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**Instructor's Manual**  
*to accompany*

# **Quality Improvement**

## **Ninth Edition**

**Dale H. Besterfield, Ph.D., P.E.**



Upper Saddle River, New Jersey  
Columbus, Ohio



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## PREFACE

The textbook was formerly titled *Quality Control—Eighth Edition*. It is re-titled as *Quality Improvement—Ninth Edition* to reflect the concept of improvement rather than control.

This manual has been published to simplify the instructor's tasks of developing learning activities and evaluating performance. It is based on the experience of the author and is meant to serve as a guide. Each instructor will need to modify this information for the particular course objectives and the ability level of the students.

For those teachers who are familiar with the *Eighth Edition* of the textbook, information on the major changes to the *Ninth Edition* is provided. This information should simplify the transition to the latest edition.

A typical course outline for a three-semester hour course is shown on Page 2. The learning activities are based on 45 class meetings of 50 minutes each. Since it is difficult for the average student to cover all of the material in a typical three-semester hour course, this outline concentrates on the basic statistical aspects of quality improvement. The instructor may wish to substitute Management and Planning Tools for Reliability. If a course in statistics is a prerequisite, the instructor may include Experimental Design and Taguchi's Quality Engineering.

Solutions for the problems start on Page 3. The author has found it advantageous to post the solutions. This action allows students to determine if their methods and answer are correct.

Typical multiple-choice test questions are given and an asterisk indicates the correct answer. These questions can be modified in a number of ways depending on the creativity of the instructor. Answers to test problems are also given. Since the tables in the body of the text and in the Appendix are needed to solve the problems, an open-book type examination should be considered. The instructor may also consider providing copies of the tables and using a closed-book format. Regardless, the multiple-choice questions can be given in the closed-book format. The author has found that allowing the students 3x5 cards for formulas and other information is a great learning experience.

## Major Changes to the Ninth Edition

### Chapter 1

1. Deleted Historical Review and Metric System.
2. Deleted the section on RESPONSIBILITY FOR QUALITY.
3. Added a section on QUALITY IMPROVEMENT TOOLS, with a brief description of those non-quantitative ones that are not covered in the text.
4. Deleted COMPUTERS AND QUALITY CONTROL.
5. Added COMPUTER PROGRAM.
6. Modified Exercise 2 and eliminated Exercises 3 and 4.

### Chapter 2

1. All previous information deleted
2. Much of the problem solving information moved to Chapter 3.
3. Chapter re-titled Lean Enterprise with all new information.

### Chapter 3

1. All previous information deleted.
2. Pareto Diagram, Cause and Effect Diagram, Check Sheet, and Process Flow Diagram moved to Chapter 4.
3. Chapter re-titled Six Sigma.
4. Statistical Aspects moved from old Chapter 5.

### Chapter 4

1. All information in old Chapter 4 becomes Chapter 5
2. Chapter is titled Statistical Process Control (SPC) and consists of Pareto Diagram, Cause and Effect Diagram, Check Sheet, and Process Flow Diagram.
3. Other elements of SPC are covered in subsequent chapters.

### Chapters 5, 6, 7, 8, 9, and 10

1. The basic change is to the number. Chapter 4 becomes 5, 5 becomes 6, 6 becomes 7, 7 becomes 8, 8 becomes 9, 9 becomes 10.
2. Gage control in Chapter 7 has been modified.

### Chapter 11

1. Old Chapter 10, Acceptance Sampling Systems is deleted and the number sequence is correct with no change to Chapter 11, Reliability.

### .Chapter 12

1. No change.

### Chapter 13

1. New chapter titled Experimental design.

### Chapter 14

1. New chapter titled Taguchi's Quality Engineering.

## TYPICAL COURSE OUTLINE

<u>Meeting</u>	<u>Topic</u>	<u>Chapter</u>
1	Introduction	1
2 and 3	Lean Enterprise	2
4 and 5	Six Sigma	3
6	SPC	4
7 thru 10	Fundamentals of Statistics	5
11 thru 16	Control Charts for Variables	6
17	Examination I	
18 and 19	Additional SPC Techniques for Variables	7
20 thru 24	Fundamentals of Probability	8
25 thru 29	Control Charts for Attributes	9
30	Examination II	
31 thru 39	Lot-by-Lot, Acceptance Sampling by Attributes	10
40 thru 44 45	Reliability or Management and Planning Tools Examination III	11 or 12

## Solution to Statistical Exercises

### Chapter 3 SIX SIGMA

1. Ans. =  $1.0 - (0.9999966^8) = 1.0 - 0.999972 = 0.000028 = 28\text{ppm}$

### Chapter 4 STATISTICAL PROCESS CONTROL

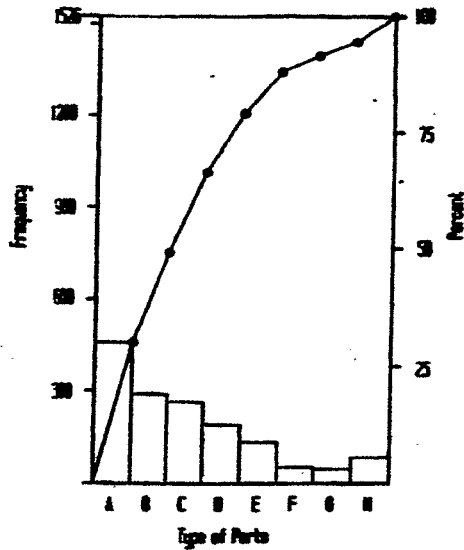
#### 1. Replacement Parts: (6-month period)

	<u>Frequency</u>	<u>Percent</u>	<u>Cumulative Frequency</u>	<u>Cumulative Percent</u>
A. front burners	460	.30	460	.30
B. rear burners	290	.19	750	.49
C. oven regulators	265	.17	1015	.66
D. oven door	193	.13	1208	.79
E. burner control	135	.09	1343	.88
F. timer	53	.03	1396	.91
G. drawer rollers	46	.03	1442	.94
H. All others	84	.06	1526	1.00
	1526	1.00		

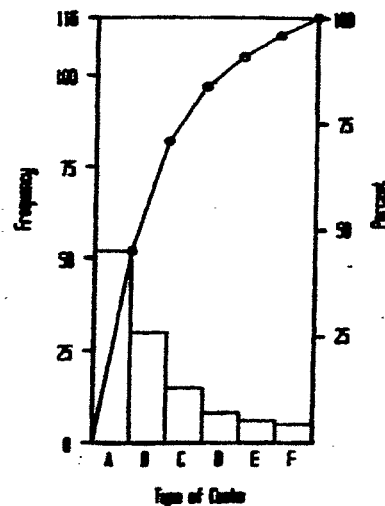
#### 2. Downtime Costs: (3-month period) in thousands of dollars

	<u>Frequency</u>	<u>Percent</u>	<u>Cumulative Frequency</u>	<u>Cumulative Percent</u>
A. lost cooling	52	.45	52	.45
B. back pressure reg.	30	.26	82	.71
C. adjust feed worm	15	.13	97	.84
D. valve replacement	8	.07	105	.91
E. jam copperhead	6	.05	111	.96
F. All others	5	.04	116	1.00
	116	1.00		

(1)



(2)



### 3 Cause of accident

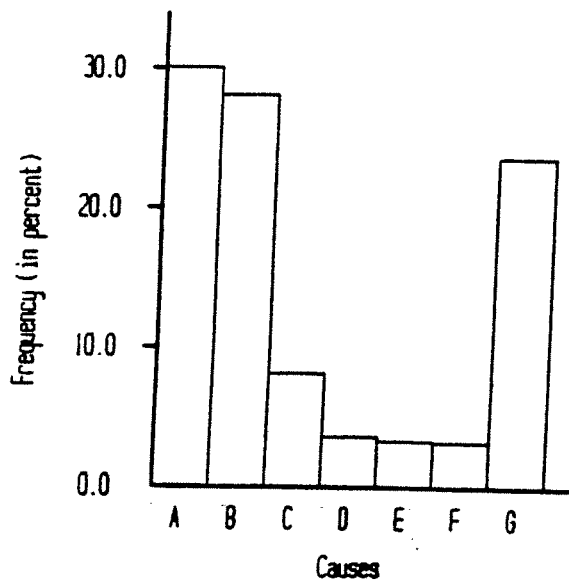
in percent

a. right-of-way violation	30.1
b. driving too fast for condition	28.1
c. following too closely	8.1
d. improper turn	3.6
e. driving left of center	3.3
f. improper overtaking	3.2
g. all other	<u>23.6</u>
	100.0

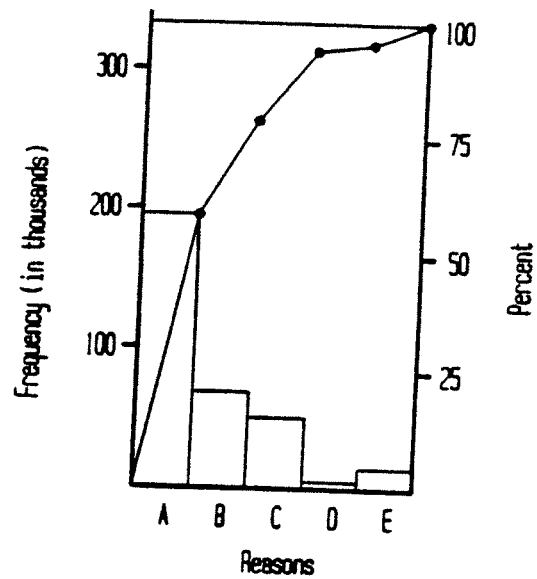
### 4. Reason for Shipment Return: (quarter) in thousands

	<u>Frequency</u>	<u>Percent</u>	<u>Cumulative Frequency</u>	<u>Cumulative Percent</u>
A. refused	195	.585	195	.59
B. wrong address	68	.20	263	.79
C. wrong selection	50	.15	313	.94
D. order canceled	5	.02	318	.96
E. All other	<u>15</u>	<u>.045</u>	333	1.00
	333	1.00		

(3)



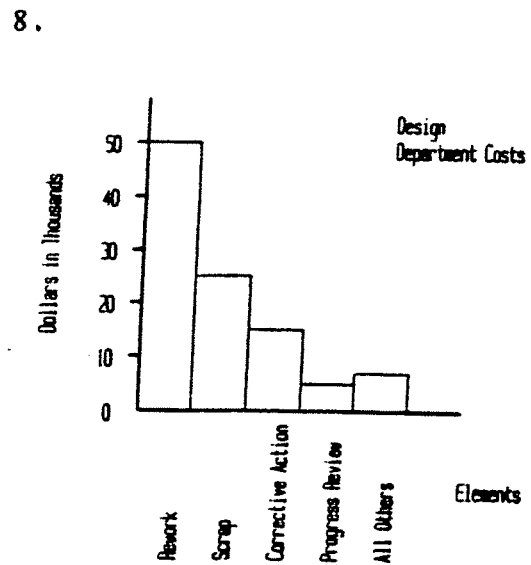
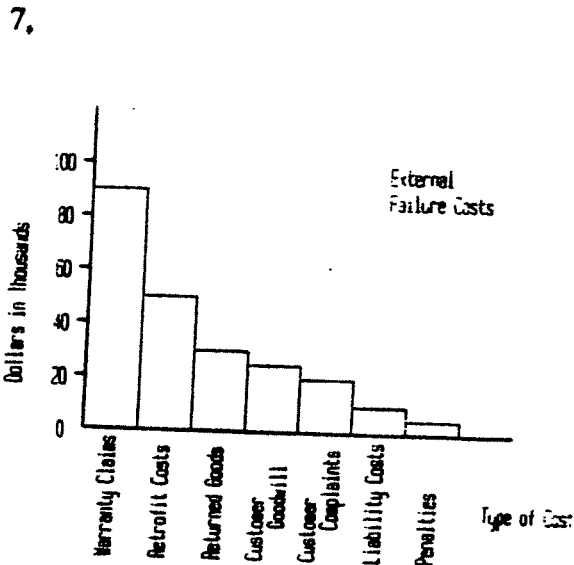
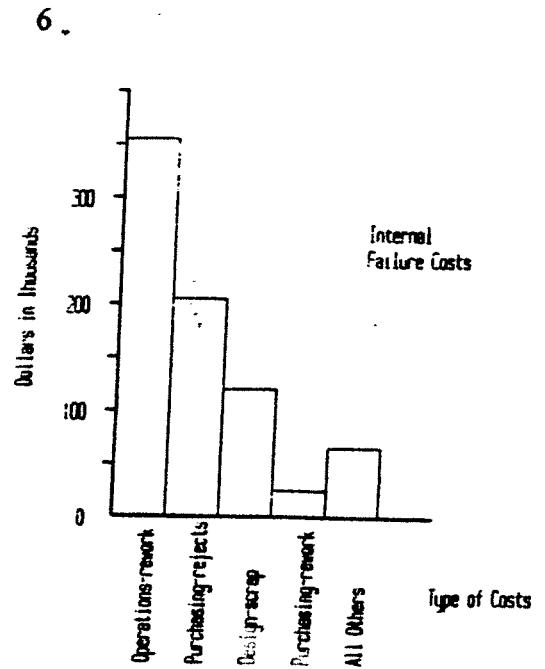
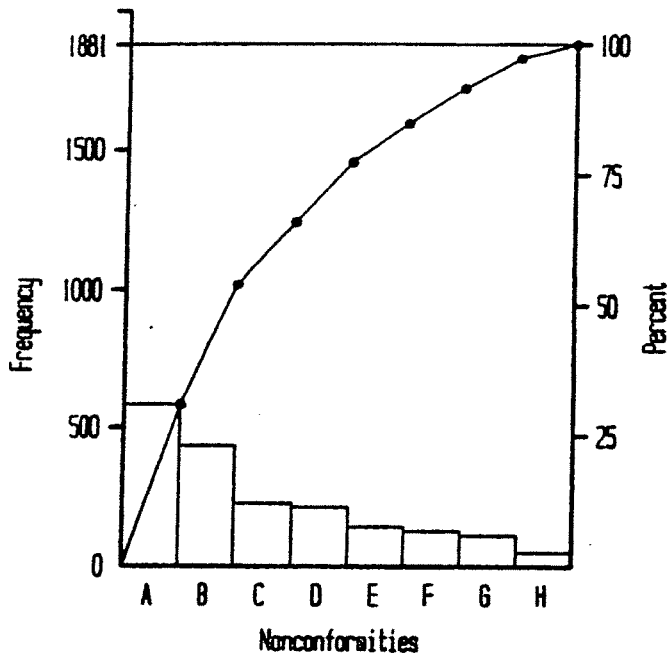
(4)





# 5. Paint Nonconformities: (1-month)

	Frequency	Percent	Cumulative Frequency	Cumulative Percent
A. light spray	582	.31	582	.31
B. runs	434	.23	1016	.54
C. drips	227	.12	1243	.66
D. blisters	212	.11	1455	.77
E. splatter	141	.07	1596	.84
F. bad paint	126	.07	1722	.91
G. overspray	109	.06	1831	.97
H. All others	50	.03	1881	1.00
	1881	1.00		



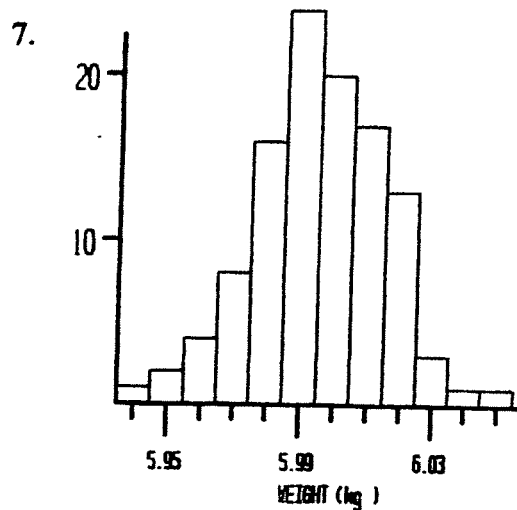
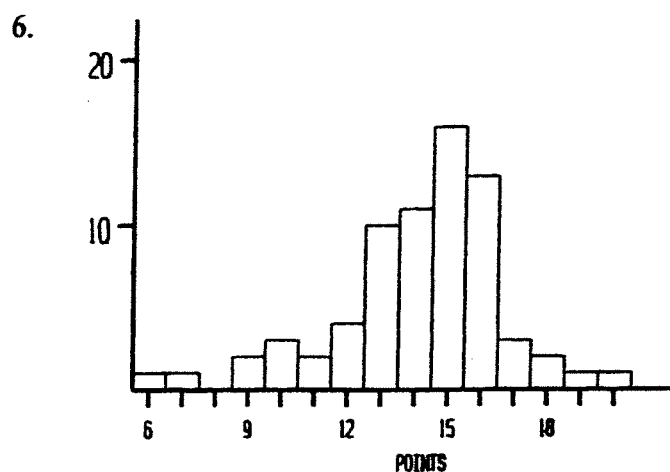
## Chapter 5 FUNDAMENTALS OF STATISTICS

1. 0.86, 0.63, 0.15, 0.48

2, 3, Number	Boundaries	Precision	g.p.e.	r.e.
(a) 8.24	$8.235 < 8.24 < 8.45$	0.01	0.005	0.0006
(b) 522	$521.5 < 522 < 522.5$	1	0.5	0.001
(c) $6.3 \times 10$	$625 < 630 < 635$	10	5	0.002
(d) 0.02	$0.015 < 0.02 < 0.025$	0.01	0.005	0.3

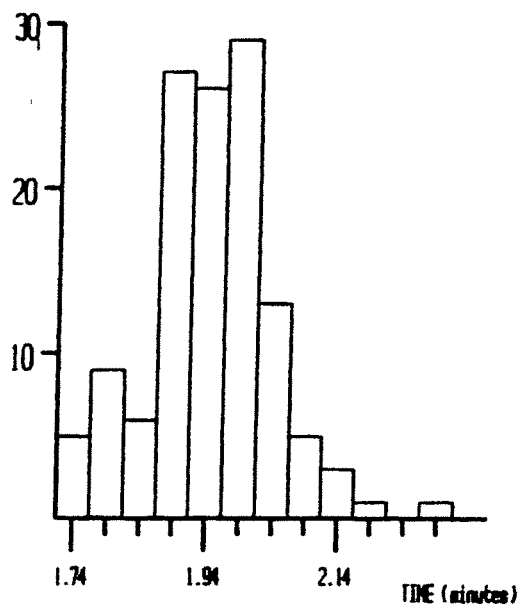
4.  $2.84 \times 10^2$ , 22, 0.64, 0.8937, 0.9

5. 66.4, 379.1, 5, 4.652,  $6.2 \times 10^2$

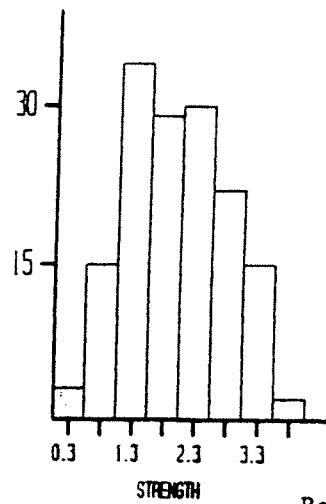


8.

<u>Cell Boundaries</u>	<u>Cell Midpoint</u>	<u>Frequency</u>
1.72-1.76	1.74	5
1.77-1.81	1.79	9
1.82-1.86	1.84	6
1.87-1.91	1.89	27
1.92-1.96	1.94	26
1.97-2.01	1.99	29
2.02-2.06	2.04	13
2.07-2.11	2.09	5
2.12-2.16	2.14	3
2.17-2.21	2.19	1
2.22-2.26	2.24	0
2.27-2.31	2.29	1



9.	Cell Boundaries	Cell Midpoints	Frequency
	0.05-0.54	0.3	3
	0.55-1.04	0.8	15
	1.05-1.54	1.3	34
	1.55-2.04	1.8	29
	2.05-2.54	2.3	30
	2.55-3.04	2.8	22
	3.05-3.54	3.3	15
	3.55-4.04	3.8	2



10.

Scores	Freq.	Relative Freq.	Cumulative Freq.	Relative Cumulative Freq.
6	1	1/70 = 0.014	0+1 = 1	1/70 = 0.014
7	1	1/70 = 0.014	1+1 = 2	2/70 = 0.029
8	0	0/70 = 0	2+0 = 2	2/70 = 0.029
9	2	2/70 = 0.029	2+2 = 4	4/70 = 0.057
10	3	3/70 = 0.043	4+3 = 7	7/70 = 0.100
11	2	2/70 = 0.029	7+2 = 9	9/70 = 0.129
12	4	4/70 = 0.057	9+4 = 13	13/70 = 0.186
13	10	10/70 = 0.143	13+10 = 23	23/70 = 0.329
14	11	11/70 = 0.157	23+11 = 34	34/70 = 0.486
15	16	16/70 = 0.229	34+16 = 50	50/70 = 0.714
16	13	13/70 = 0.186	50+13 = 63	63/70 = 0.900
17	3	3/70 = 0.043	63+3 = 66	66/70 = 0.943
18	2	2/70 = 0.029	66+2 = 68	68/70 = 0.971
19	1	1/70 = 0.014	68+1 = 69	69/70 = 0.986
20	1	1/70 = 0.014	69+1 = 70	70/70 = 1.000
	<u>70</u>	<u>1.00</u>		

Graph not shown, but similar to Problem 13

11.

Weights	Freq.	Relative Freq.	Cumulative Freq.	Relative Cumulative Freq.
5.94	1	1/110 = 0.9%	0+1 = 1	1/110 = 0.9%
5.95	2	2/110 = 1.8	1+2 = 3	3/110 = 2.7
5.96	4	4/110 = 3.6	3+4 = 7	7/110 = 6.4
5.97	8	8/110 = 7.3	7+8 = 15	15/110 = 13.6
5.98	16	16/110 = 14.5	15+16 = 31	31/110 = 28.2
5.99	24	24/110 = 21.8	31+24 = 55	55/110 = 50.0
6.00	20	20/110 = 18.2	55+20 = 75	75/110 = 68.2
6.01	17	17/110 = 15.5	75+17 = 92	92/110 = 83.6
6.02	13	13/110 = 11.8	92+13 = 105	105/110 = 95.4
6.03	3	3/110 = 2.7	105+3 = 108	108/110 = 98.2
6.04	1	1/110 = 0.9	108+1 = 109	109/110 = 99.1
6.05	1	1/110 = 0.9	109+1 = 110	110/110 = 100.0%
	<u>110</u>	<u>99.9%</u>		

Graph not shown, but similar to Problem 13

12.

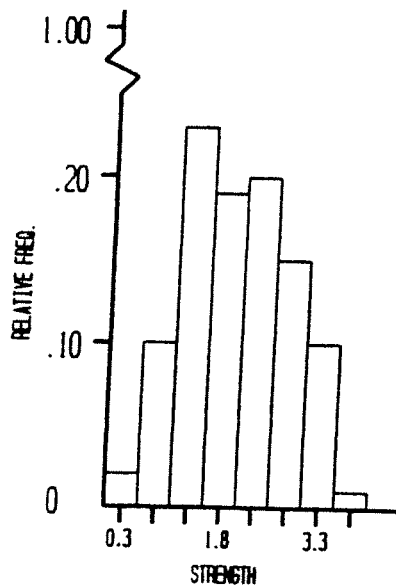
Cell Midpoint	Freq.	Relative Freq.	Cumulative Freq.	Relative Cumulative Freq.
1.74	5	$5/125 = 0.040$	$0+5 = 5$	$5/125 = 0.040$
1.79	9	$9/125 = 0.072$	$5+9 = 14$	$14/125 = 0.112$
1.84	6	$6/125 = 0.048$	$14+6 = 20$	$20/125 = 0.160$
1.89	27	$27/125 = 0.216$	$20+27 = 47$	$47/125 = 0.376$
1.94	26	$26/125 = 0.208$	$47+26 = 73$	$73/125 = 0.584$
1.99	29	$29/125 = 0.232$	$73+29 = 102$	$102/125 = 0.816$
2.04	13	$13/125 = 0.104$	$102+13 = 115$	$115/125 = 0.920$
2.09	5	$5/125 = 0.040$	$115+5 = 120$	$120/125 = 0.960$
2.14	3	$3/125 = 0.024$	$120+3 = 123$	$123/125 = 0.984$
2.19	1	$1/125 = 0.008$	$123+1 = 124$	$124/125 = 0.992$
2.24	0	$0/125 = 0$	$124+0 = 124$	$124/125 = 0.992$
2.29	1	$1/125 = 0.008$	$124+1 = 125$	$125/125 = 1.000$
	<u>125</u>	<u>1.000</u>		

Graph not shown, but similar to Problem 13

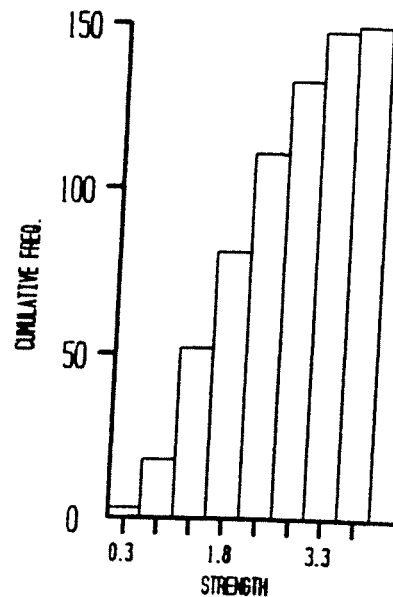
13.

Cell Midpoint	Freq.	Relative Freq.	Cumulative Freq.	Relative Cumulative Freq.
0.3	3	$3/150 = 0.020$	$0+3 = 3$	$3/150 = 0.020$
0.8	15	$15/150 = 0.100$	$3+15 = 18$	$18/150 = 0.120$
1.3	34	$34/150 = 0.227$	$18+34 = 52$	$52/150 = 0.347$
1.8	29	$29/150 = 0.193$	$52+29 = 81$	$81/150 = 0.540$
2.3	30	$30/150 = 0.200$	$81+30 = 111$	$111/150 = 0.740$
2.8	22	$22/150 = 0.147$	$111+22 = 133$	$133/150 = 0.888$
3.3	15	$15/150 = 0.100$	$133+15 = 148$	$148/150 = 0.987$
3.8	2	$2/150 = 0.013$	$148+2 = 150$	$150/150 = 1.000$
	<u>150</u>	<u>1.000</u>		

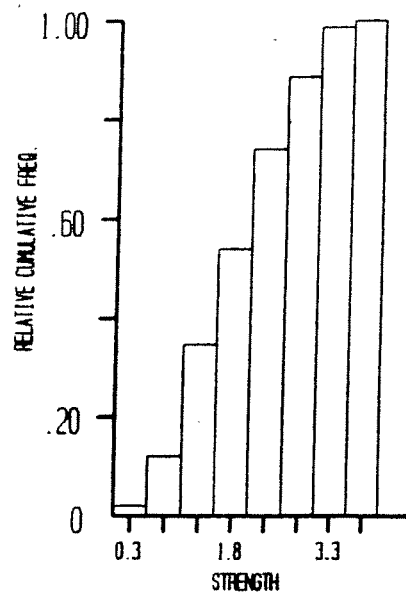
13a



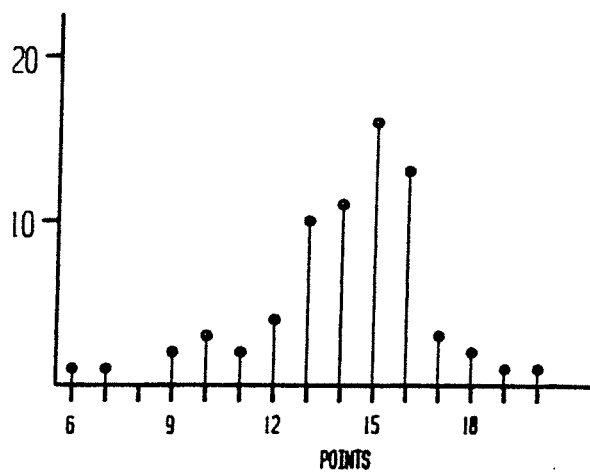
13b



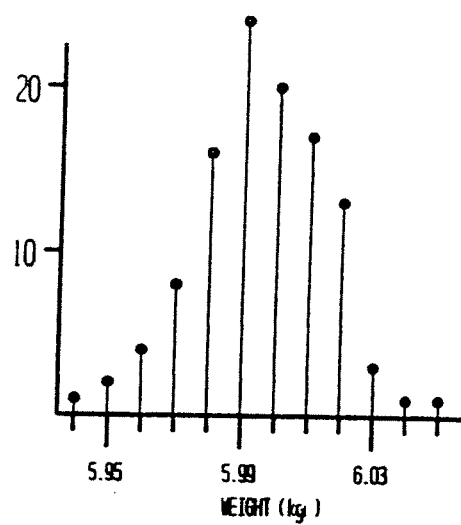
13c



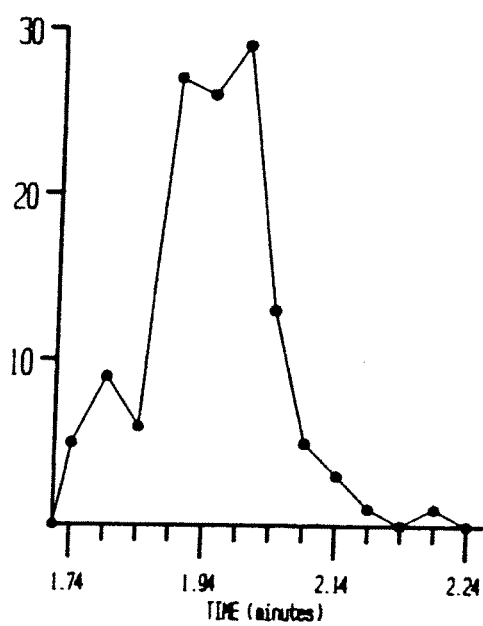
14a



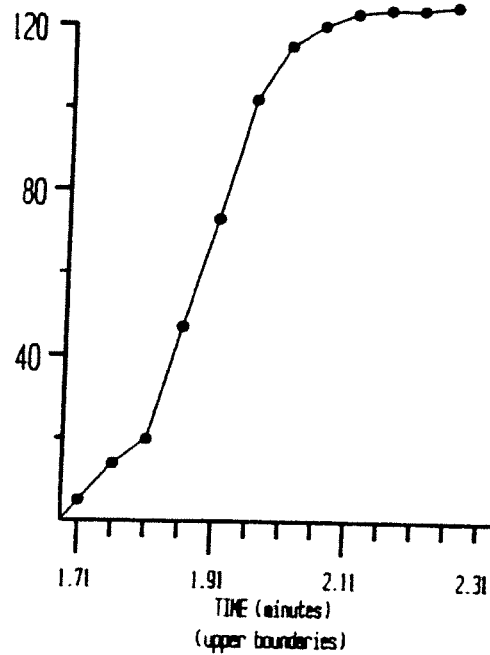
14b



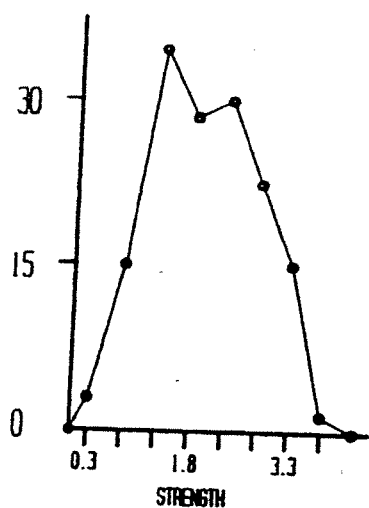
15a



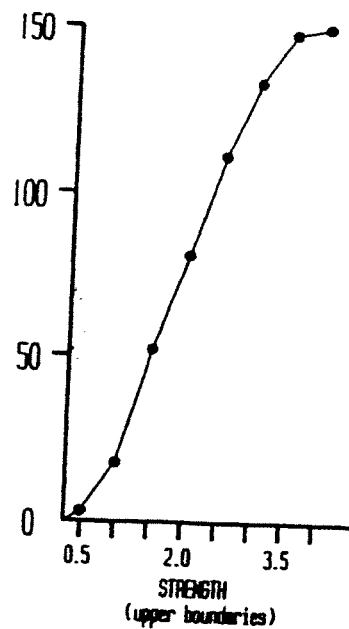
15b



16a



16b



$$17. \bar{X} = \Sigma x/n = \frac{115 + 113 + 121 + 115 + 116}{5} = 116 \text{ volts}$$

$$18. \bar{X} = \frac{\Sigma x}{n} = \frac{25.6 + 24.8 + 22.6 + 21.3 + 19.6 + 18.5 + 16.2 + 15.5}{8} = 20.5 \text{ m}$$

19.

<u>x</u>	<u>f</u>	<u>fx</u>
148	2	296
139	3	417
130	8	1,040
121	11	1,331
112	27	3,024
103	35	3,605
94	43	4,042
85	33	2,805
76	20	1,520
67	12	804
58	6	348
49	4	196
40	2	80
	<u>206</u>	<u>19,508</u>

$$\begin{aligned} \bar{X} &= \frac{\Sigma fx}{n} \\ &= \frac{19,508}{206} \\ &= 95 \text{ db} \end{aligned}$$

20.

<u>x</u>	<u>f</u>	<u>fx</u>
3.5	6	21.0
3.8	9	34.2
4.1	18	73.8
4.4	14	61.6
4.7	13	61.1
5.0	5	25.0
	<u>65</u>	<u>276.7</u>

$$\begin{aligned} \bar{X} &= \frac{\Sigma fx}{n} \\ &= \frac{276.7}{65} \\ &= 4.3 \text{ kg} \end{aligned}$$

$$21. \bar{X}_w = \Sigma w\bar{X}/\Sigma w$$

$$= \frac{(3)(3320) + (2)(3180)}{3 + 2}$$

$$= 3264 \text{ h}$$

$$22. \bar{x}_w = \Sigma w\bar{x} / \Sigma w$$

$$= \frac{(24)(1.75) + (18)(1.79) + (29)(1.68)}{24 + 18 + 29}$$

$$= 1.73 \text{ m}$$

$$23. \text{ a. } 8, 11, 15, 18, 22; \text{ Md} = 15$$

$$\text{ b. } 28, 33, 35, 36, 38, 43; \text{ Md} = \frac{35 + 36}{2} = 35.5$$

$$24. \text{ a. } \text{Md} = L + \left( \frac{\frac{n}{2} - cf}{f} \right) i = 1.915 + \left( \frac{\frac{125}{2} - 47}{26} \right) 0.05 = 1.94$$

$$\text{ b. } \text{Md} = 1.55 + \left( \frac{\frac{150}{2} - 52}{29} \right) 0.5 = 1.95$$

$$\text{ c. } \text{Md} = 90 + \left( \frac{\frac{206}{2} - 77}{43} \right) 9 = 95 \text{ db}$$

$$\text{ d. } \text{Md} = 4.0 + \left( \frac{\frac{65}{2} - 15}{18} \right) .3 = 4.3$$

$$\text{ e. } \text{Md} = 1.60 + \left( \frac{\frac{88}{2} - 39}{12} \right) 0.3 = 1.73$$

$$\text{ f. } \text{Md} = 1450 + \left( \frac{\frac{77}{2} - 19}{22} \right) 300 = 1716$$

$$25. 55, \text{ none, } 14 \text{ and } 17$$

$$26. 15, 5.99, 1.99, 1.3, 94, 4.1$$

$$27. \text{ a. } R = H - L = 25 - 14 = 11$$

$$\text{ b. } R = 45 - 39 = 6$$

$$\text{ c. } R = H - L = 20 - 6 = 14$$

$$\text{ d. } R = 6.05 - 5.94 = 0.11$$

$$28. s = \sqrt{\frac{n\Sigma x^2 - (\Sigma x)^2}{n(n-1)}} = \sqrt{\frac{5(7152350) - (5980)^2}{5(5-1)}} = 8.2 \text{ vib/sec}$$

$$29. s = \sqrt{\frac{4(0.024) - (.308)^2}{4(4-1)}} = 0.004 \text{ mm}$$

30.

Mid-point	Freq.		
(x)	(f)	(fx)	(fx <sup>2</sup> )
.5	1	.5	0.3
.8	16	12.8	10.2
1.1	12	13.2	14.5
1.4	10	14.0	19.6
1.7	12	20.4	34.7
2.0	18	36.0	72.0
2.3	16	36.8	84.6
2.6	3	7.8	20.3
	88	141.5	256.2

$$s = \sqrt{\frac{n \sum fX^2 - (\sum fX)^2}{n(n-1)}}$$

$$= \sqrt{\frac{88(256.2) - (141.5)^2}{88(88-1)}}$$

$$=.57\%$$

31a.

Mid-point	Freq.		
(x)	(f)	(fx)	(fx <sup>2</sup> )
0.3	3	0.9	0.27
0.8	15	12.0	9.60
1.3	34	44.2	57.46
1.8	29	52.2	93.96
2.3	30	69.0	158.70
2.8	22	61.6	172.48
3.3	15	49.5	163.35
3.8	2	7.6	28.88
	150	297.0	684.70

$$s = \sqrt{\frac{n \sum fX^2 - (\sum fX)^2}{n(n-1)}}$$

$$= \sqrt{\frac{150(684.7) - (297.0)^2}{150(150-1)}}$$

$$= 0.8$$

31b

Mid-point	Freq.		
(x)	(f)	(fx)	(fx <sup>2</sup> )
148	2	296	43,808
139	3	417	57,963
130	8	1,040	135,200
121	11	1,331	161,051
112	27	3,024	338,688
103	35	3,605	371,315
94	43	4,042	379,948
85	33	2,805	238,425
76	20	1,520	115,520
67	12	804	53,868
58	6	348	20,184
49	4	196	9,604
40	2	80	3,200
	206	19,508	1,928,774

$$s = \sqrt{\frac{n \sum fX^2 - (\sum fX)^2}{n(n-1)}}$$

$$= \sqrt{\frac{206(1,928,774) - (19,508)^2}{206(206-1)}}$$

$$= 20 \text{ db}$$

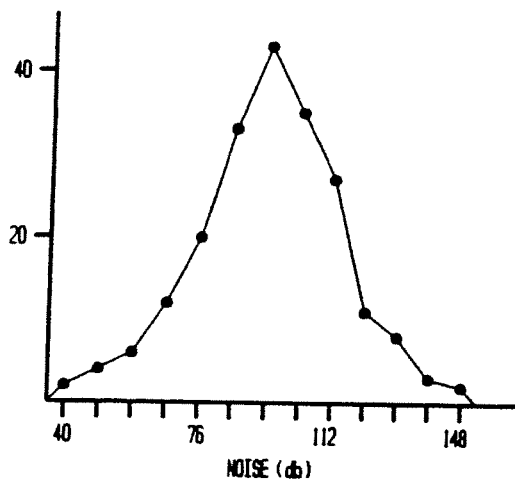


Mid-point ( $\chi$ )	Freq. ( $f$ )	( $f\chi$ )	( $f\chi^2$ )
1000	6	6000	$6.00 \times 10^6$
1300	13	16900	$21.97 \times 10^6$
1600	22	35200	$56.32 \times 10^6$
1900	17	32300	$61.37 \times 10^6$
2200	11	24200	$53.24 \times 10^6$
2500	8	20000	$50.00 \times 10^6$
	<u>77</u>	<u><math>134.6 \times 10^3</math></u>	<u><math>248.9 \times 10^6</math></u>

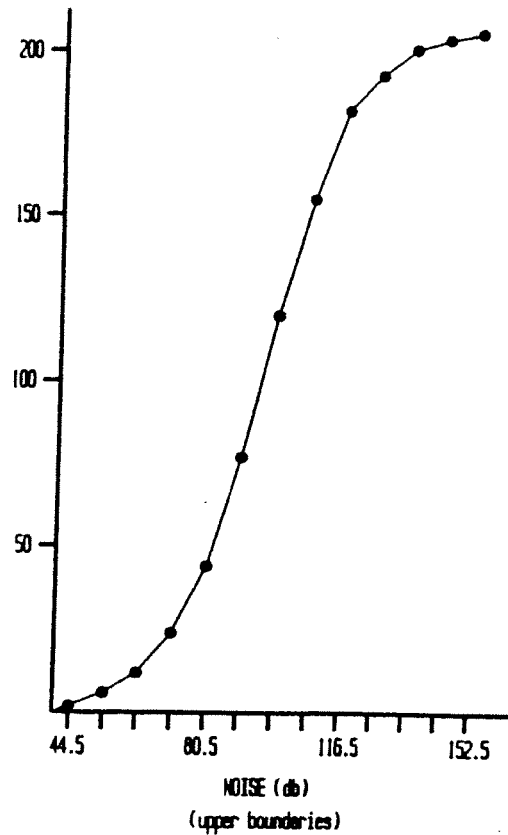
$$\bar{\chi} = \Sigma f\chi / n = 134.6 \times 10^3 / 77 = 1748 \text{ inspections}$$

$$s = \sqrt{\frac{n \Sigma f\chi^2 - (\Sigma f\chi)^2}{n(n-1)}} = \sqrt{\frac{77(248.9 \times 10^6) - (134.6 \times 10^3)^2}{77(77-1)}} = 423$$

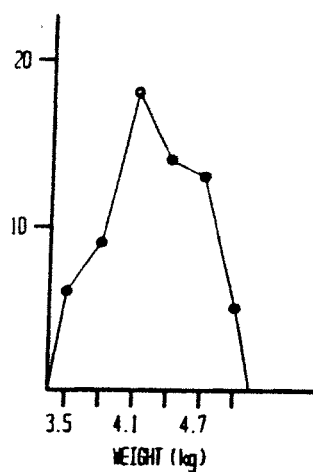
33a



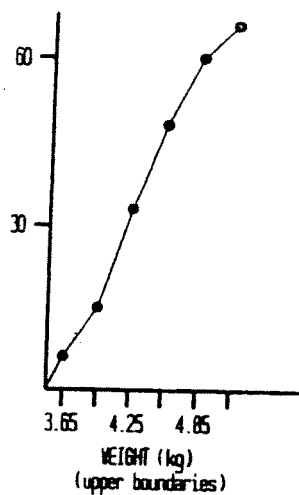
33b



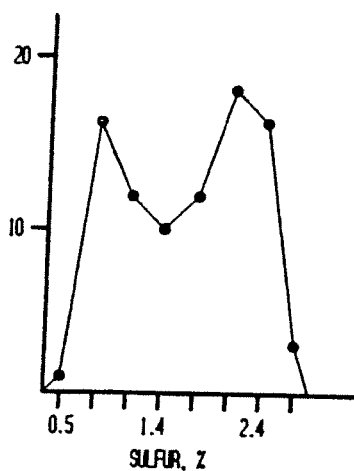
34a



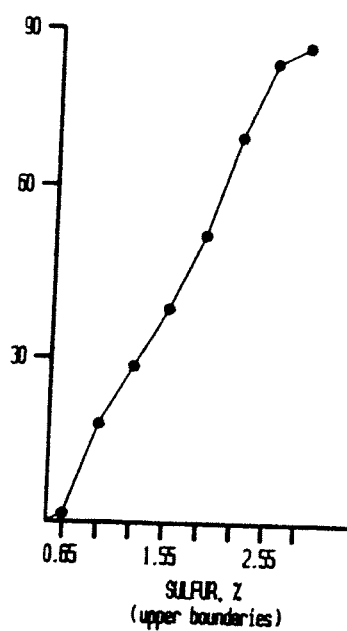
34b



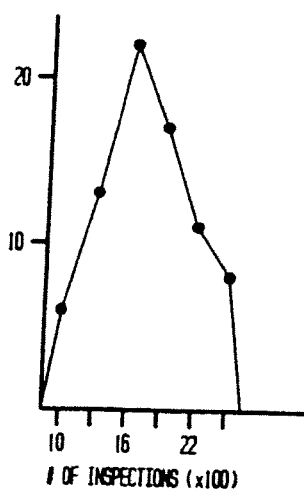
35a



35b



36a



36b

