PART

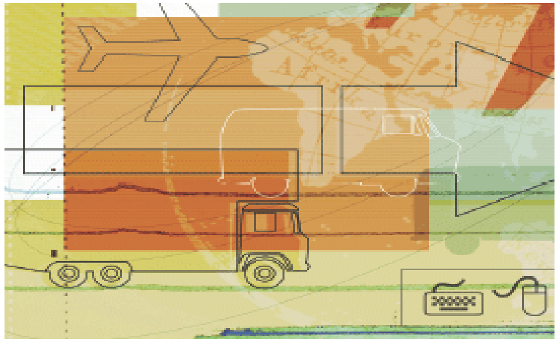
II

Process Decisions

SUPPLEMENT

Ch 6

Quality Tools for Improving Processes



ดร.มนตรี วิบูลยรัตน์

Montri Wiboonrat, Ph.D.

SUPPLEMENT OBJECTIVES

- Introduce the various tools that are used for analyzing and improving the quality of processes.
- Describe two major approaches (acceptance sampling and statistical process control) that can be used to improve process quality.
- Define the two types of errors that can occur when statistical sampling is used.
- Distinguish between the statistical analysis of processes using attributes and variables.
- Discuss Taguchi methods and how they are different from traditional statistical quality control methods.
- Describe the quantitative methodology behind Six Sigma.

Why Quality Tools Are Important to Managers

- *Characteristics of Variation:*
  - Variation is omnipresent.
  - Variation is both desirable (personalities) and undesirable (surgical outcomes).
  - Variation is both random and nonrandom.
- *Quality tools provide a structured approach to understanding process variation, identifying its causes, and eliminating the causes.*

The Basic Quality Control Tools

- *Seven Basic Quality Control (QC) Tools*
  - –Process flowcharts (or diagrams)
  - –Checksheets
  - –Bar charts and histograms
  - –Pareto charts
  - –Scatterplots (or diagrams)
  - –Run (or trend) charts
  - –Cause-and-effect (or fishbone) charts

Checksheets

Type of Complaint	Frequency
Cord too short	卌 IIII
Dirt bags hard to change	卌
Too heavy	卌 卌
Breaks down a lot	卌 II
Accessories don't always work	III
Other	IIII

Checksheet for
Recording Complaints

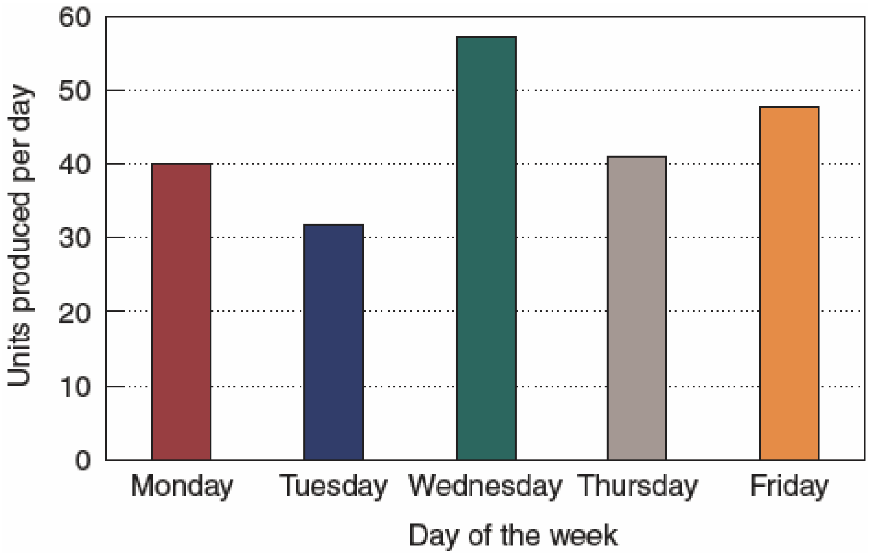
Customers in Party	Count
1	IIII
2	卌 卌 卌 卌 III
3	卌 卌 II
4	卌 卌 卌 卌 卌 卌 I
5	卌 卌 卌
6	卌 II
>6	II

Checksheet for
Group Sizes in a Restaurant

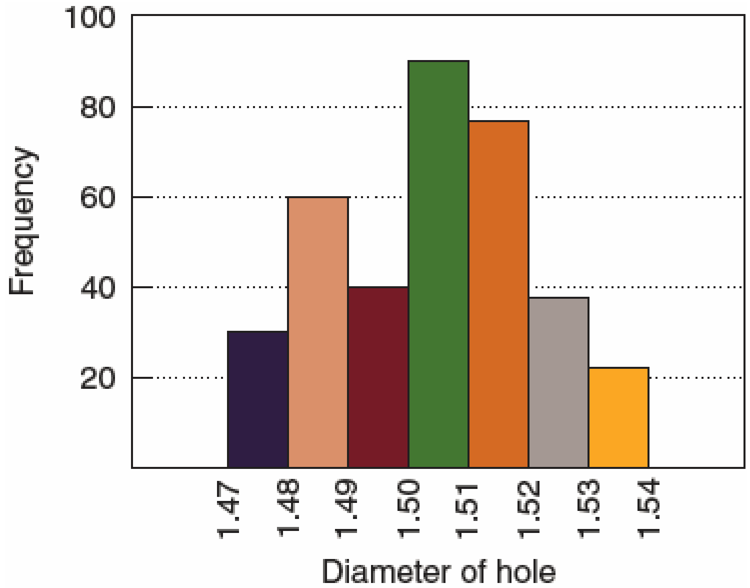
Exhibit S9.1

Exhibit S9.2

Bar Charts and Histograms



Bar Chart of Daily Units Produced



Histogram of Hole Diameters

Exhibit S9.3

Exhibit S9.4

Pareto Chart of Factors in an Emergency Room

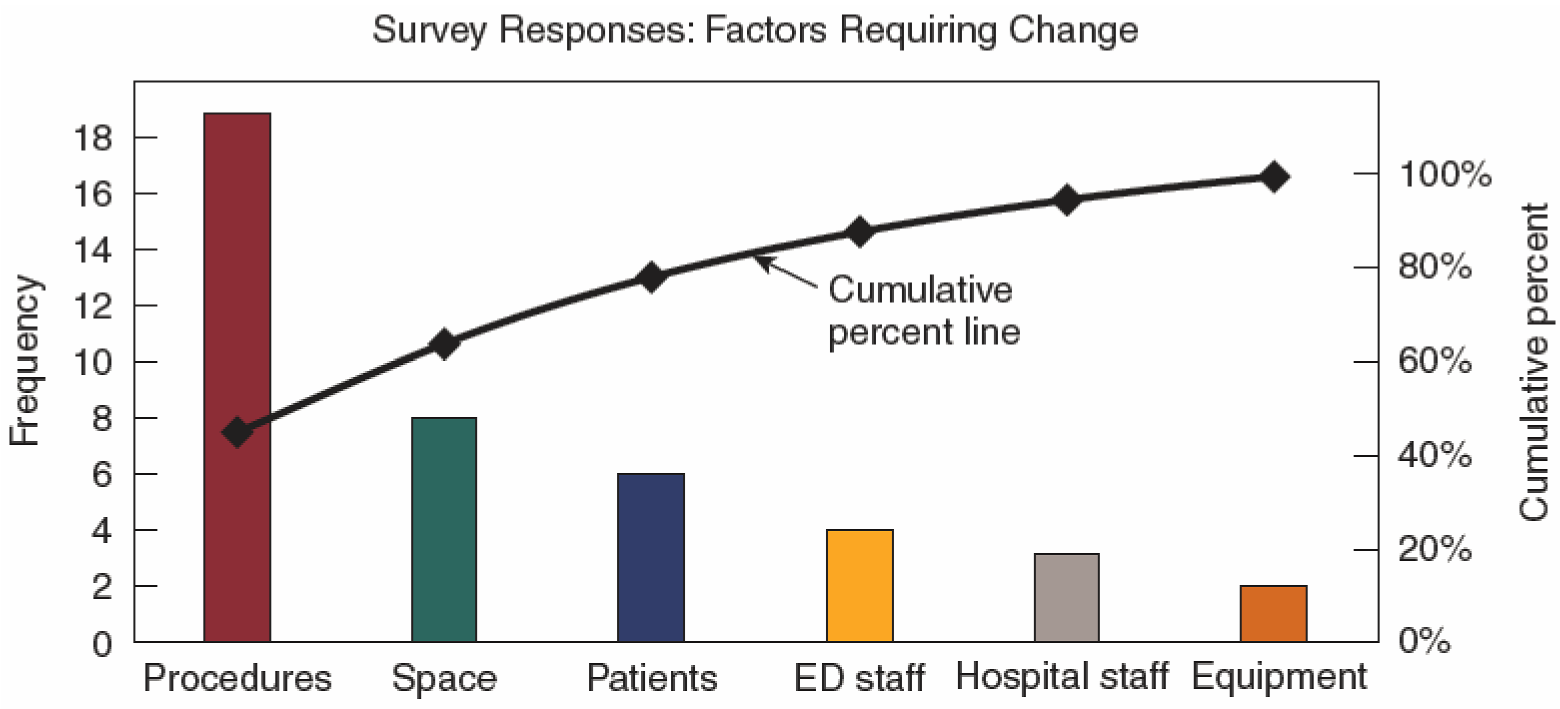


Exhibit S9.5

Scatterplot of Customer Satisfaction and Waiting Time in an Upscale Restaurant

Exhibit S9.6

Run Chart of the Number of Daily Errors

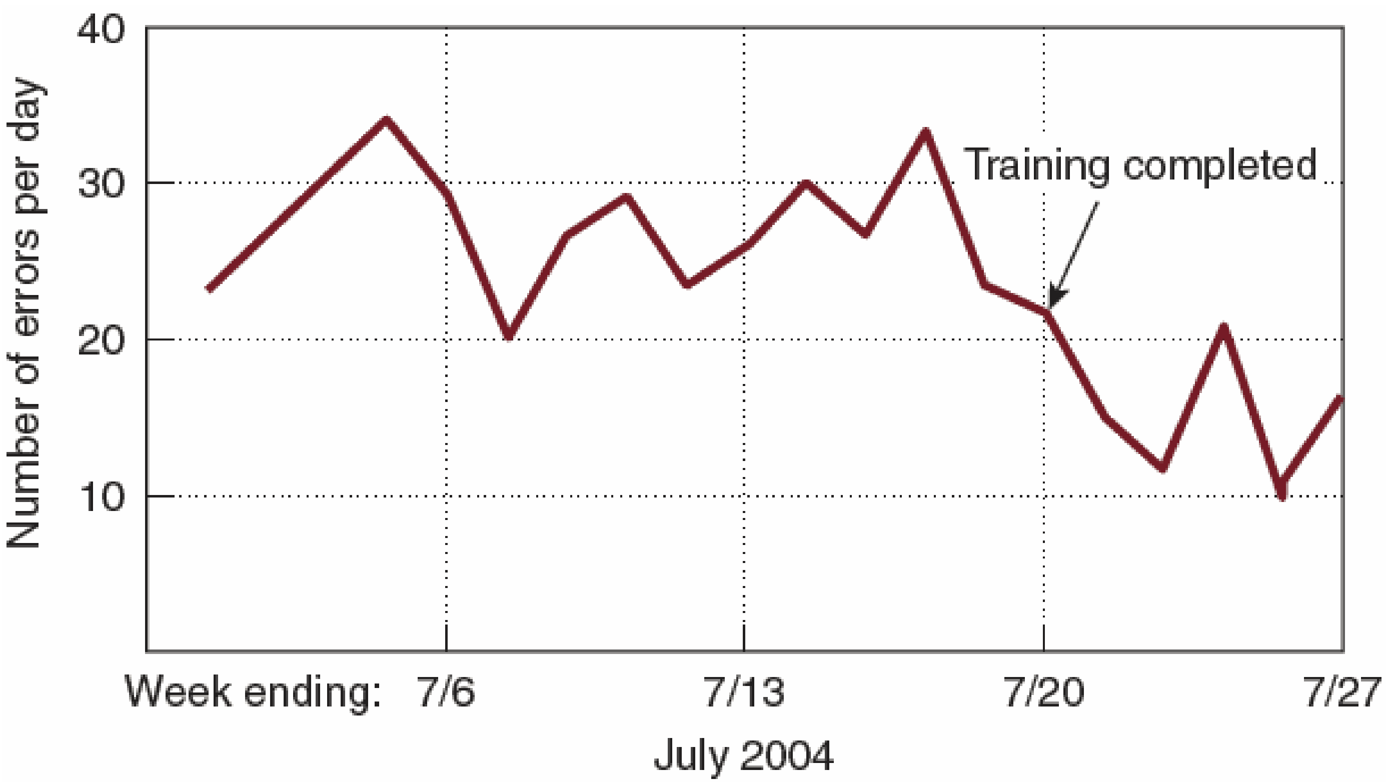
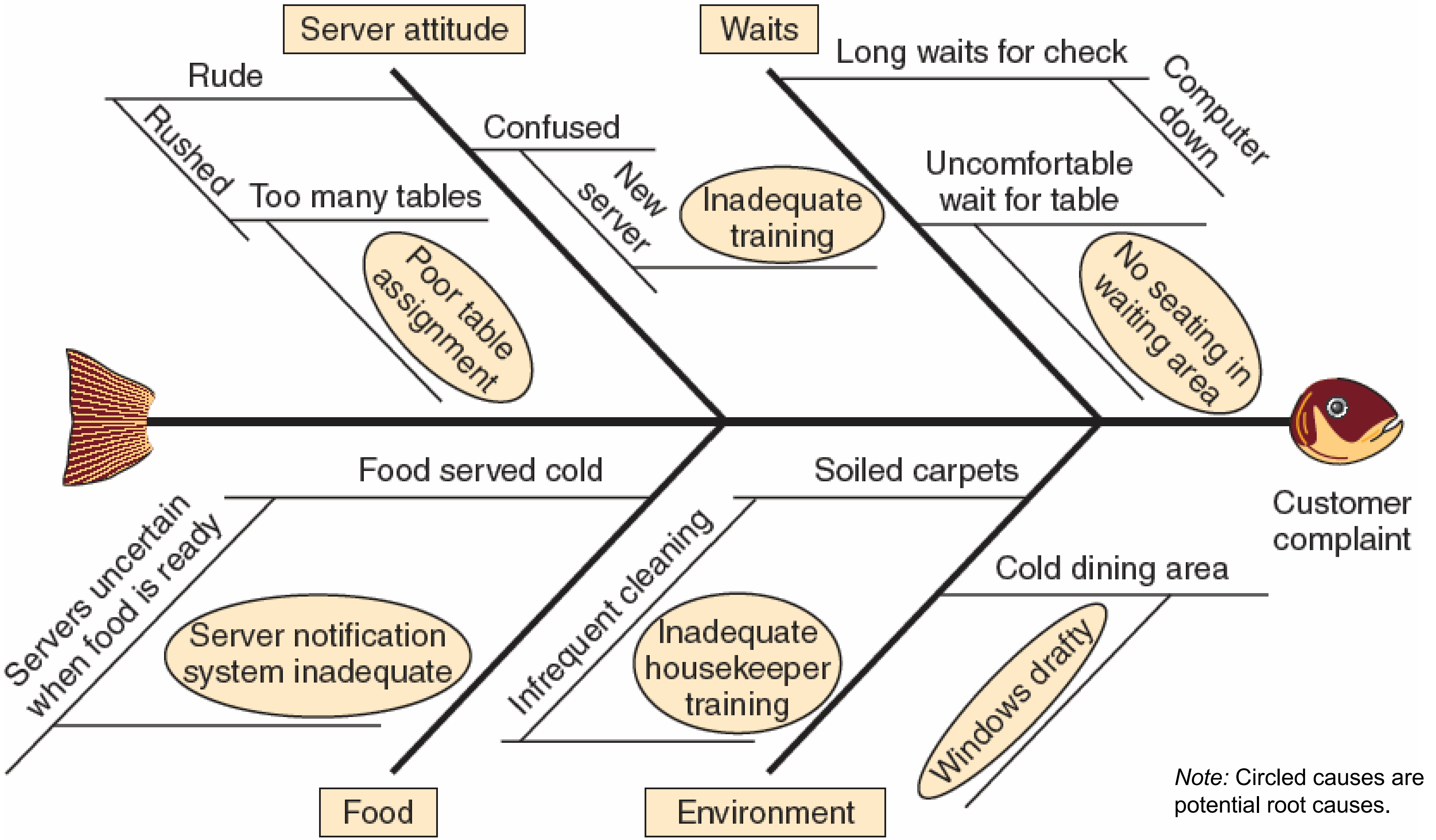


Exhibit S9.7

Cause-and-Effect Diagram for Customer Complaints in a Restaurant

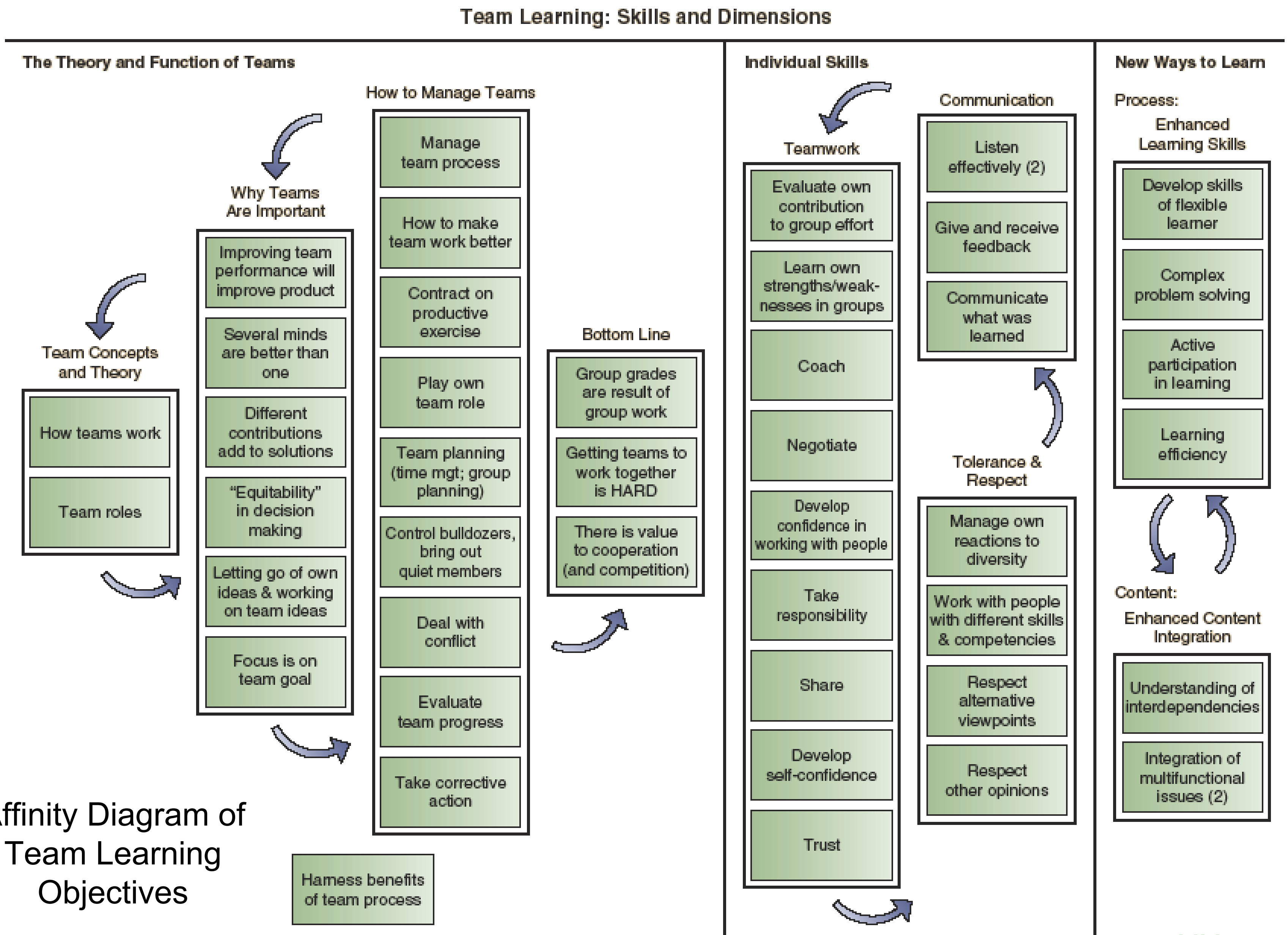


Note: Circled causes are potential root causes.

Exhibit S9.8

Advanced Quality Tools

- *Affinity diagrams*
  - Used to structure and clarify ideas by organizing them according to their affinity, or similarity, to each other.
- *Interrelationship digraph*
  - Helps to sort out cause-and-effect relationships when there are a large number of interrelated issues that need to be better understood.



Affinity Diagram of Team Learning Objectives

Exhibit S9.9

Relations Diagram for Late Hospital Discharge

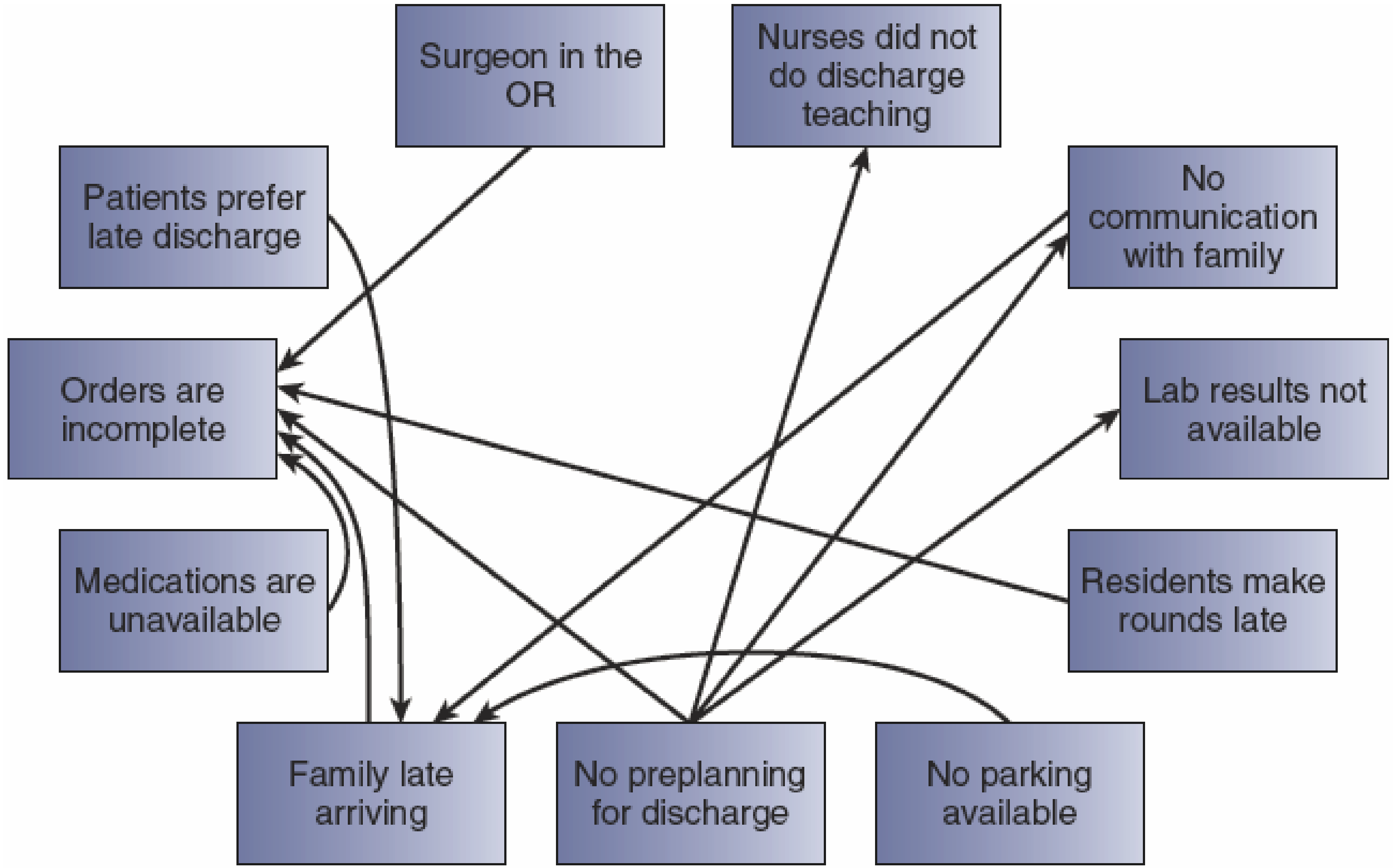


Exhibit S9.10

Advanced Quality Tools (cont'd)

- *Tree diagram*
  - Helps determine ways to meet objectives by breaking down a main goal into subgoals and actions and identify the strategy to be taken.
- *Matrix diagram*
  - Used to organize information that can be compared on a variety of characteristics in order to make a comparison, selection, or choice.
  - Arranges elements of a problem or event in rows and columns on a chart that shows relationships among each pair of elements.

Basic Structure of a Tree Diagram

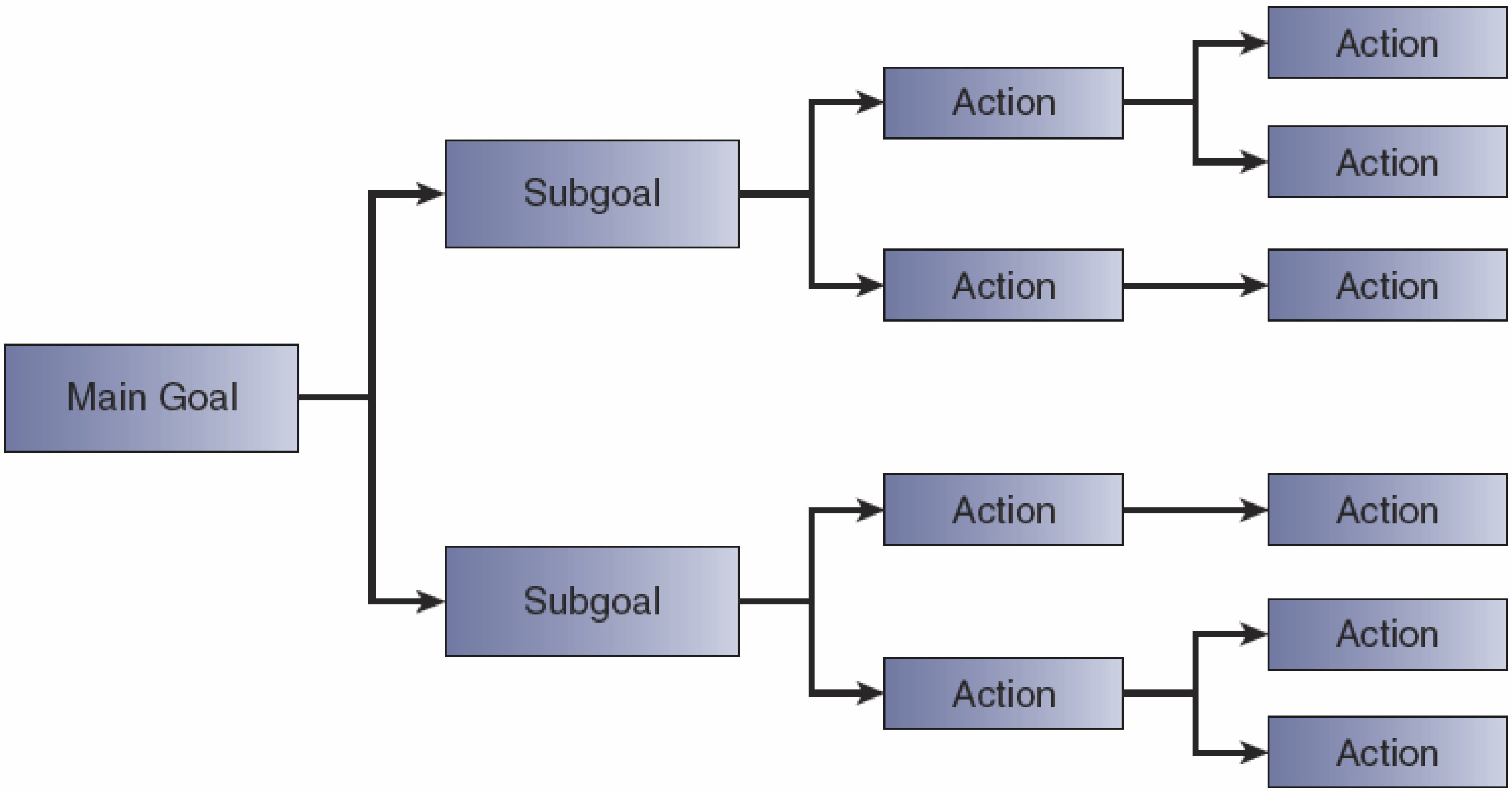


Exhibit S9.11

Matrix Diagram

◉ Excellent = 9

○ Fair = 3

△ Poor = 1

Plan \ Criteria	Strategic fit	Feasibility	Time	Cost	Total
Plan 1	◉	○	△	◉	22
Plan 2	◉	◉	◉	△	28
Plan 3	○	○	○	△	10
Plan 4	○	△	○	◉	16
Plan 5	△	○	△	◉	14

Exhibit S9.12

Statistical Analysis of Processes

- *Statistical Analysis*
  - Requires less labor (reduces costs)
  - Useful when testing destroys products
- *Categories of Statistical Tools*
  - Acceptance sampling
    - Assesses the quality of parts or products after they have been produced.
  - Statistical process control
    - Assesses whether or not an ongoing process is performing within established limits.

Attributes and Variables

- *Types of Data*
  - –Attribute data
    - Data that count items, such as the number of defective items in a sample.
  - –Variable data
    - Data that measure of a particular product characteristic such as length or width.

Statistical Quality Control Methods

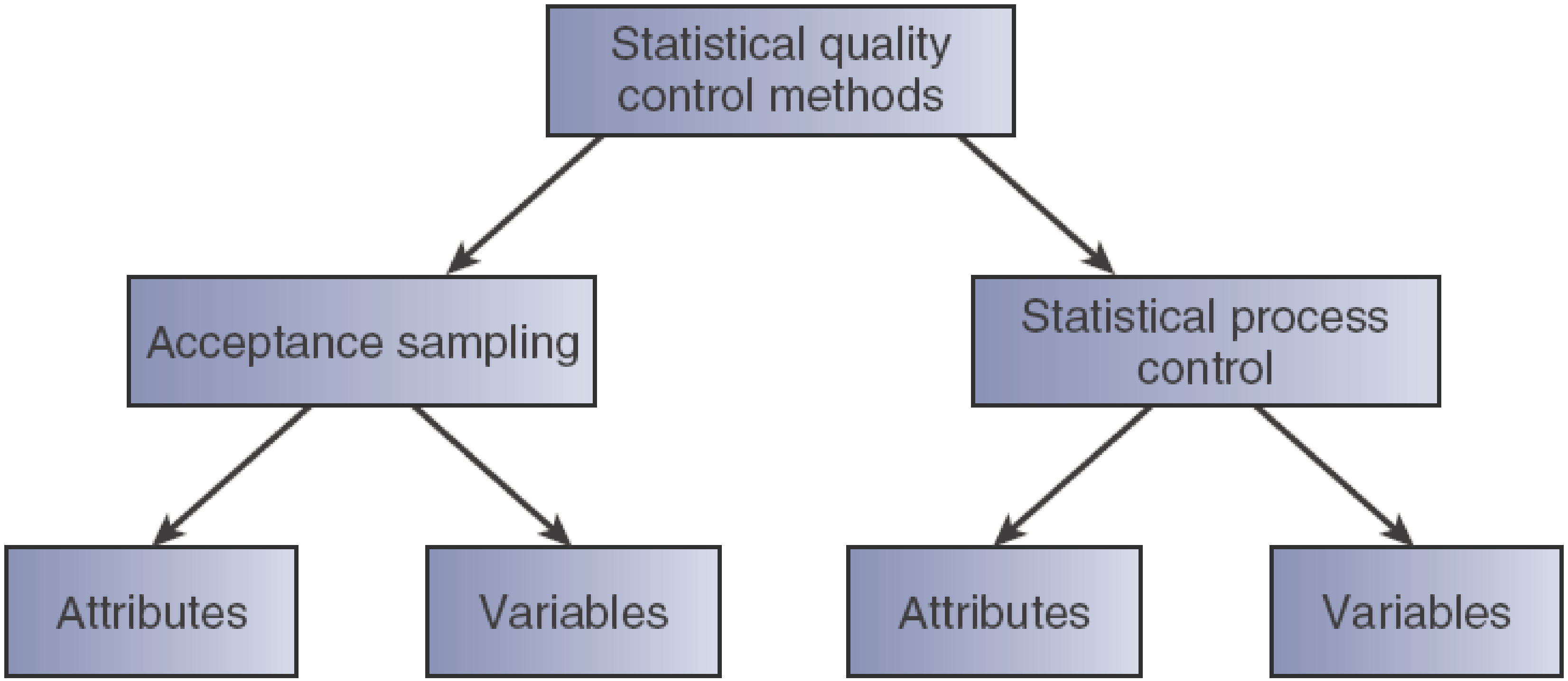


Exhibit S9.13

Sampling Errors

- *Type I (α Error or Producer's Risk)*
  - Occurs when a sample says parts are bad or the process is out of control when the opposite is true.
  - The probability of rejecting good parts as scrap.
- *Type II (β error or Consumer's Risk)*
  - Occurs when a sample says parts are good or the process is in control when the reverse is true.
  - The probability of a customer getting a bad lot represented as good.

Types of Sampling Errors

		The population or process is actually: Good or in control	Bad or out of control
The sample says that the population or process is:	Good or in control	no error	Type II error
	Bad or out of control	Type I error	no error

Exhibit S9.14

Acceptance Sampling

- *Designing a Sampling Plan for Attributes*
  - –Costs to justify inspection
    - Costs of not inspecting must exceed costs of inspecting.
  - –Purposes of sampling plan
    - Find quality or ensure quality is what it is supposed to be.
  - –Acceptable quality level (AQL)
    - Maximum percentage of defects that a company is willing to accept.
- *Operating Characteristic (OC) Curves*
  - –Curves that illustrate graphically the probability of accepting lots that contain different percent defectives.

Attribute Sampling

- *Defining an Attribute Sampling Plan*
  - *N:* number of units in the lot
  - *n*: number of units in the sample
  - c: the acceptance number (the maximum number of defectives allowed in the sample before the whole lot is rejected.
- *LTPD*
  - Lot tolerance percentage defective: the percentage of defective units that can be in a single lot.

Excerpt from a Sampling Plan Table for α = 0.05, β = 0.10

c	LTPD ÷ AQL	*n* · AQL	*c*	LTPD ÷ AQL	*n* · AQL
0	44.890	0.052	5	3.549	2.613
1	10.946	0.355	6	3.206	3.286
2	6.509	0.818	7	2.957	3.981
3	4.890	1.366	8	2.768	4.695
4	4.057	1.970	9	2.618	5.426

Exhibit S9.15

Operating Characteristic Curve for AQL = 0.02, α = 0.05, LTPD = 0.08, β = 0.10

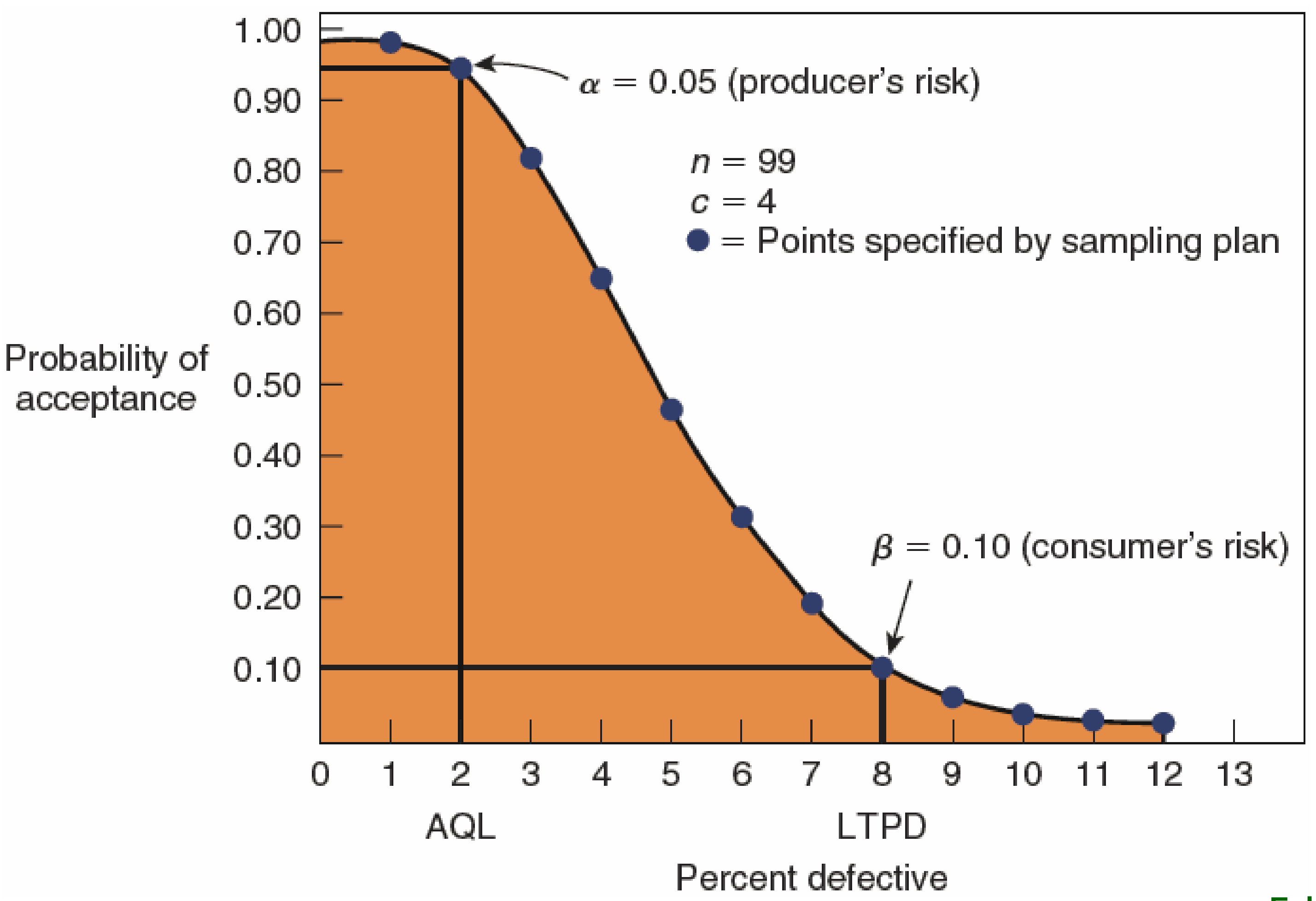


Exhibit S9.16

Developing a Sampling Plan for Variables

- *Control Limits*
  - Points on an acceptance sampling chart that distinguish the accept and reject region(s).
  - Also, the points on a process control chart that distinguish between a process being in or out of control.
- *Factors to Consider in Designing a Plan*
  - The probability of rejecting a good lot (α error)
  - The probability of accepting bad lot (β error)
  - The size of the sample (n)

Establishing Critical Values for Acceptance Sampling Using Variables

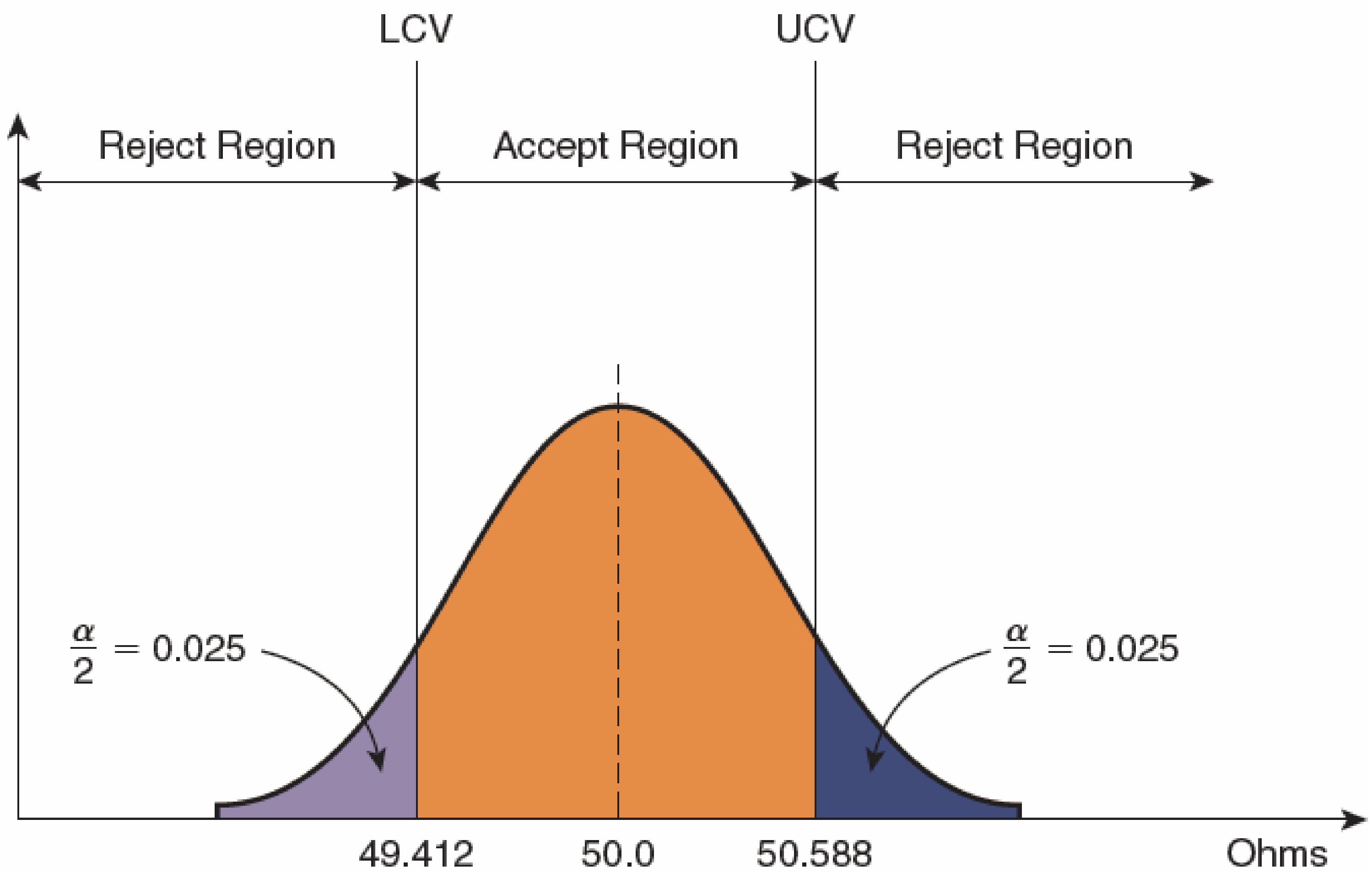


Exhibit S9.17

Determining the Probability of Committing a Type II Error

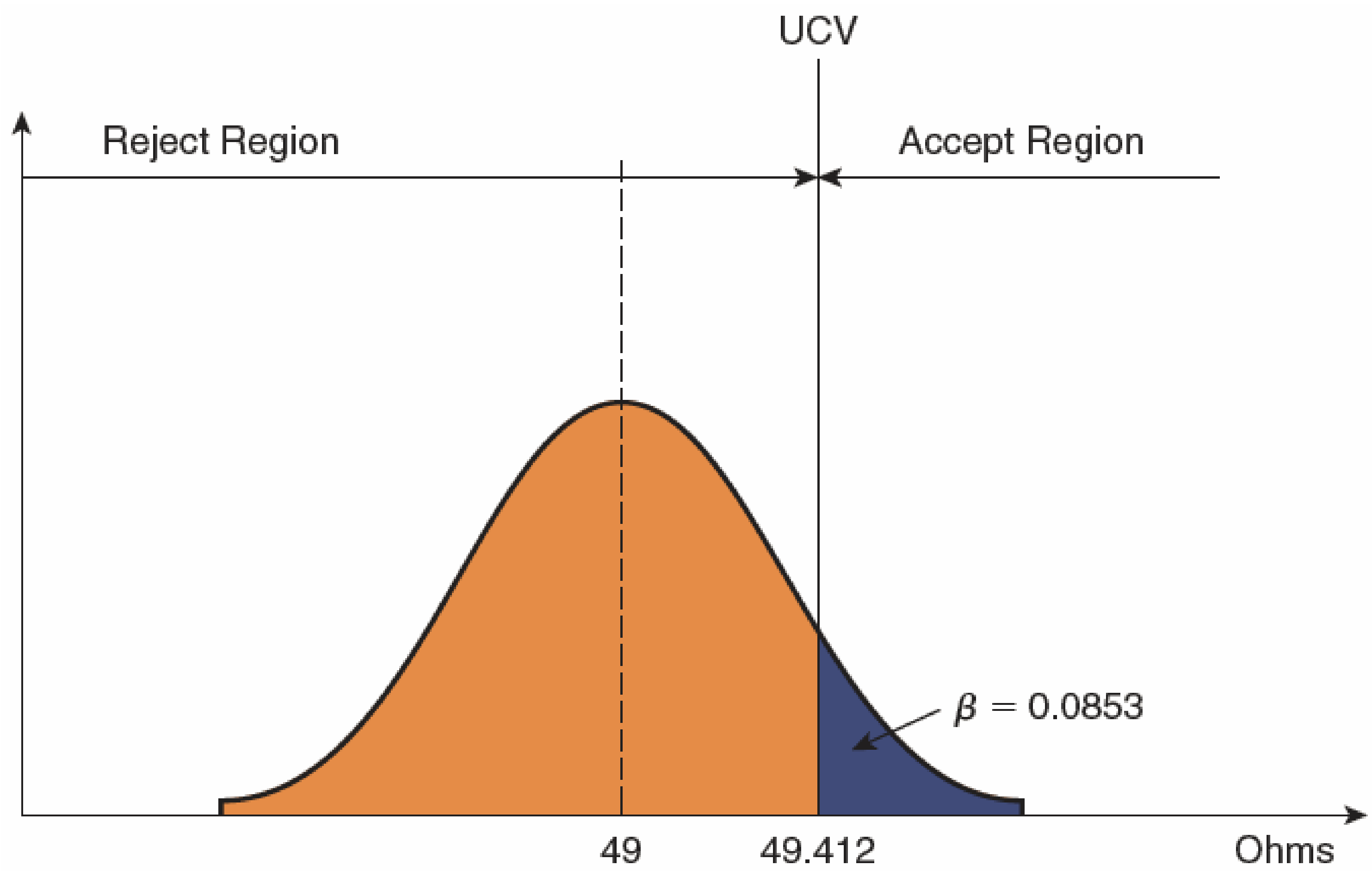


Exhibit S9.18

Statistical Process Control

- *Statistical Process Control (SPC)*
  - –A quantitative method for determining whether a particular process is in or out of control.
- *Central Limit Theorem*
  - –Sample means will be normally distributed no matter what the shape of the distribution.
- *Variation*
  - –Random variation
  - –Nonrandom (assignable) variation

Properties of a Normal Distribution

- *The distribution is bilaterally symmetrical.*
- *68.3 percent of the distribution lies between plus and minus one standard deviation from the mean.*
- *95.4 percent of the distribution lies between plus and minus two standard deviations from the mean.*
- *99.7 percent of the distribution lies between plus and minus three standard deviations from the mean.*

Areas under the Normal Distribution Curve Corresponding to Different Numbers of Standard Deviations from the Mean

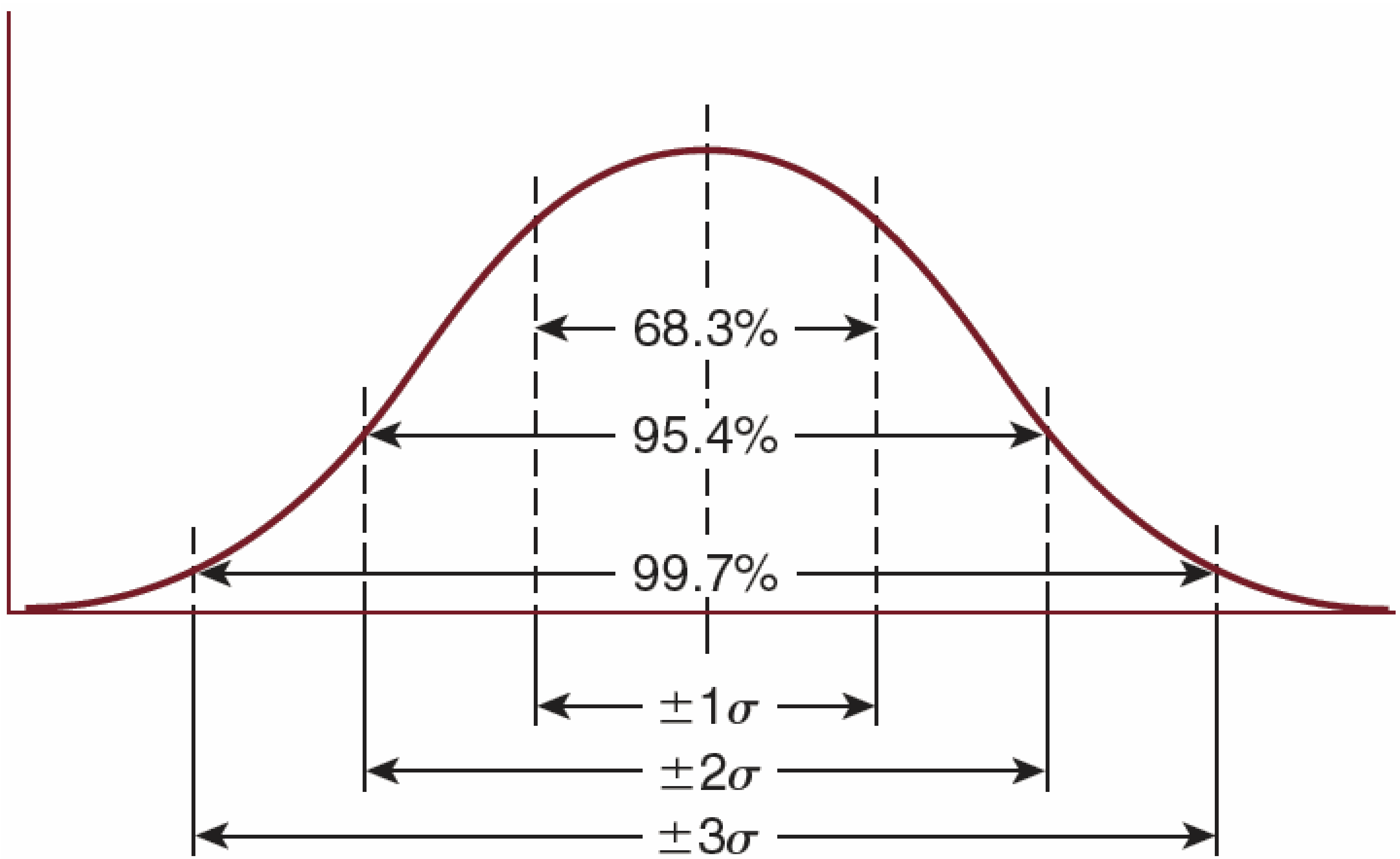


Exhibit S9.19

Statistical Process Control (cont’d)

- *Process Capability (Study)*
  - Comparing inherent variation in a process to the customer’s requirements (the specifications) to determine whether the process can produce what the customer requires
    - Collect data on the process while the process is operating without known causes of variation.
    - Compare the customer’s requirements to the inherent variation of the process.
      - If the customer’s specifications fall within the three standard deviations for the process, some predictable percentage of the time, the process will produce output that will not meet the customer’s needs.

Capability Study

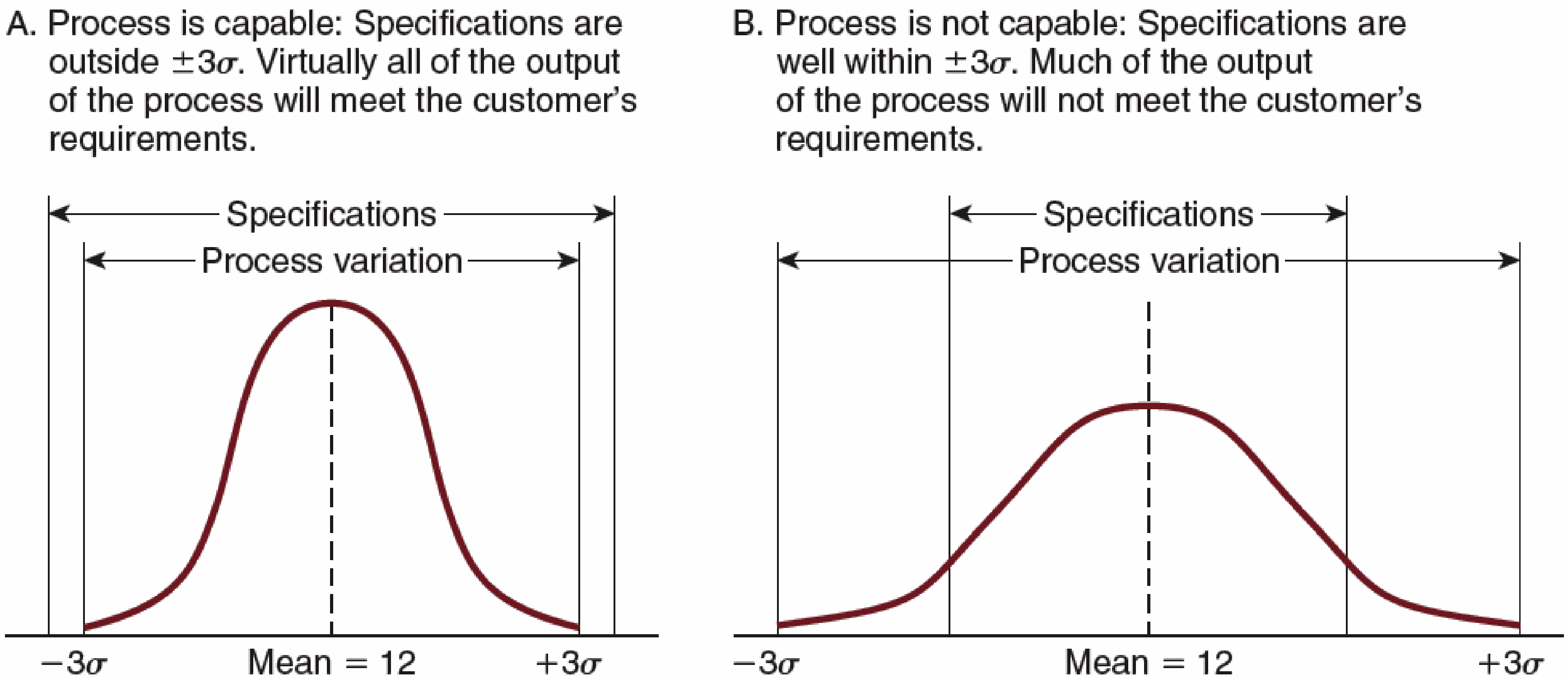


Exhibit S9.20

Statistical Process Control (cont'd)

- *Process Capability Ratio (C_p)*
  - For a process to be both in control and within specifications, the specifications (also called tolerance limits) must be equal to or outside three standard deviations of the process mean—in other words, outside ±3 sigma.
  - A ratio that is greater than 1 indicates that the tolerance limit range is wider than the actual range of measurements.

$$C_p = \frac{\text{Upper specification} - \text{lower specification}}{6\sigma}$$

Statistical Process Control (cont’d)

- *Capability Index (C_{pk})*
  - An index employed to determine whether a process mean is closer to the upper specification limit, USL, or the lower specification limit, LSL.
  - When C_{pk} equals the capability ratio, then the process mean is centered between the two specification limits. Otherwise, the process mean is closest to the specification limit corresponding to the minimum of the two C_{pk} ratios.

$$C_{pk} = \min \left[\frac{\overline{X} - \text{LSL}}{3\sigma}, \frac{\text{USL} - \overline{X}}{3\sigma} \right]$$

Statistical Process Control Chart

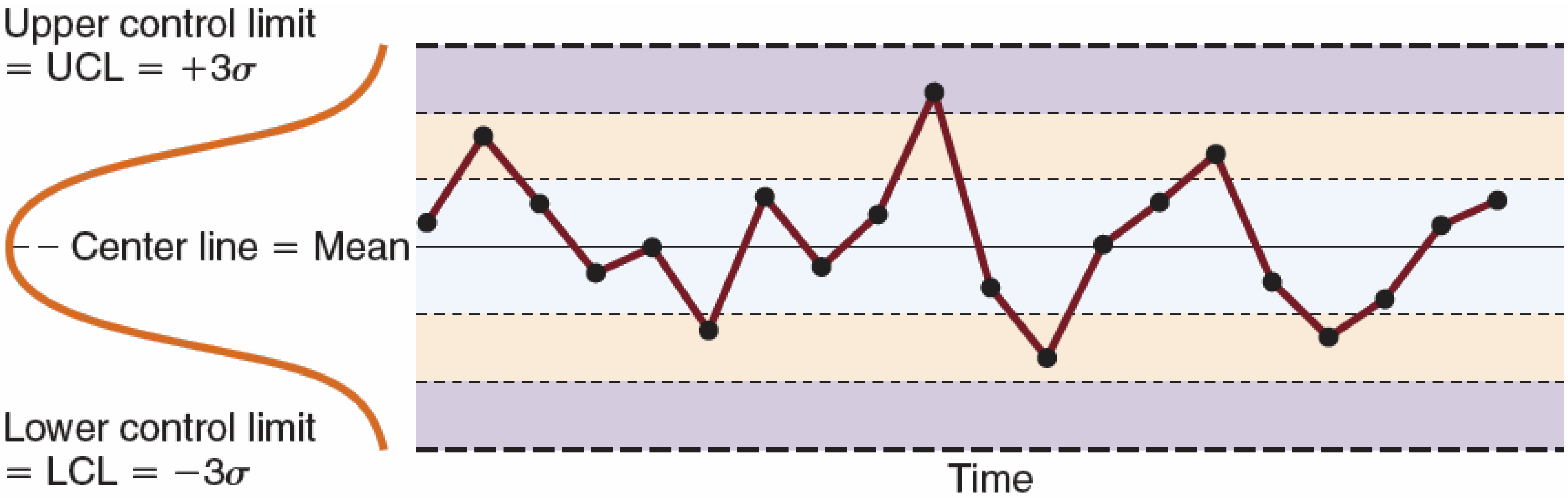
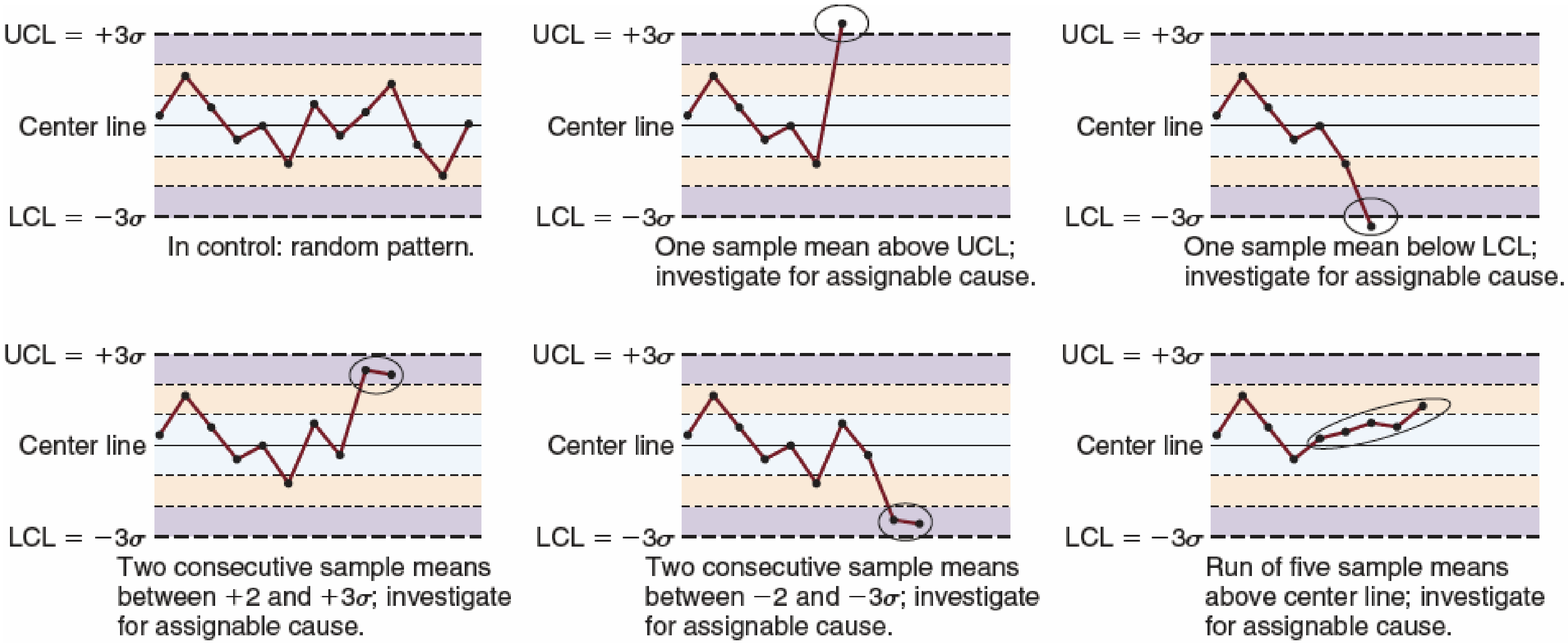


Exhibit S9.21

Control Chart Decision Rules



Source: Bertrand L. Hansen, *Quality Control: Theory and Applications* © 1963, p. 65.
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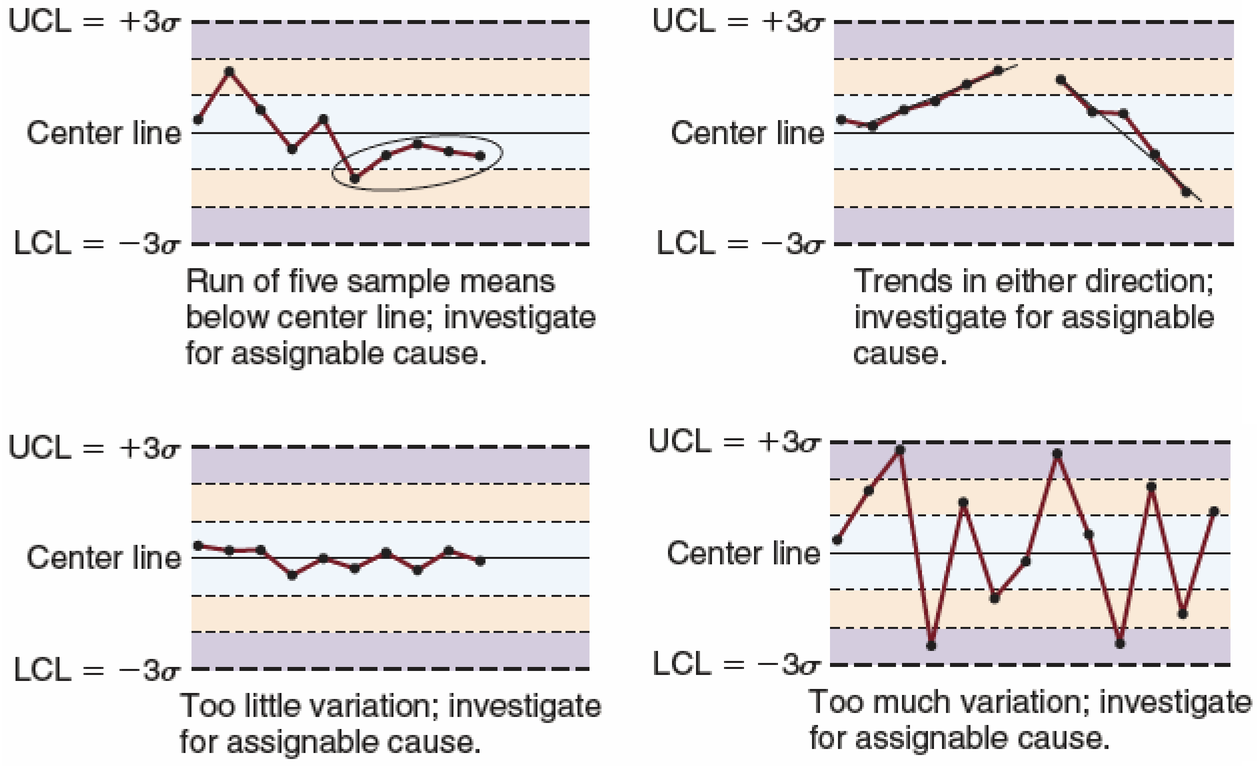
Exhibit S9.22

Control Chart Decision Rules



Source: Bertrand L. Hansen, *Quality Control: Theory and Applications* © 1963, p. 65.

Exhibit S9.22 (cont'd)

SPC Using Attribute Measurements

- *Calculating Control Limits*
  - The centerline for an attribute chart is the long-run average for the attribute in question.
    - *p*-chart: percent defective chart

Centerline = $\bar{p}$ **= Long-run average**

Standard deviation of sample = $s_p = \sqrt{\dfrac{\bar{p}(1-\bar{p})}{n}}$

Upper control limit = UCL= $\bar{p} + 3s_p$

Lower control limit = LCL= $\bar{p} - 3s_p$

Changes in Mean and Variation of Sample Mean Distributions

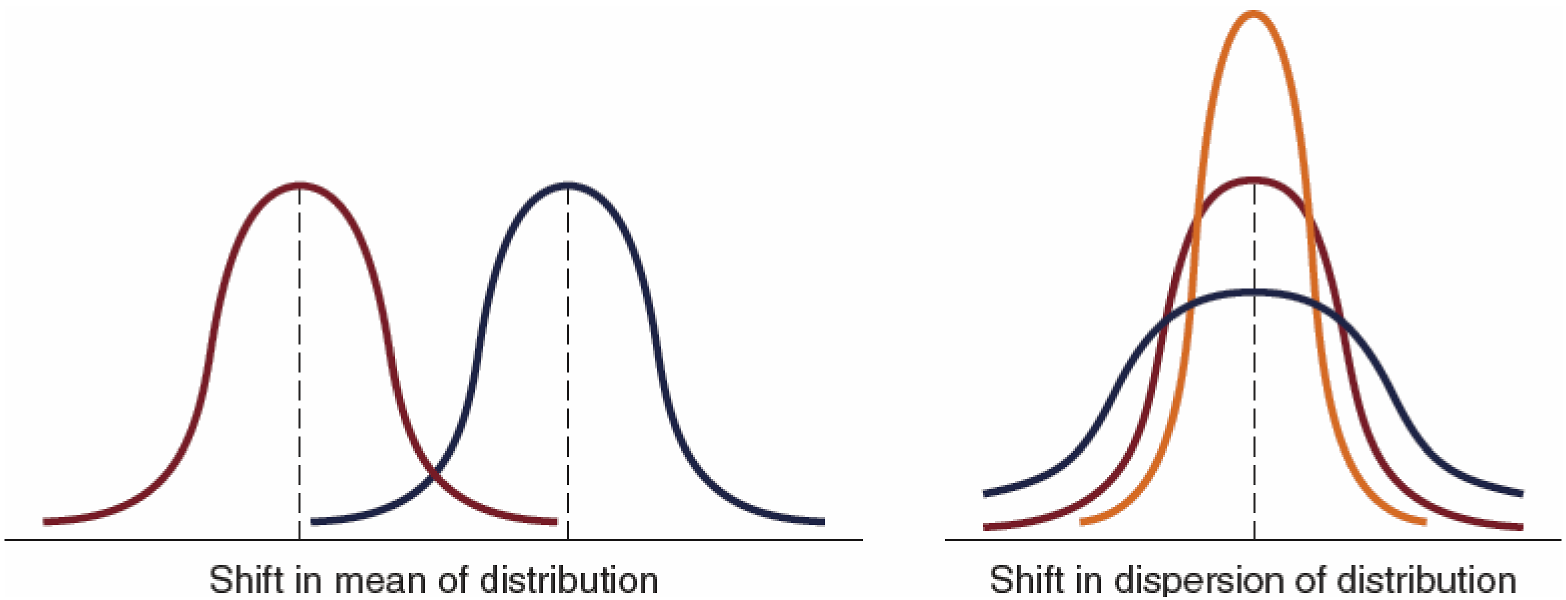


Exhibit S9.23

$\overline{X}$ and *R* Charts for Variables SPC

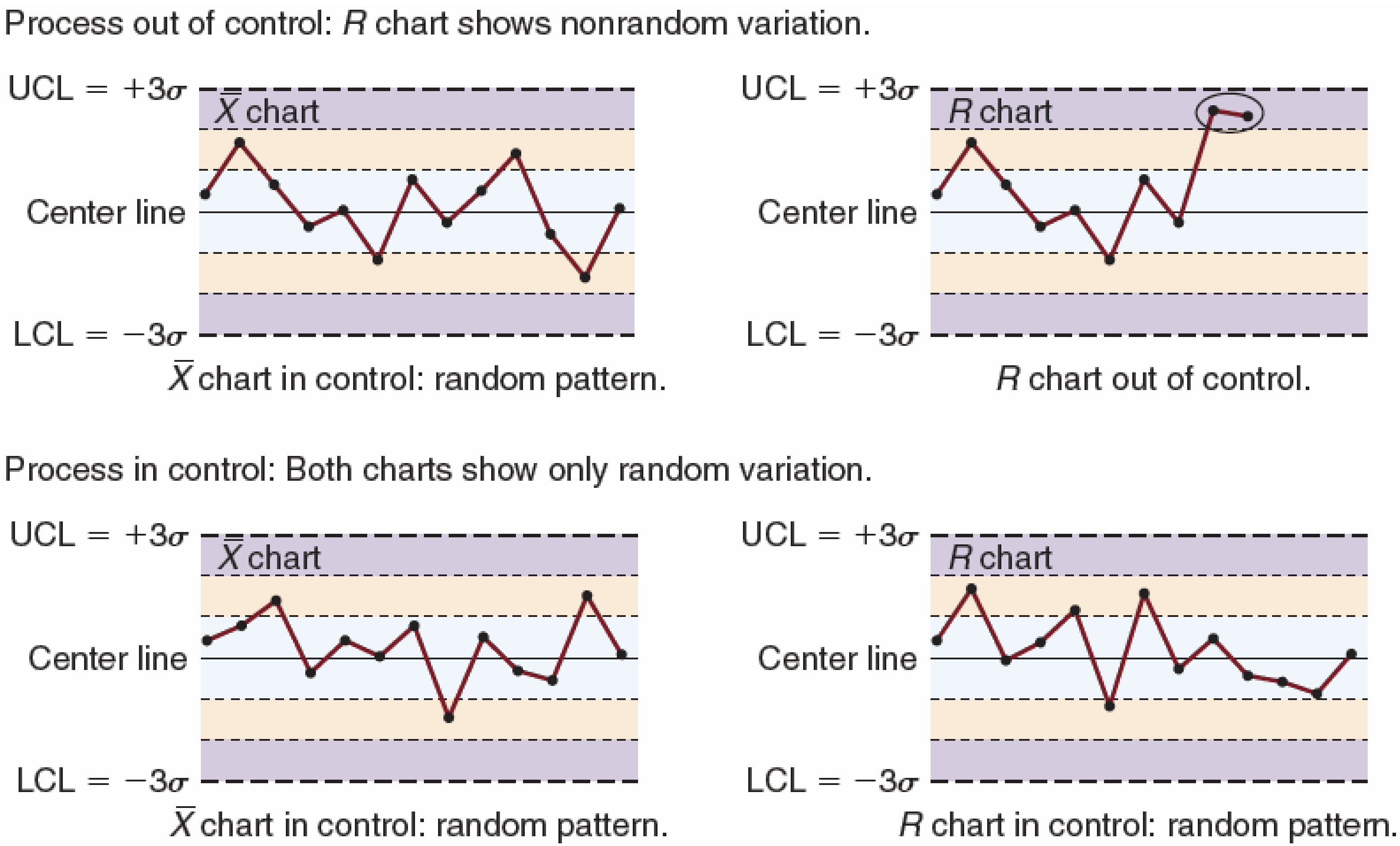


Exhibit S9.24

Variable SPC Charts Using *X-bar* and *R* Charts

- *Variable Data*
  - Data that are measured, such as length or weight.
- *Main Issues*
  - Size of Samples
  - Number of Samples
  - Frequency of Samples
  - Control limits

Constructing *X-bar* Charts

- *X-bar Chart*
  - A chart that tracks the changes in the means of the samples by plotting the means that were taken from a process.

$\bar{X}$ = Mean of the sample

i = Item number

n = Total number of items in the sample

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

$\bar{\bar{X}}$ = The average of the means of the samples

j = Sample number

m = Total number of samples

$$\bar{\bar{X}} = \frac{\sum_{j=1}^{m} \bar{X}_j}{m}$$

Constructing *R* Charts

- R *Chart*
  - A chart that tracks the change in the variability by plotting the range within each sample. The range is the difference between the lowest and highest values in that sample.

$\overline{R}$ = Average of the measurement differences *R* for all samples

R_j = Difference between the highest and lowest values in sample *j*

m = Total number of samples

$$\overline{R} = \frac{\sum_{j=1}^{m} R_j}{m}$$

Factors for Determining from $\overline{R}$ the 3-Sigma Control Limits for $\overline{X}$ and R Charts

Number of Observations in Subgroup n	Factor for $\overline{X}$ Chart A_2	Factors for R Chart: Lower Control Limit D_3	Upper Control Limit D_4
2	1.88	0	3.27
3	1.02	0	2.57
4	0.73	0	2.28
5	0.58	0	2.11
6	0.48	0	2.00
7	0.42	0.08	1.92
8	0.37	0.14	1.86
9	0.34	0.18	1.82
10	0.31	0.22	1.78
11	0.29	0.26	1.74
12	0.27	0.28	1.72
13	0.25	0.31	1.69
14	0.24	0.33	1.67
15	0.22	0.35	1.65
16	0.21	0.36	1.64
17	0.20	0.38	1.62
18	0.19	0.39	1.61
19	0.19	0.40	1.60
20	0.18	0.41	1.59

Upper control limit for $\overline{X} = UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R}$ Upper control limit for $\overline{R} = UCL_R = D_4\overline{R}$

Lower control limit for $\overline{X} = LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R}$ Lower control limit for $\overline{R} = LCL_R = D_3\overline{R}$

Note: All factors are based on the normal distribution.

Source: E. L. Grant, *Statistical Quality Control,* 6th ed. pp. 57–59 (Copyright © 1998 by The McGraw-Hill Companies, Inc. 1988). Reprinted by permission of McGraw-Hill, Inc.

Exhibit S9.25

Measurements in Samples of Five from a Process

Sample Number	Each Unit in Sample					Average $\bar{X}$	Range R
1	10.60	10.40	10.30	9.90	10.20	10.28	.70
2	9.98	10.25	10.05	10.23	10.33	10.17	.35
3	9.85	9.90	10.20	10.25	10.15	10.07	40
4	10.20	10.10	10.30	9.90	9.95	10.09	.40
5	10.30	10.20	10.24	10.50	10.30	10.31	.30
6	10.60	10.30	10.50	9.90	9.80	10.22	.80
7	9.98	9.90	10.20	10.40	10.10	10.12	.50
8	10.10	10.30	10.40	10.24	10.30	10.27	.30
9	10.30	10.20	10.60	10.50	10.10	10.34	.50
10	10.30	10.40	10.50	10.10	10.20	10.30	.40
11	9.90	9.50	10.20	10.30	10.35	10.05	.85
12	10.10	10.36	10.50	9.80	9.95	10.14	.70
13	10.20	10.50	10.70	10.10	9.90	10.28	.80
14	10.20	10.60	10.50	10.30	10.40	10.40	.40
15	10.54	10.30	10.40	10.55	10.00	10.36	.55
16	10.20	10.60	10.15	10.00	10.50	10.29	.60
17	10.20	10.40	10.60	10.80	10.10	10.42	.70
18	9.90	9.50	9.90	10.50	10.00	9.96	1.00
19	10.10	10.30	10.20	10.30	9.90	10.16	.40
20	10.60	10.40	10.30	10.40	10.20	10.38	.40
21	9.90	9.60	10.50	10.10	10.60	10.14	1.00
22	9.95	10.20	10.50	10.30	10.20	10.23	.55
23	10.20	9.50	9.60	9.80	10.30	9.88	.80
24	10.30	10.60	10.30	9.90	9.80	10.18	.80
25	9.90	10.30	10.60	9.90	10.10	10.16	.70
				$\bar{\bar{X}} =$		10.21	
				$\bar{R} =$			.60

Exhibit S9.26

$\overline{X}$ and *R* Charts

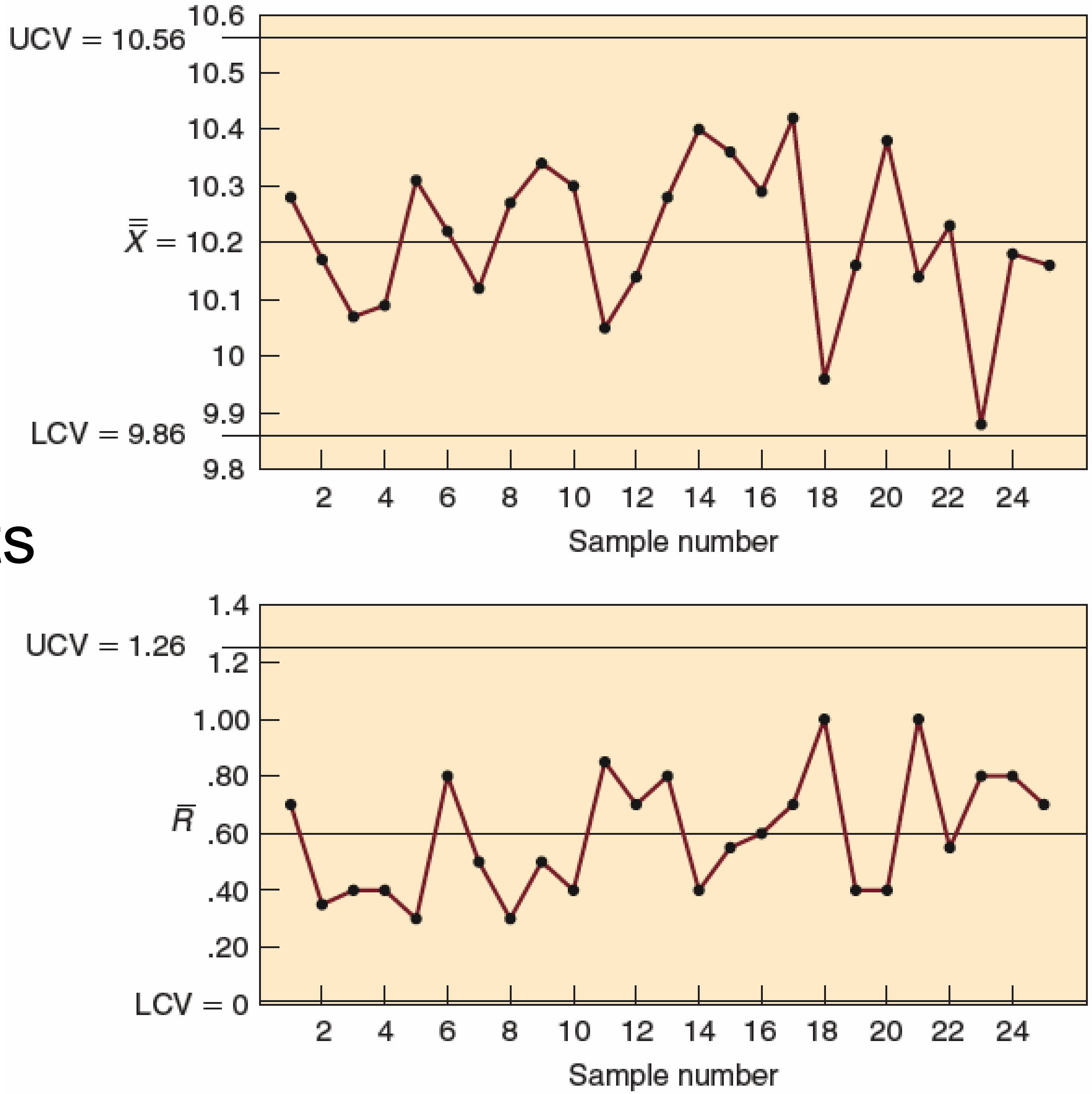


Exhibit S9.27

A Framework for Applying the Different Quality Control Tools

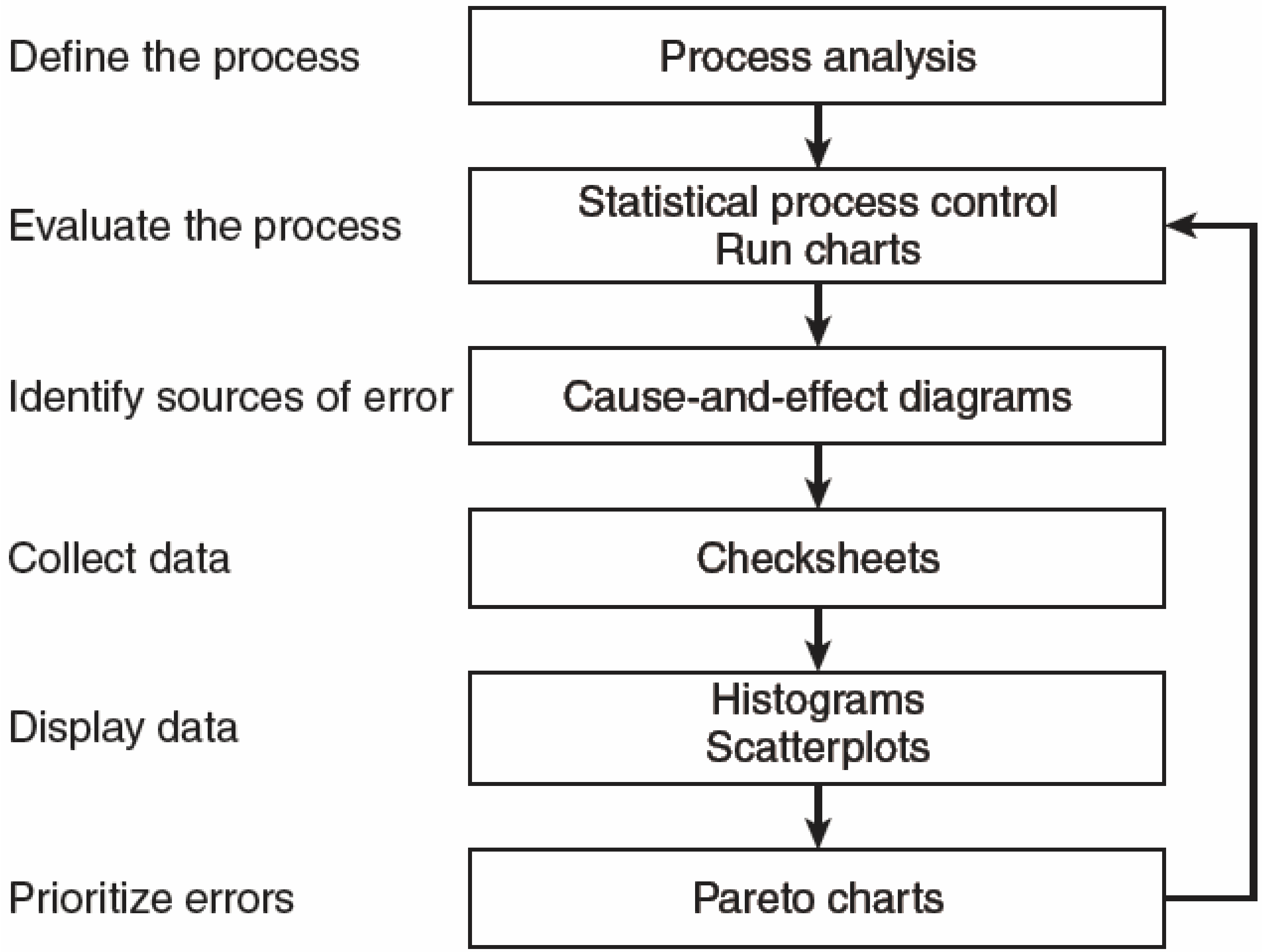


Exhibit S9.28

The Goal of Six Sigma

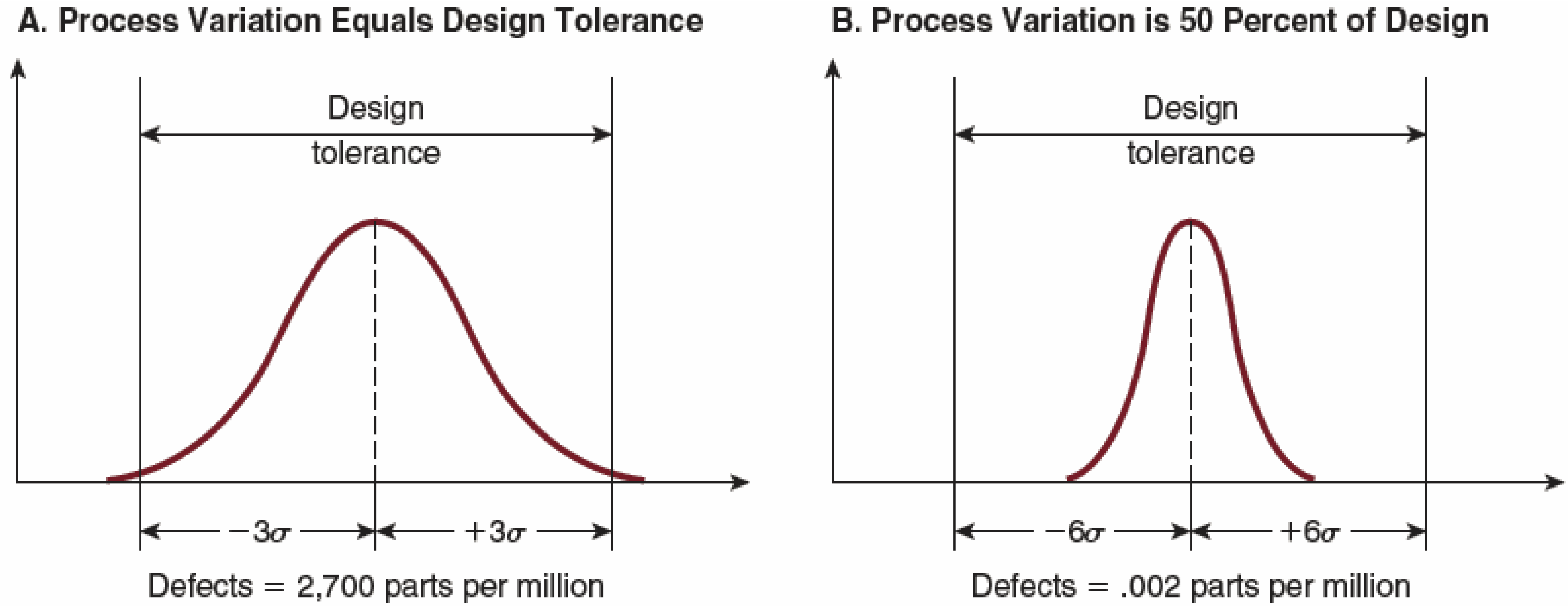


Exhibit S9.29

Impact of 1.5σ Shift on 3σ Process

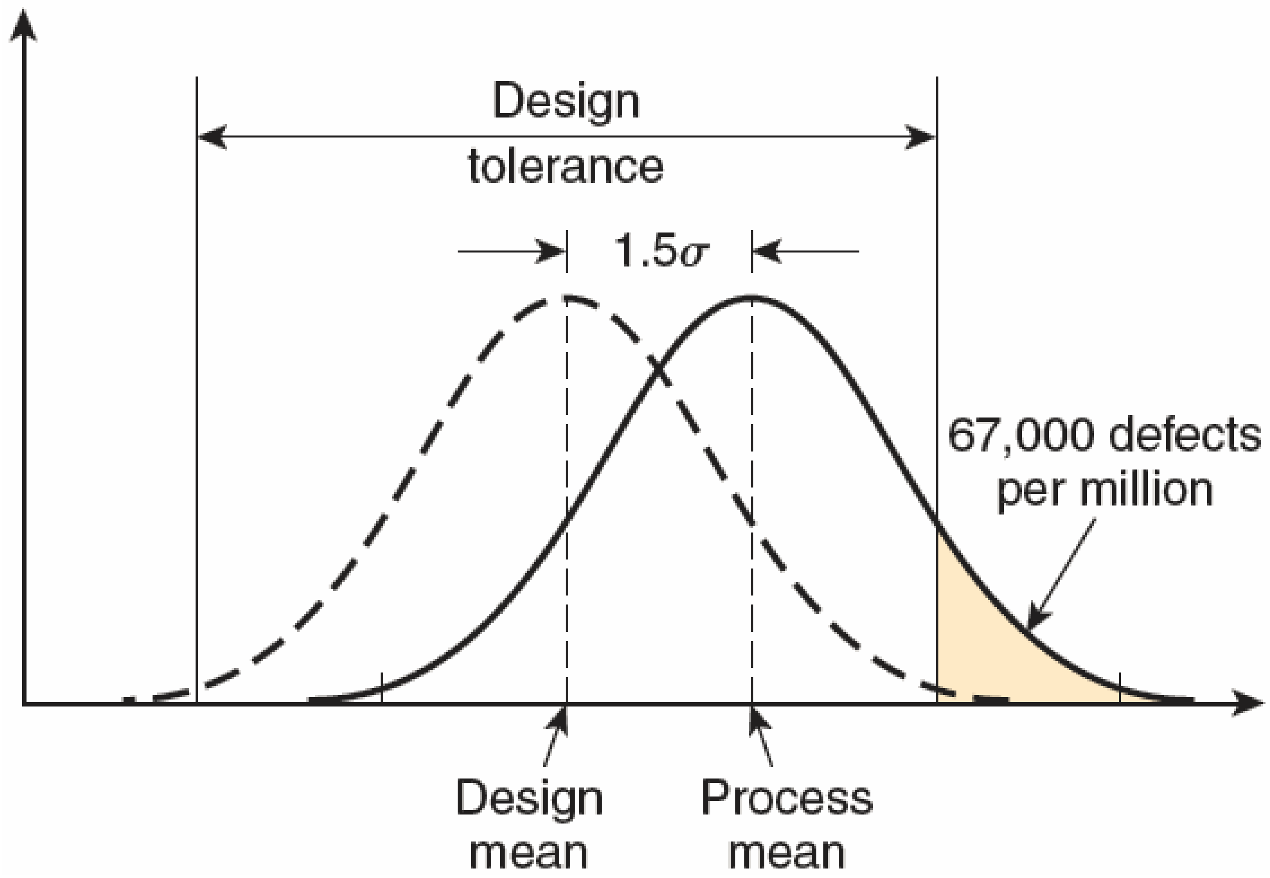


Exhibit S9.30A

Impact of 1.5σ Shift on 6σ Process

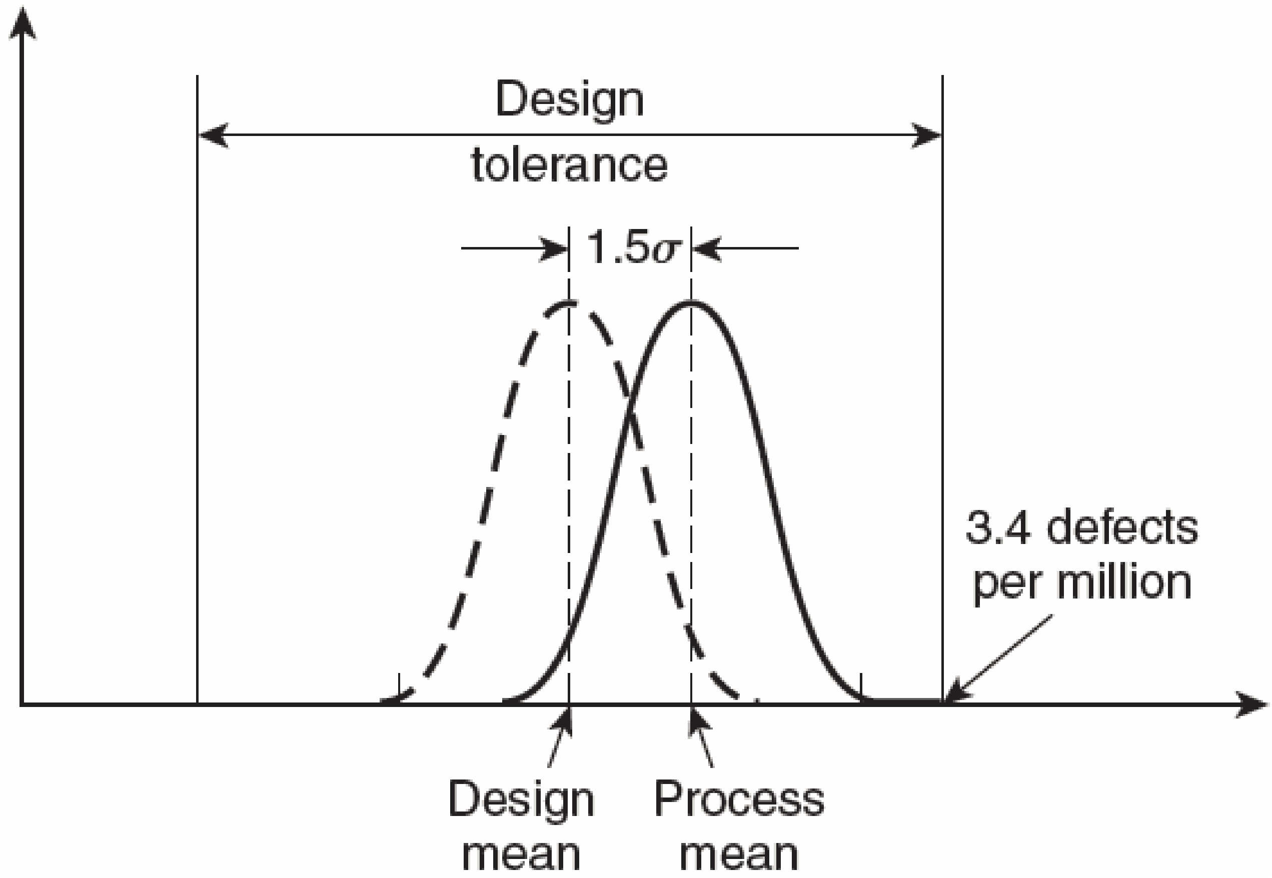


Exhibit S9.30B

Defect Rates for Different Levels of Sigma (σ) Assuming a 1.5 Shift in Actual Mean from Design Mean

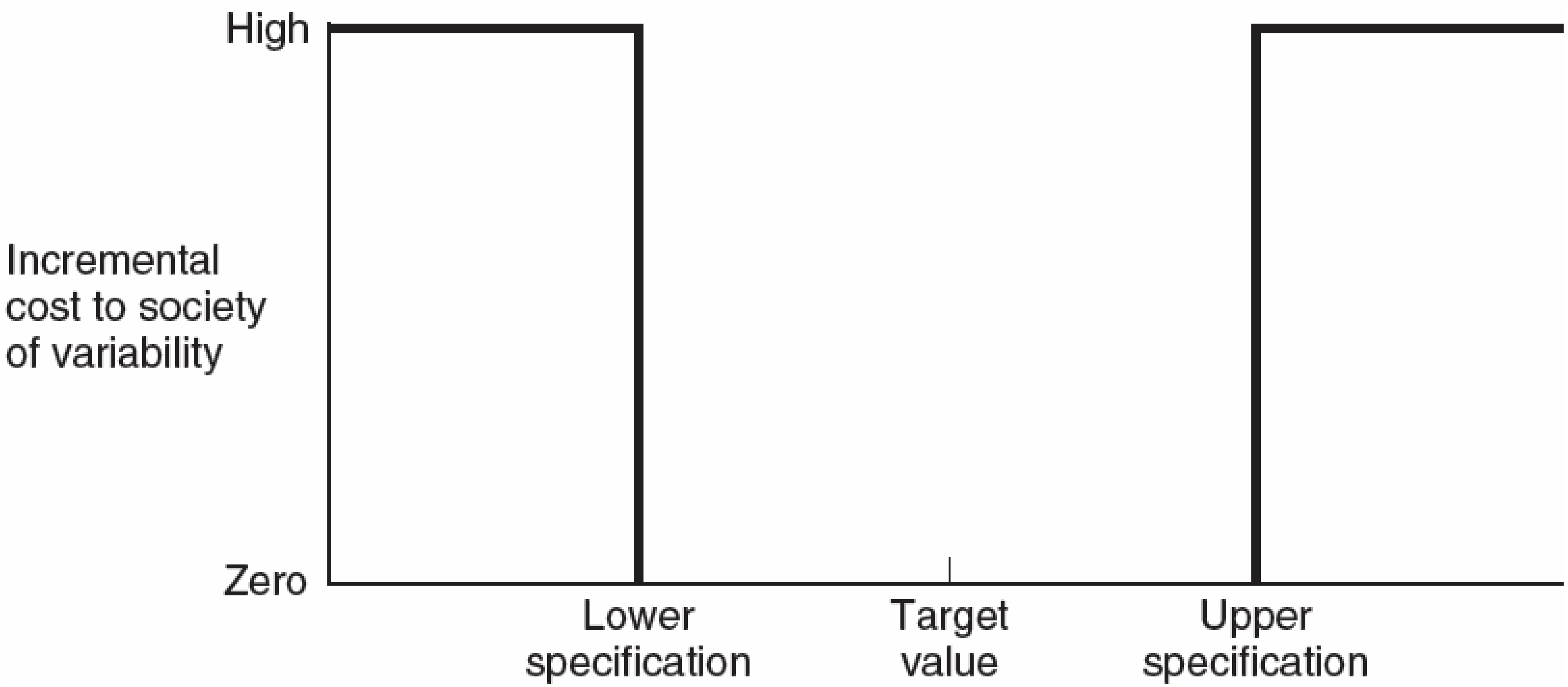
Sigma Level of Quality	Defects per Million
1.5σ	500,000
2.0σ	308,300
2.5σ	158,650
3.0σ	67,000
3.5σ	22,700
4.0σ	6,220
4.5σ	1,350
5.0σ	233
5.5σ	32
6.0σ	3.4

Exhibit S9.31

Taguchi Methods

- *Taguchi Methods*
  - Used for identifying the cause(s) of process variation that reduces the number of tests that are necessary.
  - Use to conduct experiments to determine the best combinations of product and process variables to make a product at the lowest cost with the highest uniformity.
  - Quality loss function
    - Relates the cost of quality directly to variation in a process.
    - Any deviation from target quality is a loss to society.

A Traditional View of the Cost of Variability



Source: Adapted from Joseph Turner, "Is an Out-of-Spec Product Really Out of Spec?" *Quality Progress*, December 1990, pp. 57–59. Reprinted with permission from *Quality Progress* Magazine. © 1990 American Society for Quality.

Exhibit S9.32

Taguchi’s View of the Cost of Variability

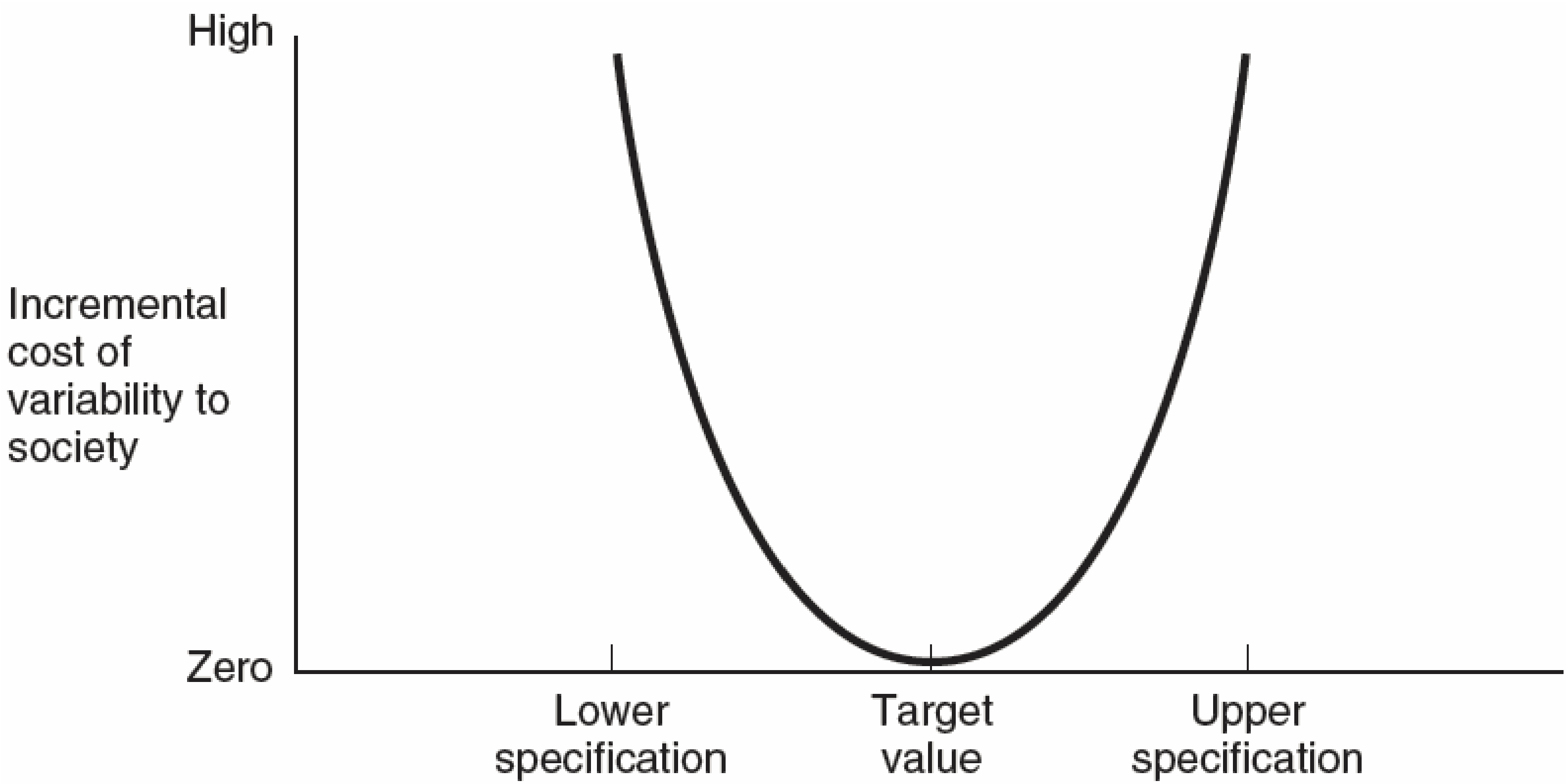


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Exhibit S9.33