	20.0	26.0	22.0	26.0

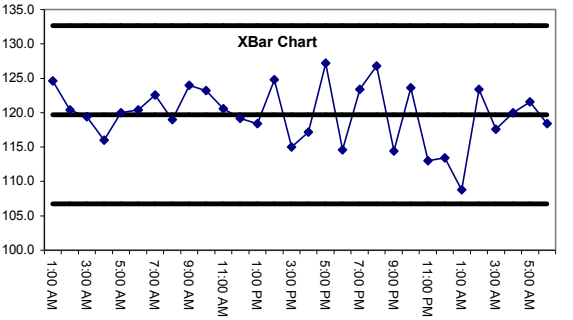
	21:00	22:00	23:00	24:00	1:00	2:00	3:00	4:00	5:00	6:00
$\bar{x}$	114.4	123.6	113.0	113.4	108.8	123.4	117.6	120.0	121.6	118.4
R	18.0	21.0	29.0	15.0	9.0	19.0	24.0	13.0	20.0	26.0

Using the X-bar and R values that are shown in the table above, X double-bar and R-bar are calculated for consistency alarms on the control charts. These calculations produce an X double-bar equal to 119.70, and an R-bar equal to 22.50.

In this center, five calls are sampled per subgroup. This sample size, or N, is used in the control chart table to determine the values of A_2, D_3, and D_4. The A_2 value is 0.577 and will be used to compute the control limits on the X-bar control chart. The D_3 value is 0, which will be used to compute the R control chart's lower control limit and D_4 value is 2.114 to compute the R chart's upper control limit.

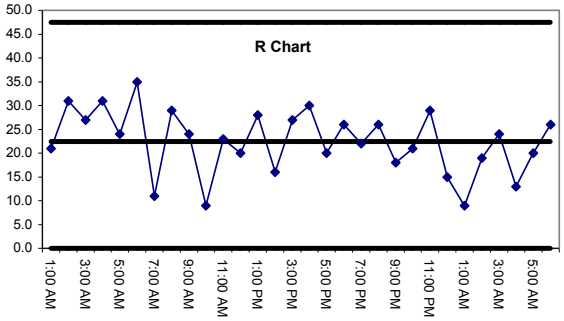
The A_2 constant is used to compute the X-bar control limits. The values and the control limits are used to build the control chart below.

$$\text{Control Limits} = \overline{\overline{X}} + A_2 * \overline{R} = 119.70 \pm .577 * 22.5 = 106.74 \Leftrightarrow 132.66$$



The D_3 and D_4 constants are used to compute the R chart control limits.

$$UCL = D_4 * \overline{R} = 2.114 * 22.5 = 47.4945 \qquad LCL = D_3 * \overline{R} = 0 * 22.5 = 0$$



Chapter Ten

Solution 10-2

The X-bar and R call pickup time results are shown in the table below. These values will be used as the data on the control charts for determining consistency.

	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
$\bar{X}$	14.45	14.16	14.01	14.04	14.18	13.96	13.71	14.25	13.99	13.74
R	0.15	0.28	0.14	0.17	0.21	0.33	0.23	0.21	0.28	0.32

	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
$\bar{X}$	13.90	13.70	13.64	13.83	13.80	14.03	13.94	13.84	13.75	14.26
R	0.22	0.15	0.18	0.19	0.10	0.34	0.25	0.18	0.31	0.38

	21:00	22:00	23:00	24:00	1:00	2:00	3:00	4:00	5:00	6:00
$\bar{X}$	13.86	14.06	14.08	13.74	14.80	14.24	14.66	14.60	14.46	14.23
R	0.30	0.18	0.23	0.20	0.33	0.25	0.33	0.21	0.25	0.23

Using the X-bar and R values that are shown in the table above, X double-bar and R-bar are calculated for consistency alarms on the control charts. These calculations produce an X double-bar equal to 14.06, and an R-bar equal to.24.

In this center five calls are sampled per subgroup and is used in the control chart table to determine the values of A_2, D_3, and D_4. The A_2 value is 0.577, the D_3 value is 0, and the D_4 value is 2.114.

The A_2 constant is used in the equations below to compute the X-bar control limits.

$$\text{Control Limits} = \bar{\bar{X}} + A_2 * \bar{R} = 14.06 \pm .577 * .24 = 13.93 \Leftrightarrow 14.20$$

Note the X-bar chart has several out of control conditions. We should not be surprised when the first control charts for a center show out of control conditions. This simply means that the process is changing; we have the opportunity to learn with the objective of making the process consistent.

The D_3 and D_4 constants are used to compute the R chart control limits.

$$UCL = D_4 * \bar{R} = 2.114 * .24 = .502 \qquad LCL = D_3 * \bar{R} = 0 * .24 = 0$$

Even though the X-bar has patterns, trends, and out-of-control points, the R chart appears consistent. Both central tendency and variability must be monitored independently.

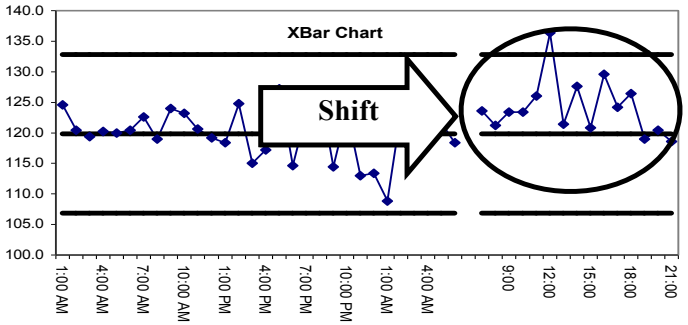
Solution 10-3

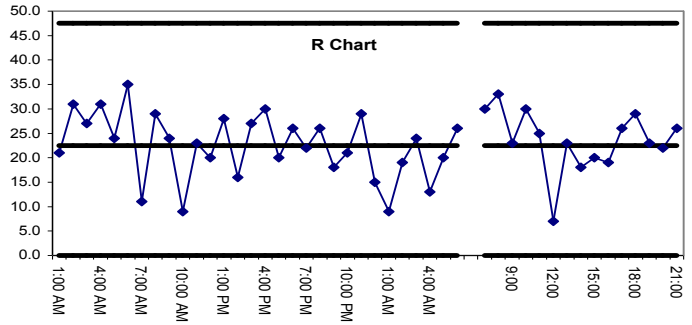
The results of the call duration calculations are shown in the table below, and will be used as the data on the control charts for determining consistency.

	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
$\bar{X}$	124	121	123	123	126	136	121	128	121	130
R	30	33	23	30	25	7	23	18	20	19

	17:00	18:00	19:00	20:00	21:00
$\bar{X}$	124	126	119	120	119
R	26	29	23	22	26

The X-bar chart shows a shift has occurred. We now investigate the shift to determine the reason or cause. For this exercise, we are assuming the shift has been assessed by the strategic decision makers and is a change that will be permanent. With this permanent shift, limits will be recalculated establishing a new consistency baseline. The R chart is shown below. The call duration time variability is totally stable.

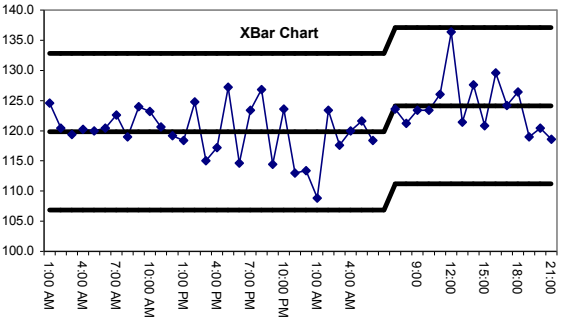




Using the new 7:00 am till 9:00 pm X-bar and R values only, new X double-bar and R-bar are calculated for consistency alarms on the control charts. These calculations produce X double-bar equal to 124.13 and R-bar equal to 23.6. The recomputed the X-bar control limits are shown below.

$$\text{Control Limits} = \overline{\overline{X}} + A_2 * \overline{R} = 124.13 \pm .577 * 23.6 = 110.52 \Leftrightarrow 137.75$$

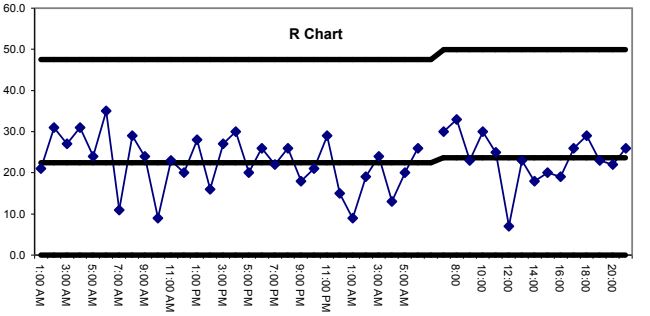
The X-bar chart is now plotted showing the old control limits, new control limits, and all the subgroup X-bar readings.



The revised R limits are recomputed below.

$$UCL = D_4 * \overline{R} = 2.114 * 23.6 = 49.89 \qquad LCL = D_3 * \overline{R} = 0 * 23.6 = 0$$

The R chart is now plotted showing the old control limits, new control limits, and all the subgroup R readings.



The control limit stair step shows the new level of consistency that the center is running.

Solution 10-4

A retail store is tracking the number of weekday orders. Each subgroup's moving range results are shown in the table below and are used on the control chart.

	1:00	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**
Moving R		11	27	12	51	35	18	6	28	7

	11:00	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Moving R	4	35	28	19	38	11	8	2	8	11

	21:00	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
Moving R	14	30	5	9	11	43	67	41	2	15

We use the X and moving range values to calculate that X double-bar equals 85.233 and R-bar equals 20.552. These new values are used to compute the control limits. The X-bar chart control limits are calculated with the following formula after inserting the appropriate values.

$$\text{Control Limit} = \overline{\overline{X}} + E_2 * \overline{R} = 85.233 \pm 2.66 * 20.552 = 30.566 \Leftrightarrow 139.901$$

Now the X-bar chart control is plotted. An out-of-control alarm is formed by seven consecutive values below the mean starting at 3:00pm.

The D_3 and D_4 constants are used to compute the moving range control limits.

$$UCL = D_4 * \overline{R} = 3.267 * 20.552 = 67.142 \qquad LCL = D_3 * \overline{R} = 0 * 20.552 = 0$$

No out-of-control conditions are detected on the Moving Range chart.

Chapter Ten

Solution 10-5

An IT help desk is monitoring the number of calls received hour by hour. Each subgroup's moving range results are shown in the table below. These values are used on the control chart.

	1:00	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**
Moving R		64	67	41	25	39	87	76	70	32

	11:00	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
Moving R	7	13	22	26	18	81	4	21	3	169

	21:00	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
Moving R	116	22	2	10	7	21	99	82	11	63

Calculated from the X and moving range values, the X double-bar, equal to 486.467, and R-bar, equal to 44.759, are used to compute the control limits. The X-bar chart control limits are calculated with the following formula.

$$\text{Control Limit} = \overline{\overline{X}} + E_2 * \overline{R} = 486.467 \pm 2.66 * 44.759 = 367.409 \Leftrightarrow 605.525$$

Now the X-bar control chart is plotted and no change is detected.

The D_3 and D_4 constants are used to compute the Moving Range chart control limits with the equations below.

$$UCL = D_4 * \overline{R} = 3.267 * 44.759 = 146.22 \qquad LCL = D_3 * \overline{R} = 0 * 44.759 = 0$$

Now the Moving Range chart is plotted. A change is detected outside the control limits at 8:00pm on the Moving Range chart.

Solution 10-6

The following table is the utilization rate of the claims call center and the P values for the P chart.

	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
% Utilized	70%	67%	58%	71%	62%	72%	64%	56%	72%	75%
	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
% Utilized	77%	70%	65%	72%	70%	76%	63%	70%	73%	68%
	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
% Utilized	69%	56%	63%	67%	73%	72%	72%	76%	68%	66%

The P-bar, equal to.683, and N-bar, equal to 63.9. will be used to compute the P chart control limits.

$$\text{Control Limits} = \overline{P} \pm 3 * \frac{\sqrt{\overline{P} * (1 - \overline{P})}}{\sqrt{\overline{N}}} = .683 \pm 3 * \frac{\sqrt{.683 * .317}}{\sqrt{63.9}} = .508 \Leftrightarrow .858$$

No out-of-control points are noted so the claims center utilization rate is consistent.

Solution 10-7

The IT help desk has a staffing level that is designed to support varying call volumes; the night shift is lightly staffed. Since the total number of possible hours available varies according to the time of day, we must use a different standard deviation for each change in staff. The overall utilization or P-bar=.56. These values are now inserted into the control limit calculations as shown below:

$$UCL = \bar{P} \pm 3 * \frac{\sqrt{\bar{P} * (1 - \bar{P})}}{\sqrt{N}} = .56 \pm 3 * \frac{\sqrt{.56 * .44}}{\sqrt{N}} = .56 \pm 3 * \frac{.496}{\sqrt{N}}$$

Finally, the table following is built to calculate the control limits and each intermediate step: the square root of N, the standard deviation, and the upper and lower control limits.

Time of Day	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
P	50%	19%	38%	38%	75%	63%	67%	56%	72%	75%
UCL	109%	109%	109%	109%	109%	94%	87%	75%	75%	75%
LCL	4%	4%	4%	4%	4%	19%	26%	38%	38%	38%

Time of Day	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
P	77%	70%	65%	72%	70%	76%	63%	67%	78%	67%
UCL	75%	75%	75%	75%	75%	75%	75%	81%	81%	87%
LCL	38%	38%	38%	37%	38%	37%	38%	32%	32%	26%

Time of Day	21:00	22:00	23:00	24:00	1:00	2:00	3:00	4:00	5:00	6:00
P	50%	63%	38%	63%	25%	25%	38%	25%	50%	63%
UCL	87%	109%	109%	109%	109%	109%	109%	109%	94%	87%
LCL	26%	4%	4%	4%	4%	4%	4%	4%	19%	26%

The results from the table are now used to build the control chart.

Change one has 12 consecutive points above the mean with two values being outside the upper control limit. As we investigate to determine the cause, two patterns emerge: day utilization and night utilization.

The chart presents a vivid picture that two groups should be formed. One option is to separate the day and night work into two charts. A second option is to optimize the utilization of all time periods.

Solution 10-8

The call center will now track the percent of dropped calls. This changing number of calls, or N, forces us to use a changing standard deviation. The overall dropped call rate or P-bar=2.6%. These values are inserted into the control limit calculations as shown below:

$$\text{Control Limits} = \bar{P} \pm 3 * \frac{\sqrt{\bar{P} * (1 - \bar{P})}}{\sqrt{N}} = .026 \pm 3 * \frac{\sqrt{.026 * .974}}{\sqrt{N}} = .026 \pm 3 * \frac{.160}{\sqrt{N}}$$

Finally, the table below is built to calculate the control limits and each intermediate step: the square root of N, the standard deviation, and the upper and lower control limits.

Time of Day	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
P	4.0%	2.1%	3.3%	0.0%	2.2%	2.3%	2.3%	0.8%	1.0%	2.4%
UCL	9%	10%	11%	10%	10%	10%	10%	5%	5%	5%
LCL	-4%	-4%	-6%	-5%	-5%	-5%	-5%	0%	0%	0%

Time of Day	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
P	2.6%	6.4%	2.4%	2.7%	3.7%	2.9%	4.2%	5.5%	0.7%	1.7%
UCL	5%	5%	5%	5%	5%	5%	5%	6%	7%	7%
LCL	0%	0%	0%	0%	0%	0%	0%	-1%	-1%	-2%

Time of Day	21:00	22:00	23:00	24:00	1:00	2:00	3:00	4:00	5:00	6:00
P	3.0%	2.0%	2.5%	2.2%	3.3%	2.2%	5.0%	2.2%	2.0%	1.1%
UCL	7%	9%	10%	10%	11%	10%	10%	10%	7%	6%
LCL	-2%	-4%	-5%	-5%	-6%	-5%	-5%	-5%	-2%	-1%

The results from the table are now used to build the control chart below. Since negative values are impossible, the lower control limit is positioned at zero percent.

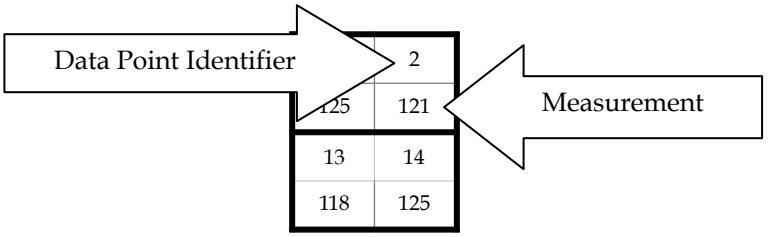
Change one, at 12:00 pm, has a point above the upper control limit.

Chapter Eleven

Change Detection Playbook: Tactical Alarms Explained

Exercises

In this chapter's exercises the data will be found in a table like the one shown below. The data point identifier is posted on the x-axis and the measurement is posted on the y-axis.



The following tables contain measurements for plotting on a graph. Build the charts using an average of 120, an upper control limit of 138, and a lower control limit of 102. Then, check for out-of-control conditions.

Exercise 11-1

1	2	3	4	5	6	7	8	9	10	11	12
125	121	119	120	120	120	123	119	124	123	121	119
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
118	125	115	117	138	115	123	140	114	123	113	113
25	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
109	123	118	120	122	118	118	116	118	118	121	132
37	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
117	123	116	125	119	121	114	116	114	126	113	123
49	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
123	125	121	116	125	110	118	126	124			

Exercise 11-2

1	2	3	4	5	6	7	8	9	10	11	12
125	121	130	120	120	120	105	119	124	123	121	120
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
119	126	117	119	132	117	126	135	117	126	116	117
25	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
112	127	122	124	126	123	124	122	124	124	127	138
37	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
124	130	123	132	127	130	123	124	123	135	123	133
49	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
134	136	132	127	136	122	130	138	137			

Chapter Eleven

Exercise 11-3

1	2	3	4	5	6	7	8	9	10	11	12
125	121	119	120	120	120	120	119	122	123	121	119
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
118	121	115	117	120	115	123	125	114	123	113	113
25	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
118	120	118	120	122	118	118	116	118	118	121	120
37	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
117	123	116	125	119	121	114	116	114	126	120	123
49	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
123	125	121	116	125	116	118	121	124			

Exercise 11-4

1	2	3	4	5	6	7	8	9	10	11	12
124	120	119	120	119	120	122	119	124	123	120	119
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
118	124	115	117	136	121	129	139	120	129	119	119
25	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
115	129	124	126	128	124	124	122	124	124	127	138
37	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
123	129	122	131	125	127	120	122	120	132	119	129
49	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
129	131	127	122	131	116	124	132	130			

Chapter Eleven

Exercise 11-5

1	2	3	4	5	6	7	8	9	10	11	12
125	120	119	127	119	119	121	130	122	121	118	116
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
115	113	111	113	126	110	118	128	109	117	107	107
25	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
102	116	110	112	114	110	110	107	109	109	111	122
37	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
106	112	105	113	108	110	102	103	101	113	100	110
49	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
110	111	107	102	110	95	102	110	108			

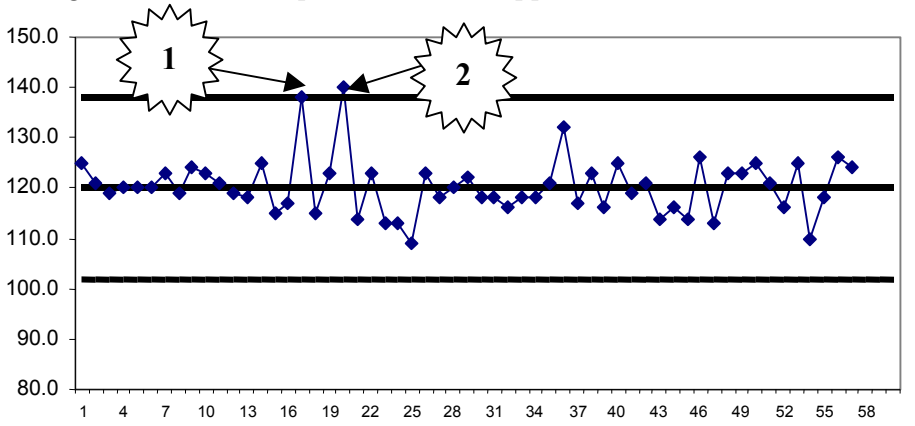
Exercise 11-6

1	2	3	4	5	6	7	8	9	10	11	12
137.0	105.0	136.0	135.0	135.0	106.0	108.0	112.0	107.0	132.0	137.0	136.0
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
135.0	104.0	105.0	137.0	106.0	110.0	132.0	137.0	109.0	110.0	113.0	133.0
25	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
134.0	110.0	137.0	103.0	104.0	106.0	118	116	118	118	121	132
37	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
117	123	116	125	119	121	114	116	114	126	113	123
49	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
123	125	121	116	125	110	118	126	124			

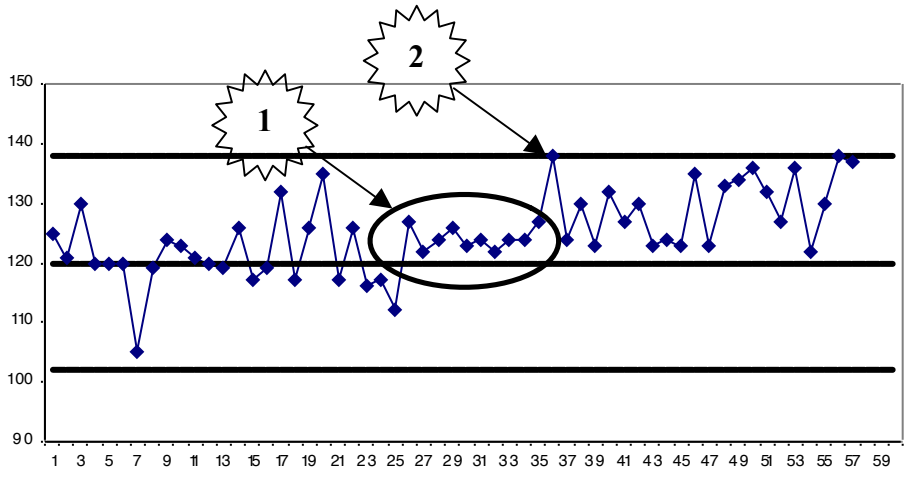
Chapter Eleven

Solution 11-1

Change one and two are points above the upper control limits.

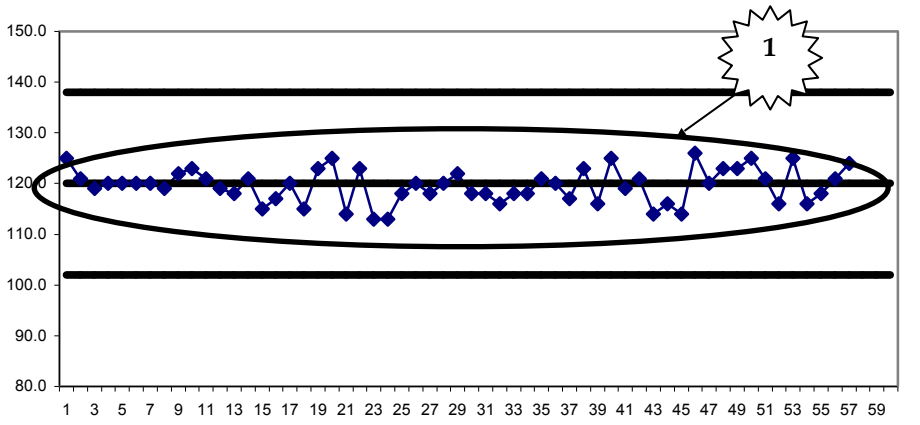


Solution 11-2



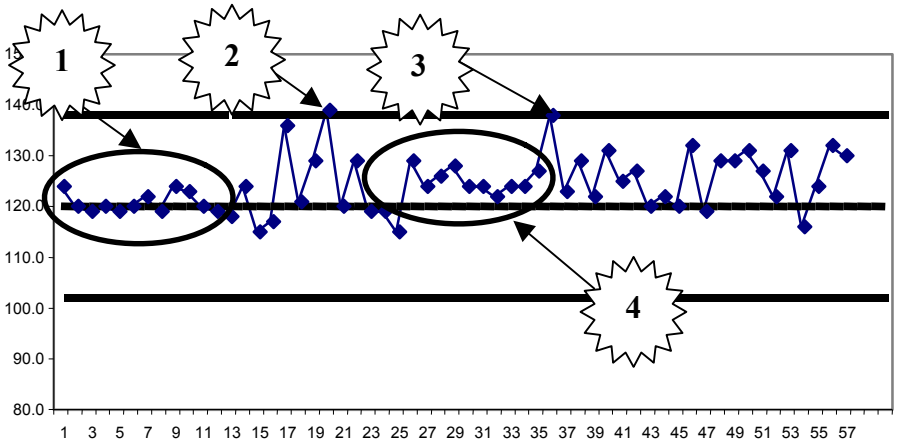
Change one is seven consecutive values above the mean but no values outside the limits. Change two is a point outside the upper control limit.

Solution 11-3
This control chart has one change. The change is too many points too close to the mean. This change will need to be investigated.



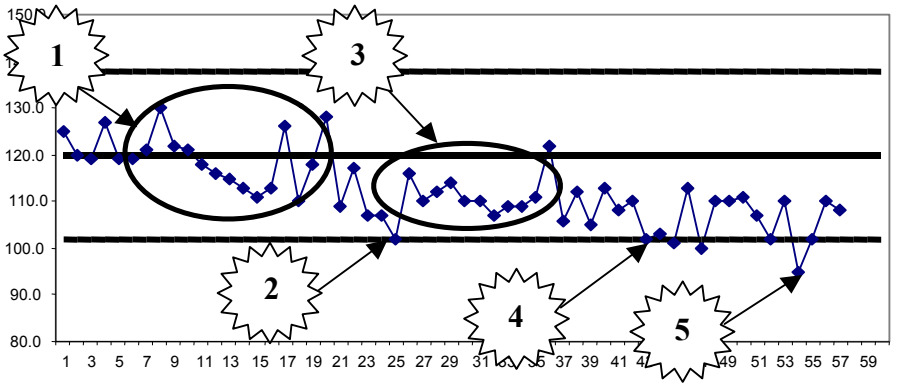
Solution 11-4

This control charts has four alarms that would need to be investigated. Change one is too many values too close to the mean. Change two and four are points above the upper control limit. Change three is ten consecutive values above the mean with no value outside the control limits.



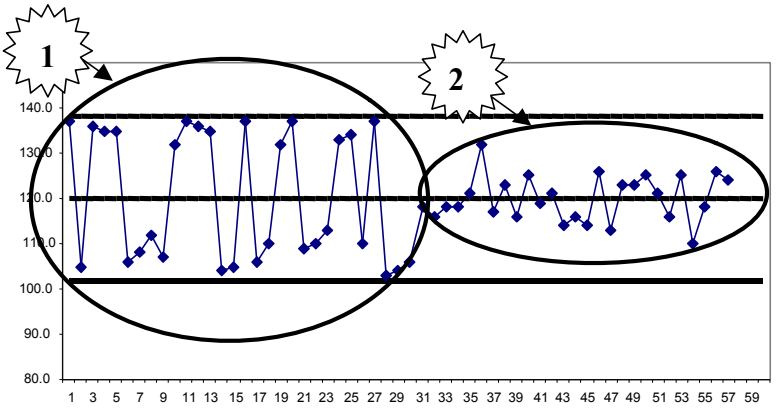
Solution 11-5

This control charts has five alarms. Change one is a trend of seven consecutive values in downward trend with no value outside the control limits. Change two is one point below the lower control limit. Change three is ten consecutive points below the mean but no value outside the control limits. Change four has several points below the lower control limit. Change five is one point below the lower control limit.



Solution 11-6

Change one is a series of values from the 1st to the 30th with none close to the mean. Change two is too many values close the mean.



Chapter Twelve

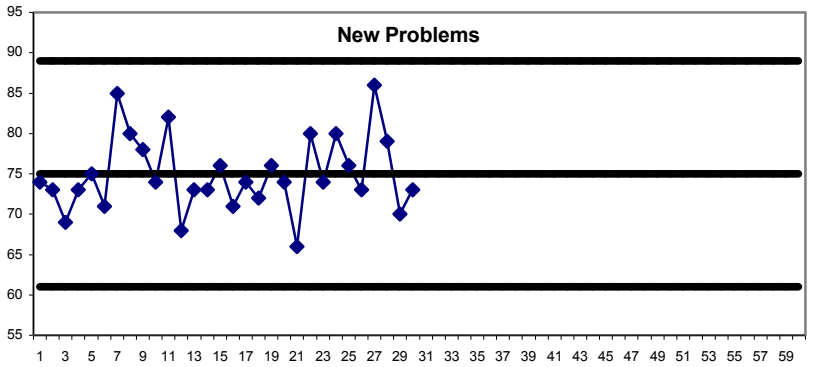
Change Detected: Cause Hunted

Exercise 12-1

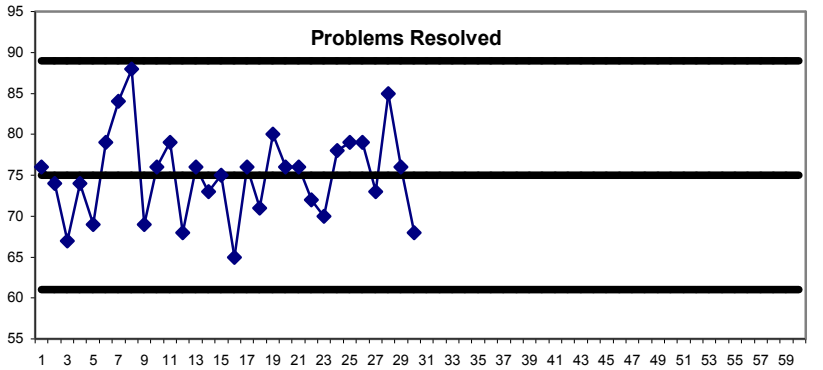
We are using control charts in a problem resolution call center. The problems may take several days to resolve. The three metrics that we will monitor are the number of new problems each day (new problems), the number of problems fixed each day (resolved problems), and the number of problems still open at the end of each day (open problems.)

The focus of this exercise is identifying areas that need more research. We will use three separate Individuals charts to monitor the metrics of new problems, resolved problems, and open problems. To keep this exercise short, we will track central tendency only. However, keep in mind that actual tactical views must track both central tendency and variability.

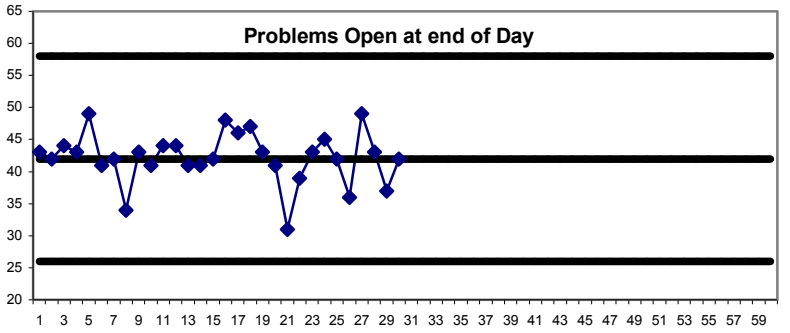
The number of new problem calls coming into the center each day for the last 30 days is shown in the control chart below. This chart shows a very consistent pattern.



The problems resolved in the last 30 days are shown in the next control chart. This chart shows a very consistent pattern.



The next chart shows the number of problems that are still open (that have not been resolved) at the end of the day. The new problems each day, subtracted by the closed or resolved problems each day, is how much the open problems will grow or drop each day. The open problems control chart for the last 30 days shows a very consistent pattern.



The three control charts show that the call center has been consistent for the last 30 days. Now post the measurements for the next seven days. First, post the three data points for day 31 (78, 62, 58). Next, post the three values for day 32 (72, 65, 65). Continue posting one day at a time, looking for out-of-control conditions. Then begin the process of causal research.

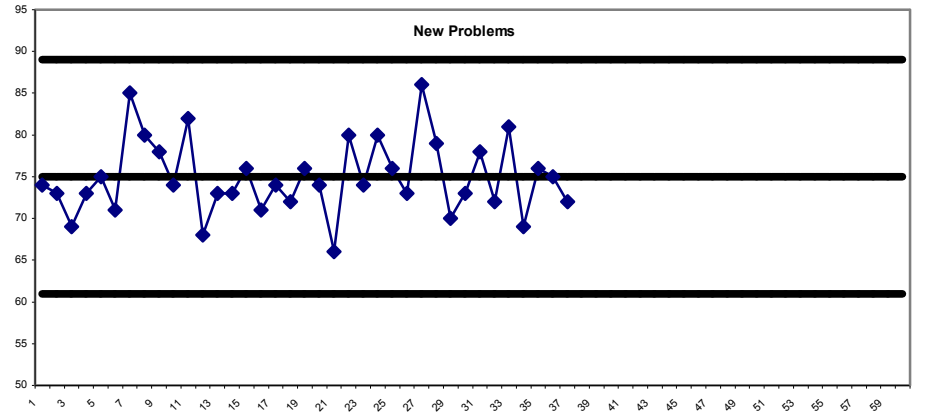
Day	New Problems	Completed Problems	Open Problems
31	78	62	58
32	72	65	65
33	81	64	82
34	69	62	89
35	76	63	102
36	75	66	111
37	72	70	113

Chapter Twelve

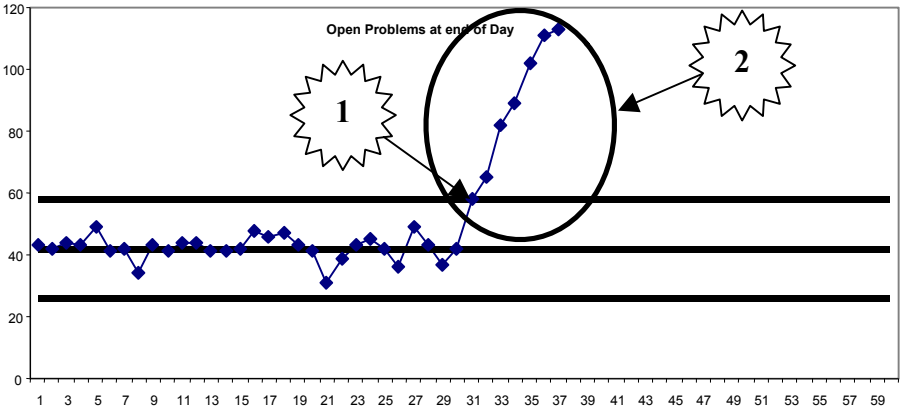
Solution 12 -1

The new problems are posted to their control chart below. This shows no change in the number of new problems coming into the call center each day. The number of new problems arriving at the call center is still consistent.

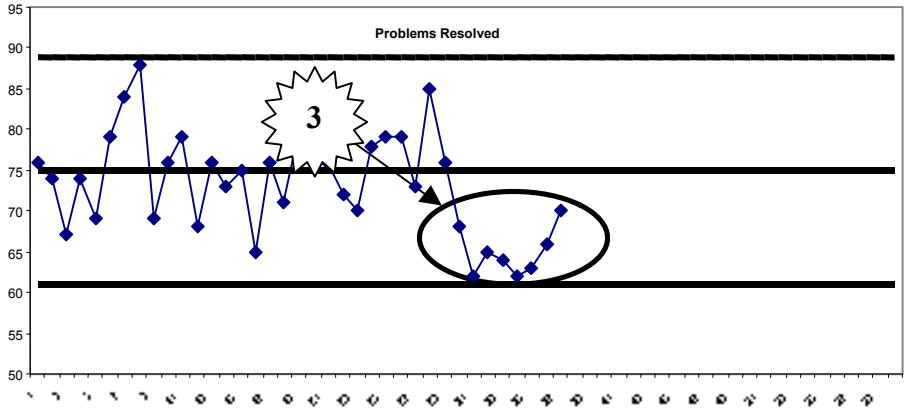
The open problem chart shows a point outside the control limits on the first day's posting



as shown on alarm one. Investigation should begin immediately into the cause of the alarm. As the remaining measurements are posted, the readings continue to climb as shown by alarm two.



The number of resolved problems has dropped, as indicated by alarm three having seven points below the mean.



Chapter Fourteen

Strategic View: Visualizing Data Distribution

Exercise 14-1

Every workday our call center accounting manager drives the same route to work. The following table shows the drive times that he has experienced recently. Compute the average, range, and standard deviation for drive time in minutes. Using his drive time data, build a frequency table, construct a histogram, and test for normality.

Accountant Drive Time to Work

Wk	Mon	Tue	Wed	Thr	Fri	Wk	Mon	Tue	Wed	Thr	Fri
1	43.5	42.8	42.8	45.1	42.4	**16**	42.5	43.6	39.9	45.2	42.3
2	46.3	46.8	44.5	45.4	42.0	**17**	40.6	41.6	43.0	44.8	39.8
3	39.4	40.6	46.9	46.4	40.6	**18**	42.5	46.1	45.7	43.1	41.2
4	45.5	40.3	43.4	44.2	41.3	**19**	42.7	43.2	44.3	45.9	45.0
5	42.4	43.6	44.1	43.4	41.4	**20**	44.0	43.5	44.7	40.6	43.5
6	43.6	42.2	39.3	46.6	41.9	**21**	42.9	45.9	38.2	43.0	41.0
7	42.5	44.8	41.6	43.8	43.4	**22**	44.1	47.4	38.6	45.4	42.0
8	47.3	41.1	44.5	43.1	43.0	**23**	43.1	46.4	43.8	40.5	41.7
9	43.5	41.3	38.8	42.0	40.5	**24**	45.6	44.8	38.8	42.6	44.9
10	45.7	44.1	47.8	39.0	42.2	**25**	43.7	42.2	43.3	47.2	43.0
11	44.4	43.3	42.9	39.8	43.9	**26**	44.3	37.9	42.4	45.6	41.3
12	48.1	40.7	44.9	41.8	41.9	**27**	45.9	41.4	42.9	40.4	44.8
13	46.8	41.9	40.5	44.6	44.7	**28**	43.7	43.5	41.8	46.2	39.5
14	41.3	40.3	37.5	46.9	46.3	**29**	44.5	45.5	45.0	46.9	43.2
15	43.8	43.6	42.5	48.4	41.5	**30**	41.0	40.3	40.9	42.0	45.8

Exercise 14-2

Our production manager drives the same route to work each day. The following table shows her drive times during the summer months. Compute the average, range, and standard deviation for drive time in minutes. Now using this drive time data, build a frequency table, construct a histogram, and test for normality.

Date	Day of Week	Time (Min)
6/5	Mon	34
6/6	Tue	37
6/7	Wed	39
6/8	Thr	39
6/9	Fri	34
6/12	Mon	36
6/13	Tue	35
6/14	Wed	35
6/15	Thr	34
6/16	Fri	37
6/19	Mon	34
6/20	Tue	37
6/21	Wed	32
6/22	Thr	39

Date	Day of Week	Time (Min)
6/23	Fri	35
6/26	Mon	36
6/27	Tue	34
6/28	Wed	34
6/29	Thr	36
6/30	Fri	36
7/6	Thr	35
7/7	Fri	37
7/10	Mon	36
7/11	Tue	33
7/12	Wed	34
7/13	Thr	38
7/14	Fri	36
7/17	Mon	38

Date	Day of Week	Time (Min)
7/18	Tue	35
7/19	Wed	36
7/20	Thr	32
7/21	Fri	33
7/24	Mon	39
7/25	Tue	32
7/26	Wed	38
7/27	Thr	38
7/28	Fri	34
8/7	Mon	36
8/8	Tue	37
8/9	Wed	37
8/10	Thr	34
8/11	Fri	35

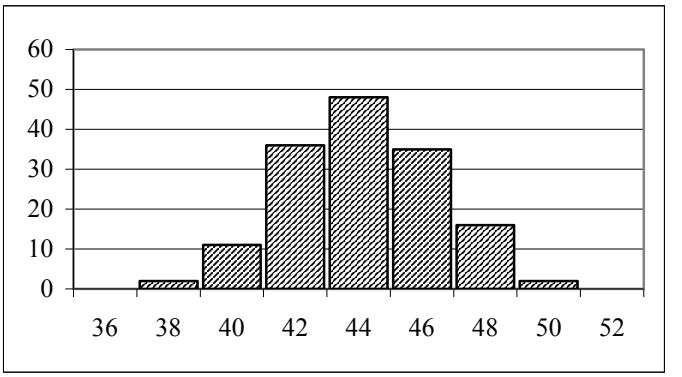
Chapter Fourteen

Solution 14-1

This is the drive time for our accounting manager. This distribution formed around the average of 43.2, a range of 10.9, and the standard deviation of 2.3 has an almost perfect normal distribution.

The peak is formed at the average. As we move farther away from the average the number of occurrences gets smaller. The bars above the average are symmetric in shape to the bars below the average. Thus we have a well-formed bell or normal distribution.

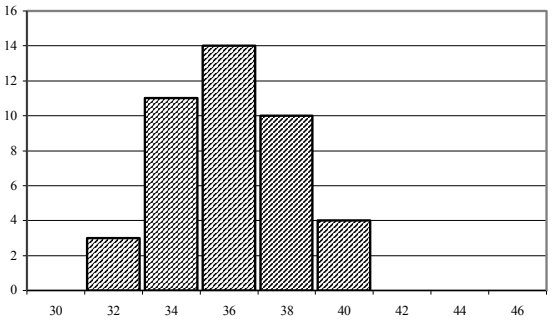
Time Groups	Number of Occurrences
0-38	2
38+-40	11
40+-42	36
42+-44	48
44+-46	35
46+-48	16
48+-50	2



Exercise 14-2 Solution

The following are the results of analyzing the production manager's summer drive time to work. This set of data has an average of 35.62 minutes and a standard deviation of 1.97 minutes. It is normally distributed.

Drive time Groups	Number of Occurrences
0-30	0
30+-32	3
32+-34	11
34+-36	14
36+-38	10
38+-40	4
40+-42	0
42+-44	0
44+-46	0



Chapter Sixteen

Metric Focused Center Engineering

Exercise 16-1

Using an average of .51 minutes and a standard deviation of .12 minutes for the phone pickup time, compute the probability of having pick up times less than each of the following values: .40, .30, .20, .25. The normal distribution is assumed.

Compute the probability of having phone pick up times greater than each of the following values: .55, .60, .70, .80.

Exercise 16-2

This exercise uses the data from our accounting manager's drive to work in minutes. The average (43.2 minutes) and standard deviation (2.3 minutes) were provided. The histogram passed the test so the distribution is normal.

For the following times, what is the probability that he will arrive at the center in that number of minutes or fewer?

42, 40, 38, 36, 34, 32, 30

For the following times, what is the probability that he will arrive in that number of minutes or greater?

44, 46, 48, 50, 52

Exercise 16-1 Solution

We have assumed a normal distribution for pickup time. The following table is the probability stated as a percentage of pickup time occurring at various points. For example, the probability of having a pickup time of .4 or less is 18%.

Pickup Time	0.40	0.30	0.20	0.25
Z	0.90	1.72	2.54	2.13
Probability	18%	4%	.55%	1.66%

Pickup Time	0.55	0.60	0.70	0.80
Z	0.33	0.74	1.56	2.38
Probability	37%	23%	6%	.87%

Exercise 16-2 Solution

The following table is the probability stated as a percentage of our accountant's drive time to work. As an example, the probability of his drive time being 38 minutes or less is 1.19%.

Average	42	40	38	36	34	32	30
Z	0.52	1.39	2.26	3.13	4.00	4.87	5.74
Probability	30.1%	8.2%	1.19%	0.09%	0.003%	0.0000560%	0.0000005%

Average	44	46	48	50	52
Z	0.35	1.22	2.09	2.96	3.83
Probability	36.3%	11%	1.8%	0.2%	0.0%

Chapter Seventeen

Metric Focused Center Engineering

Comprehensive Capability Study

Each one of the following exercises is intended to develop a thorough and rigorous capability study. All components should be completed. A set of control charts must be built to test for consistency. Calculate the strategic statistical results required for a capability study. The strategic study must include the average monitoring central tendency, the standard deviation monitoring variability, and the histogram testing for normality. Calculate the percent defective for the SLA. Finally, make recommendations.

Exercise 17-1

We have built a call center that must meet a SLA where all calls can be processed in 75 minutes or less. The following table shows consecutive calls that are processed in hourly intervals. The samples showing call duration are selected at the start of each hour. Develop a complete capability study validating all assumptions.

	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
1	61.324	59.550	66.221	59.614	61.032	55.525	63.034	62.743	61.538	66.571
2	61.177	61.401	62.282	62.748	62.300	60.697	57.245	51.350	54.592	61.541
3	54.014	56.397	56.931	63.653	65.510	53.853	55.404	51.007	71.859	57.483
4	53.540	55.639	55.131	63.656	60.766	63.457	66.552	63.945	54.533	62.251
5	61.774	62.670	57.792	62.788	50.599	65.006	63.645	63.104	55.949	61.482

	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
1	61.220	58.212	62.534	57.193	54.866	60.085	54.578	60.008	57.221	66.895
2	55.911	64.998	58.118	57.583	59.305	62.354	61.440	58.176	63.833	63.394
3	62.480	60.412	62.829	68.244	55.651	64.706	56.678	66.420	57.696	61.786
4	62.318	57.689	60.771	53.677	60.454	61.011	58.251	58.060	64.410	68.677
5	61.545	57.611	53.944	65.137	57.870	68.378	51.384	60.021	67.476	59.504

	21:00	22:00	23:00	24:00	1:00	2:00	3:00	4:00	5:00	6:00
1	57.110	61.642	57.562	58.101	63.245	63.413	59.984	71.649	63.206	65.146
2	56.792	60.390	61.310	61.971	67.230	55.879	67.688	59.936	55.995	70.501
3	54.721	68.125	57.487	53.917	60.665	60.656	63.288	64.363	60.704	57.780
4	56.808	60.488	58.628	54.390	56.224	50.718	66.908	58.583	60.184	62.823
5	52.954	58.844	57.035	48.373	57.172	59.918	68.152	52.726	57.507	59.270

Exercise 17-2

To support our customers we have built an IT helpdesk call center to share software content information about our products. The following table lists the call durations of the first five calls received at the start of each hour. The SLA for our IT helpdesk is 30 minutes. No caller should have to be on the phone longer than the SLA of 30 minutes.

Develop a complete capability study validating all assumptions.

	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
1	25.05	23.49	22.79	27.36	26.04	21.58	21.89	23.37	23.72	24.20
2	24.56	23.31	22.48	27.65	26.33	21.05	21.63	23.32	23.68	24.70
3	24.59	23.22	22.11	28.95	26.13	19.93	21.65	23.91	23.70	24.16
4	24.39	24.35	21.76	28.63	27.10	19.91	21.72	23.52	22.70	25.27
5	24.65	25.38	22.49	29.02	27.25	20.82	20.93	24.18	23.78	25.81

	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
1	23.87	25.45	26.09	20.42	25.81	27.84	28.68	25.62	23.65	27.61
2	24.34	25.54	27.19	20.58	25.30	26.49	27.90	25.35	23.20	28.14
3	23.55	24.72	26.63	19.99	26.11	27.92	27.62	26.11	23.37	28.9
4	23.33	25.68	26.65	20.46	25.93	29.19	26.74	26.46	22.98	28.83
5	22.63	24.79	25.95	21.39	25.06	30.41	27.21	26.34	21.98	28.66

	21:00	22:00	23:00	24:00	1:00	2:00	3:00	4:00	5:00	6:00
1	29.27	24.22	23.82	26.32	26.22	25.61	20.91	27.18	30.15	26.23
2	28.76	24.94	24.48	25.83	25.72	25.31	23.59	27.50	30.12	22.83
3	28.59	25.50	23.27	26.12	23.11	24.87	24.25	27.21	30.06	26.13
4	28.79	26.01	23.28	26.65	25.56	23.63	23.31	26.90	30.42	22.67
5	28.12	26.66	22.08	27.50	26.08	24.44	24.11	27.49	30.11	26.77

Exercise 17-3

A call center that processes customer orders from a mailed brochure must answer calls in a timely manner. The following are the times in seconds until pickup of five consecutive calls received on the hour. Call center management has determined that all calls must be answered within 20 seconds, which provides our pickup time SLA. Develop a complete capability study validating all assumptions.

	1:00	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**
1	14.08	14.05	11.25	17.24	18.19	17.19	18.77	19.34	17.41	15.59
2	12.36	21.02	14.56	16.17	16.15	15.96	11.81	19.44	11.41	17.06
3	12.27	20.95	16.42	16.75	12.25	15.14	12.78	13.37	14.75	14.81
4	16.06	19.23	13.41	15.87	14.89	17.18	15.06	11.75	13.96	14.65
5	15.61	15.28	16.50	13.81	19.31	17.21	16.97	18.06	14.85	16.31

	11:00	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
1	16.74	14.33	16.57	14.50	12.40	16.11	10.56	13.59	9.44	19.63
2	12.36	14.84	15.47	17.51	8.96	12.29	15.05	14.07	13.80	16.99
3	10.64	14.72	14.73	13.75	18.77	14.88	16.26	11.80	17.34	14.57
4	8.79	10.72	16.97	11.34	19.63	14.02	14.37	18.10	15.81	19.65
5	14.62	12.87	14.94	18.73	19.06	13.17	11.50	15.11	13.73	18.32

	21:00	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
1	14.39	13.21	10.58	19.84	11.44	15.95	14.40	14.93	11.99	19.23
2	12.60	13.03	12.66	15.05	16.35	11.78	13.29	11.58	15.11	13.99
3	16.75	16.86	16.47	9.91	16.48	16.35	10.69	12.65	10.02	15.31
4	17.48	13.08	15.38	14.78	18.90	13.51	13.49	12.51	18.97	13.79
5	16.82	16.90	11.84	14.10	14.41	11.28	16.65	14.62	17.45	14.50

Exercise 17-4

We have a credit card processing center. The following table lists the call durations of the first call received at the start of each hour. The SLA for call duration is 100 seconds. Develop a complete capability study validating all assumptions.

1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
82	93	88	90	150	94	112	90	101	25

11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
90	116	70	60	70	65	64	70	62	52

21:00	22:00	23:00	24:00	1:00	2:00	3:00	4:00	5:00	6:00
59	89	94	103	92	88	140	75	77	62

Exercise 17-5

For this exercise we are an IT organization. We have built an IT help desk to support and advise our users. The table below shows the number of calls received each day. Build the control charts for the data below, and test for consistency.

The SLA is 45 calls per day. Develop a complete capability study validating all assumptions and computing if our process is capable.

Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
29	38	28	27	27	36	26	31	30	31

Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
31	24	32	36	30	32	30	30	26	31

Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
25	32	33	29	34	34	33	30	33	33

Exercise 17-6

Our organization supports retail stores with point of sale software. As of this Monday, the development department is releasing an update to the software.

The values in the table below (number of calls) are a continuation of the table in exercise 15-5. Using the values below, post them to the control charts built in Exercise 15-5 and check for any out-of-control conditions.

Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
35	30	29	40	45	33	42	28	29	45

Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
32	35	34	45	49	44	37	32	37	40

Make recommendations as to a course of action. Should these values detect a permanent shift, do everything required to maintain the proper operational methods. Build a new set of control limits and the capability study that corresponds with them.

Chapter Seventeen

Solution 17-1

The call duration results are transformed into X-bar and R readings for posting onto control charts. These results are shown in the table below.

	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
$\bar{X}$	58.365	59.131	59.671	62.491	60.041	59.708	61.176	58.430	59.694	61.866
R	8.234	7.031	11.090	4.042	14.911	11.153	11.148	12.938	17.326	9.088
	11:00	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
$\bar{X}$	60.694	59.784	59.639	60.366	57.629	63.307	56.466	60.537	62.127	64.051
R	6.569	7.387	8.885	14.567	5.588	8.293	10.056	8.360	10.255	9.173
	21:00	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
$\bar{X}$	55.677	61.897	58.404	55.350	60.907	58.116	65.204	61.451	59.519	63.104
R	4.156	9.281	4.275	13.598	11.006	12.695	8.168	18.923	7.211	12.721

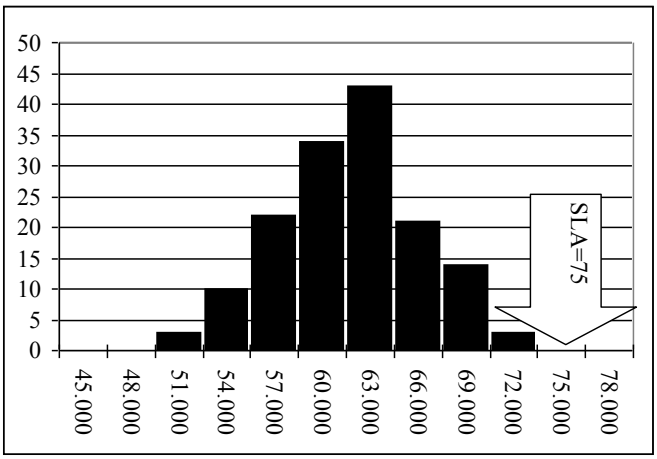
The X-bar and R values are used to calculate the control limits for charts below.

Range Control Limits	
$\bar{R}$	9.9376
UCL	21.0081
LCL	0

$\bar{\bar{X}}$ **Control Limits**	
$\bar{\bar{X}}$	60.1603
UCL	65.8943
LCL	54.4263

The control charts show no out-of-control conditions. With the knowledge in hand that our center's duration is consistent, the capability study may continue. The call duration histogram (see below) shows a well-formed bell-shaped curve. This allows the use of a normal table to project the calls that will fall above the SLA of 75 minutes.

Using average of 60.16minutes and the standard deviation = 4.524425, the table below projects the number of calls that will exceed the SLA of 75 minutes, based on the statistical



results of the actual individual calls and the look up in the normal distribution table.

		Z	Percent Defective
SLA	75.000	3.27990	0.052%

From the capability study our center's call duration is well below our SLA of 75 minutes. It should be a rare occurrence when a call's duration exceeds 75 minutes. Stated using our statistics, .05% of the time we would expect a call's duration to be longer than 75 minutes.

Solution 17-2

The IT helpdesk call duration data is transformed into X-bar and R readings for posting onto control charts. These results are shown in the table below.

	1:00	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**
$\bar{X}$	24.648	23.950	22.326	28.322	26.570	20.658	21.564	23.660	23.516	24.828
R	0.660	2.160	1.030	1.660	1.210	1.670	0.960	0.860	1.080	1.650
	11:00	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
$\bar{X}$	23.544	25.236	26.502	20.568	25.642	28.370	27.630	25.976	23.036	28.428
R	1.710	0.960	1.240	1.400	1.050	3.920	1.940	1.110	1.670	1.290
	21:00	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
$\bar{X}$	28.706	25.466	23.386	26.484	25.338	24.772	23.234	27.256	30.172	24.926
R	1.150	2.440	2.400	1.670	3.110	1.980	3.340	0.600	0.360	4.100

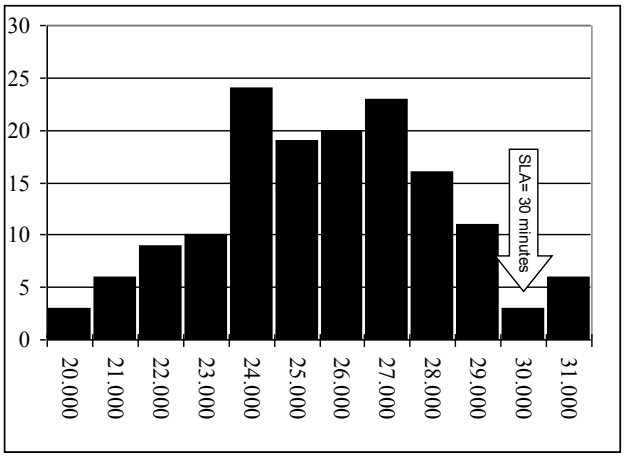
The X-bar and R-values are used to calculate the control limits for the charts below.

Range Control Limits	
$\bar{R}$	1.679
UCL	3.550
LCL	0

$\bar{\bar{X}}$ **Control Limits**	
$\bar{\bar{X}}$	25.157
UCL	26.126
LCL	24.188

The X-bar control chart shows significant inconsistency. There are 11 points above the upper control limit, and 11 points below the lower control limits. Out of 30 X-bar time-period readings, there are 22 that are outside the control limits. The R control chart shows two R readings above the upper control limits. Also, a run of eight consecutive points (3:00 am until 9:00 pm) is below the R-bar value. The control charts show that the call center's call duration is totally inconsistent and out of control.

The histogram of the individual call duration times is shown below. Two peaks are shown, one at 24 minutes and one at 27 minutes. A valley appears at 25 minutes and 26 minutes. This distribution is definitely not a normal distribution.



The capability study must not be continued since the center's duration time is not consistent and does not have a normal distribution. Any results from this set of values will be flawed.

Solution 17-3

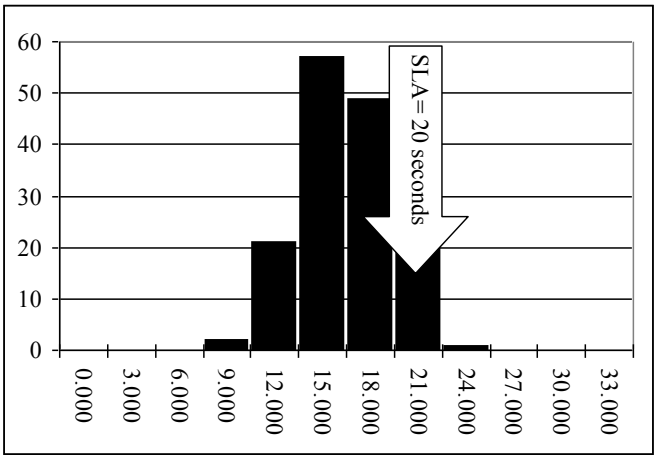
A call center's time-until-pickup data have been transformed into X-bar and R readings for posting onto control charts. These X-bar and R values are shown in the table below and are used to compute the control limits.

	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
$\bar{X}$	14.076	18.106	14.428	15.968	16.158	16.536	15.078	16.392	14.476	15.684
R	3.79	6.97	5.25	3.43	7.06	2.07	6.96	7.69	6.00	2.41
	11:00	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
$\bar{X}$	12.630	13.496	15.736	15.166	15.764	14.094	13.548	14.534	14.024	17.832
R	7.95	4.12	2.24	7.39	10.67	3.82	5.70	6.30	7.90	5.08
	21:00	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
$\bar{X}$	15.608	14.616	13.386	14.736	15.516	13.774	13.704	13.258	14.708	15.364
R	4.88	3.87	5.89	9.93	7.46	5.07	5.96	3.35	8.95	5.44

Range Control Limits	
$\bar{R}$	5.787
UCL	12.233
LCL	0

$\bar{\bar{X}}$ Control Limits	
$\bar{\bar{X}}$	14.947
UCL	18.285
LCL	11.608

The X-bar and R control charts show that the process is in control. With this knowledge in hand, the capability study may continue. The histogram of time-until-pickup data is shown below. This histogram shows a well-formed bell curve. Using the average of 14.95 seconds and Standard Deviation = 2.618786, this allows the use of a normal table to project the call pickup time that will fall above the upper specification limit of 20 seconds.



This table projects that 2.68% of the call times will exceed the upper specification of 20 seconds. These projections are based on the statistical results of the actual individual calls, and the look up in the normal distribution table.

		Z	Percent Defective
SLA	20	1.929699	2.682%
		Total	2.682%

This call center is a revenue producer for our mail order business. The profile of our typical call is at about 20 seconds (the SLA.) At that point our customers will drop off the line and we lose the opportunity to make the sale. Our percent above the SLA is 2.68%. This percentage is high because of our lost revenue. We should investigate ways to change the facility so that the time to pickup is reduced. One facility change is to add more agents so that the average pickup time is reduced.

Chapter Seventeen

Solution 17-4

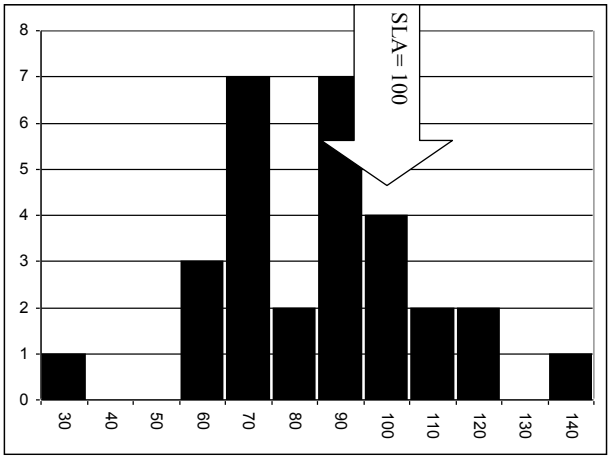
The following table shows the Individual and Moving Range (R) readings for the call duration.

	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
	82	93	88	90	150	94	112	90	101	25
R		11	5	2	60	56	18	22	11	76
	11:00	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**
	90	116	70	60	70	65	64	70	62	52
R	65	26	46	10	10	5	1	6	8	10
	21:00	**22:00**	**23:00**	**24:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**
	59	89	94	103	92	88	140	75	77	62
R	7	30	5	9	11	4	52	65	2	15

$\bar{\bar{X}}$ Control Limits	
$\bar{\bar{X}}$	84.100
UCL	143.537
LCL	24.663

Range Control Limits	
$\bar{R}$	22.345
UCL	73.001
LCL	0

The control charts have many out-of-control conditions. On the Individual chart, two points outside the control limits, seven points above the mean, and seven points below the mean are observed. On the Moving Range chart two points outside the control limits and eight points below the mean are seen. The credit card center call duration is very inconsistent, so our capability study is flawed.



The call duration histogram below shows two spikes one at the 70 second and a second at the 90 second. The capability study must not be continued since the center's duration time is not consistent and does not have a normal distribution. Any results from this set of values will be flawed.

Solution 17-5

The following table shows the Individual and Moving Range (R) readings for the call duration.

	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
	29	38	28	27	27	36	26	31	30	31
R		9	10	1	0	9	10	5	1	1
	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
	31	24	32	36	30	32	30	30	26	31
R	0	7	8	4	6	2	2	0	4	5
	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
	25	32	33	29	34	34	33	30	33	33
R	6	7	1	4	5	0	1	3	3	0

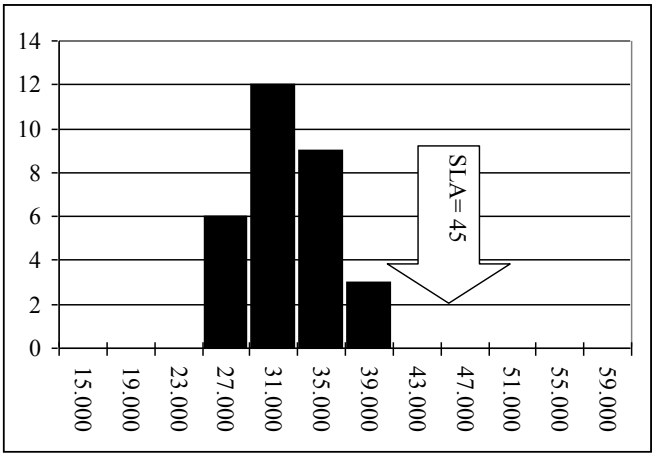
The Individual and moving R values are used to calculate the control limits for charts below.

$\bar{\bar{X}}$ Control Limits	
$\bar{\bar{X}}$	30.700
UCL	41.157
LCL	20.243

Range Control Limits	
$\bar{R}$	3.9310
UCL	12.843
LCL	0

The control charts have no out-of-control conditions so our capability study may continue.

The call duration histogram below shows a well-formed bell curve which allows the use of a normal table to project the percent of points that will fall above the SLA of 45 calls per day.



Using the average of 30.7 calls per day and standard deviation = 3.334, the table below projects the percent defects based on the actual results and the normal table.

		Z	Percent Defective
SLA	45.0000	4.289	0.001%

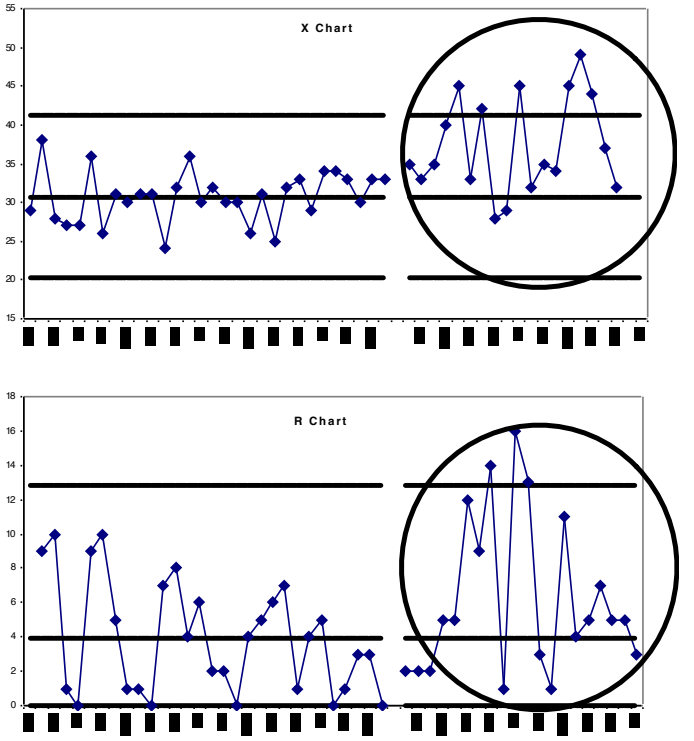
The capability study shows a defect rate of .001%. Our conclusion is that the center will consistently meet the SLA.

Solution 17-6

The following table shows the X-bar and R readings for the call volume after the point of sale software update was released to the field.

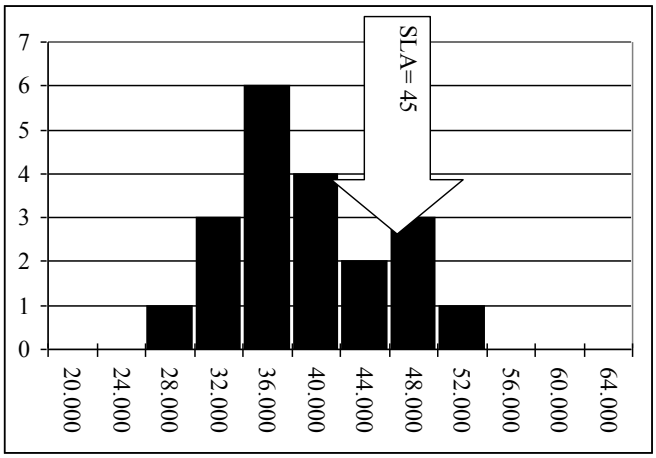
	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
	35	30	29	40	45	33	42	28	29	45
R	2	5	1	11	5	12	9	14	1	16
	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
	32	35	34	45	49	44	37	32	37	40
R	13	3	1	11	4	5	7	5	5	3

Both the Individual and Moving Range charts show significant change.



After a thorough investigation, the updated point of sales software has caused an increase in the call volume. The time frame of the four weeks of information after the change will now be compiled to assess the impact on our center. Our SLA is still 45 calls per hour.

The histogram below only reflects the 20 data points of the four weeks after the software update.



The histogram shows that we will have significant number of days when the call volume will exceed the capability of the call center. Using the average of 37.05 calls and standard deviation = 6.362, the table below projects the percent defects based on the actual results and the normal table.

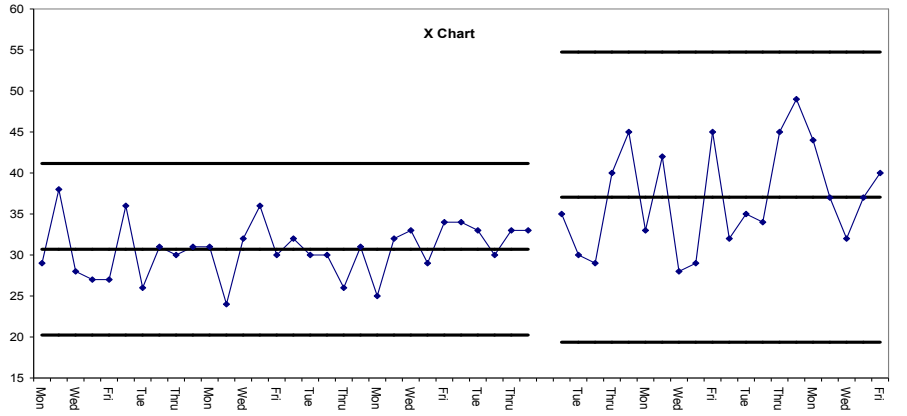
		Z	Percent Defective
SLA	45.0000	1.250	10.571%

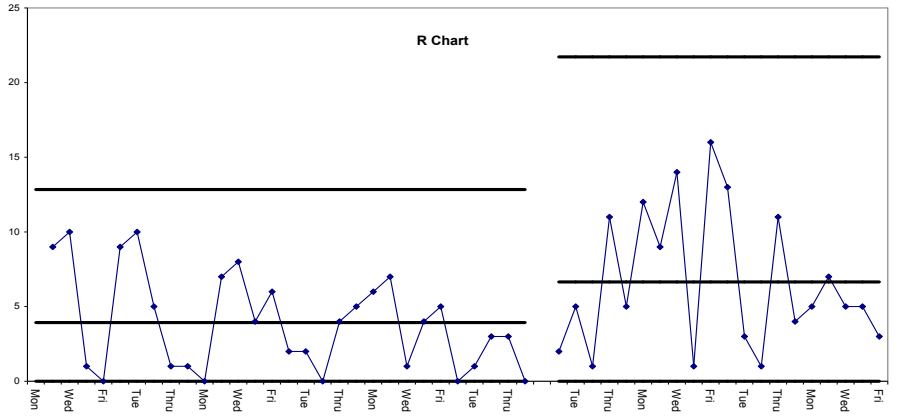
The average call volume has increased from 30.5 calls to 37.1 call. The variability has increased from 3.334 calls to 6.362 calls. The call center must be optimized to reflect the higher call volumes. This will require increased resources.

We must now recompute our control limits to reflect the call volume increase. The Individual and Moving Range values are used to calculate the control limits for charts below.

$\overline{\overline{X}}$ Control Limits	
$\overline{\overline{X}}$	37.050
UCL	54.7390
LCL	19.3610

R Control Limits	
$\overline{R}$	6.650
UCL	21.7256
LCL	0





Chapter Eighteen

Keeping the Center Optimal

Exercise 18-1

In an earlier exercise we computed an average if .51 seconds and standard deviation of .12 seconds for a call pickup time. We will assume a normal distribution.

Answer the following questions:

a) What would the pickup time be when pickup time probabilities are 10% above this point?
b) What would the pickup time be when pickup time probabilities are 10% below this point?
c) What would the pickup time be when pickup time probabilities are 5% above this point?
d) What would the pickup time be when pickup time probabilities are 5% below this point?
e) What would the pickup time be when pickup time probabilities are 1% above this point?
f) What would the pickup time be when pickup time probabilities are 1% below this point?

Exercise 18-2

We will use the accounting manager's drive time statistics and assume a normal distribution.

	Drive Time
Average	43.2
Standard Deviation	2.3

a. How much time would he need to allow to assure that 97.5% of the time he is on time and only 2.5% of the time he is late?
b. How much time would he need to allow to assure that 95% of the time he is on time and only 5% of the time he is late?

Chapter Eighteen

Solution 18-1

The following table is the pickup time at certain points based on a given probability.

Probability	10%
Z	1.28
Probability	5%
Z	1.645
Probability	1%
Z	2.33

Exercise		
a.	Point Above 10%	0.67
b.	Point below 10%	0.35
c.	Point Above 5%	0.71
d.	Point below 5%	0.31
e.	Point Above 1%	0.79
f.	Point below 1%	0.23

Solution 18-2

The following table is the production manager's summer drive time at certain points based on a given probability. If the production manager allows 47.7 minutes, she will be on time 97.5% of the time. If she allows 47.0 minutes, she will be on time 95% of the time.

Exercise a	
	Z
2.50%	1.96
Point	47.7

Exercise b	
	Z
5.00%	1.645
Point	47.0

About the Author:

James Abbott has made a career out of taking technical topics and explaining them so that "the rest of us" can understand. As professional engineer, James learned early on that even the best methods are useless unless they are delivered in a fashion that allows their swift and effective implementation.

Inspired by the great Southern tradition of storytelling, James uses anecdotes about Grandma's biscuits, NASCAR, candy company, and a visit to the grocery store to explain scientific concepts like queuing theory and reporting metrics.

James isn't afraid to get his hands dirty. In the course of his engineering he's worked alongside electric engine assemblers, in a high-pressure customer care center, and on the third shift of a global IT help desk. It is his ability to learn a business—from the ground up—that has allowed James to develop methods and tools for everyone from the CEO to the custodial staff.

Though he has worked throughout the Western Hemisphere, James's home is in Greenville, South Carolina.

For more information about James Abbott, his books, resources, and his classes

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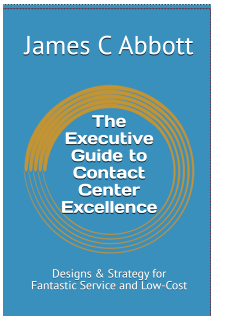

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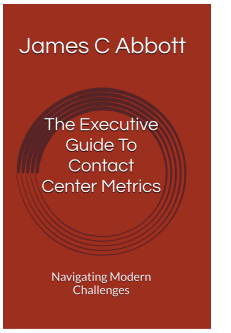

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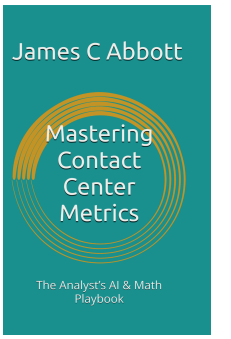

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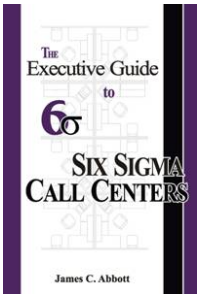

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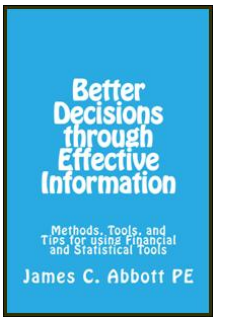

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