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O T T A W A June 1st, 1942.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1235.

Quality Control: Engineering Science Applied to Inspection Practice.

(Copy No. 36.)

BUREAU OF MINES
DIVISION OF METALLIC MINERALS

ORE DRESSING AND
METALLURGICAL LABORATORIES

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
MINES AND GEOLOGY BRANCH

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## The Three Phases of Inspection:

The inspection of any manufactured product must go through three phases in its evolution. First is the research phase, during which designs are tried out with variations. Dimensions and composition are recorded and the results on the performance of the product are noted. After some knowledge of the characteristics of the product has been obtained, the final design is established. Then begins the

(The Three Phases of Inspection, cont'd) -

second phase of inspection, during which the performance of the manufacturing machines is studied and the major causes of variations in the manufactured product are discovered and brought under approximate control.

At this point a considerable fund of information has been developed. It includes knowledge of the effect of variation in the product on its performance, and also a knowledge of the causes of variation in the manufactured product. With this background it is possible to set up an inspection program for a mass production process. The third phase of inspection is directed at those properties found to be of greatest importance to the final performance of the product. Mass production inspection should serve as a guide to the manufacturer so that the desired condition can be maintained constantly and causes of variation may be detected long before they become significant enough to cause the product to depart from specified limits. The statistical quality control chart method is applied only after the ground work of research and trial runs is completed and mass production is under way. The importance of preliminary research, model tests, proving ground tests, and trial production runs should not be underestimated, because it is through them that the most important variables are discovered. Once discovered they can be measured and placed under the statistical quality control chart system.

Quality Control:

The green helmsman, nervously watching the compass, swings the ship's wheel at every tremor of the needle and in so doing puts the vessel off its course. The experienced helmsman turns the wheel very slightly and only when the compass has deviated a certain number of degrees from the established point. As a result the vessel holds to its true course. Thus the experienced man applies much less corrective action and produces the best results, because he knows when to leave well enough alone and when to take corrective action. "Know-How" is based first on experience and secondly on the ability to interpret conditions.

The manufacturer is in exactly the same position as the helmsman on a ship. Test data serve as a guide but without statistical methods or long experience he cannot know exactly when the variation in test results is normal and when it indicates that the process is going off its course.

By using Go-Nogo gauges the manufacturer can tell that he has departed from the specified course. This information is about as valuable to him as the knowledge to an automobile driver that he is in the ditch. The automobile driver would prefer to take corrective action before he gets in the ditch; similarly, the manufacturer would rather avoid exceeding specified limits than wait until they were exceeded and then take corrective action.

Quality Control methods assist in determining the limits of each measurable factor within which action is unnecessary and outside of which corrective action is required to get the process back on its normal course. Statistical methods also evaluate the relationship between separate measurable factors (for example, rest proof and gun proof or

(Quality Control, cont'd) -

hardness of armour and ballistic limit); information can be obtained in this way in fairly short periods. Without statistical aid it takes a long period of costly trial-and-error, hit-or-miss experimenting to obtain the same information.

Variation:

Production engineers, metallurgists, explosives manufacturers, machine shop superintendents, and others seem to resent the idea that there is any variation in their product and claim that since there is no variation therefore chance plays no part in the process and statistical methods do not apply. The fallacy of such a contention can be easily exposed. There is hardly any property of a manufactured product that does not vary. The size of ball bearings, the weight of pistons, hardness and tensile strength of steel parts, density of tetryl pellets, velocity of projectiles, ballistic limits of armour plate, and thousands of other measurable properties have been shown to fluctuate. Since it is a practical impossibility to make things exactly identical, variation in quality is a generally accepted fact.

Quality:

It is useless to consider quality otherwise than as the performance of a thing under definite test conditions; for example, one measure of the quality of time fuzes is the time in seconds which it takes to detonate the shell at a given setting. Quality of a group of objects therefore can be expressed as a series of numbers.

Quality Level:

In describing the quality of a group or lot of material the concept of quality level must be used. This is, that a distribution of test values describes quality. It is the usual practice to record test values in columns and the record contains many pages. The quality when so expressed is difficult to comprehend and cannot effectively be expressed. The mind cannot grasp the central value, the high value and the low value; the relative number of results in each part of the range from the lowest to the highest value absolutely cannot be perceived from such a record. There is a great wealth of information wasted because the data are not classified and arranged in a logical manner. The need for a better way to describe Quality Level is obvious. The distribution can be very accurately described by means of two terms only. These are Average and Standard Deviation.[*]

Statistical Control:

A product is assumed to be in statistical control when test values do not exceed the bounds of its normal or previous distribution. For practical purposes a distribution may be considered to be bounded by the values of its average $\pm 3X$ standard deviations. If one or more test values falls outside of these limits, the process is assumed to be out of control and it is reasonable to conclude that either the

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[*] There are several other descriptive terms which are used to give additional information about the distribution of quality values, namely:

Skewness, kurtosis, median, and mode.

(Statistical Control, cont'd) -

testing procedure or the manufacturing process has changed. The statistical control idea has proven to be an unequalled method of determining WHEN TO INVESTIGATE AND START CORRECTIVE MEASURES AND WHEN TO LEAVE THE PROCESS ALONE.

Characteristics of a Process:

If a process remains constant the test results on the product will vary within a constant range. This range is bounded by Average ±3 Standard Deviations.

EXAMPLE.

Let us take, for example, the process of weighing out sugar into 1-pound bags. Following are results of imaginary check tests on this operation taken at regular intervals:

| Weight, in pounds |
|---|
| 0.81 |
| 1.01 |
| 0.93 |
| 1.10 |
| 1.23 |
| 1.13 |
| 1.02 |
| 0.91 |
| 0.87 |
| 0.99 |
| 1.00 |
| 1.14 |
| 1.03 |
| 0.97 |
| 0.86 |
| 0.85 |
| 0.98 |
| 1.07 |
| 1.16 |
| 1.00 |

(Continued on next page)

(Characteristics of a Process, cont'd) -

(Example, cont'd) -

The characteristics of this process can be described by:

1. Average ($= \bar{X}$)

$$\bar{X} = \frac{\text{Sum of test values}}{\text{Number of test values}} = \frac{20.06}{20} = 1.00 \text{ pound.}$$

2. Standard Deviation = Sigma.

$X$ represents a test value

$\bar{X}$ " average.

$N$ " number of test values.

| $X$ | $X-\bar{X}$ | $(X-\bar{X})^2$ |
|---|---|---|
| 0.81 | -0.19 | 0.0361 |
| 1.01 | 0.01 | 0.0001 |
| 0.93 | -0.07 | 0.0049 |
| 1.10 | 0.10 | 0.0100 |
| 1.23 | 0.23 | 0.0529 |
| 1.13 | 0.13 | 0.0169 |
| 1.02 | 0.02 | 0.0004 |
| 0.91 | -0.09 | 0.0081 |
| 0.87 | -0.13 | 0.0169 |
| 0.99 | -0.01 | 0.0001 |
| 1.00 | 0 | 0 |
| 1.14 | 0.14 | 0.0196 |
| 1.03 | 0.03 | 0.0009 |
| 0.97 | -0.03 | 0.0009 |
| 0.86 | -0.14 | 0.0196 |
| 0.85 | -0.15 | 0.0225 |
| 0.98 | -0.02 | 0.0004 |
| 1.07 | 0.07 | 0.0049 |
| 1.16 | 0.16 | 0.0256 |
| 1.00 | 0 | 0 |
| | Total | 0.2408 |

$$\text{Sigma} = \sqrt{\frac{\Sigma(X-\bar{X})^2}{N}} = \sqrt{\frac{0.2408}{20}} = \sqrt{0.012014} = 0.11 \text{ pound.}$$

Significance of Average and Sigma:

If the process of weighing out sugar remains constant the weights of the bags will vary within average ±3 sigma, that is, from 0.67 to 1.33 pounds. A result falling outside of this range means that the process has changed. Immediate action would be necessary to find out and correct the cause of the variation, which might be due to:

1. Weigh scale defective.
2. Carelessness of the operator.
3. Change in properties of sugar (lumps).
4. Change in accuracy of checking scale or method.
5. Other causes.

Any result falling between 0.67 and 1.33 pounds would be considered normal and no action would be taken. In fact, if action were taken the process would be made worse rather than better.

If the range 0.67 to 1.33 pounds is not acceptable, a new and different process would have to be substituted. This might involve new personnel or more accurate weighing devices, or perhaps different material-handling equipment. But unless a new process is installed it would be absolutely useless to worry and fuss about the wide range of results on the present process.

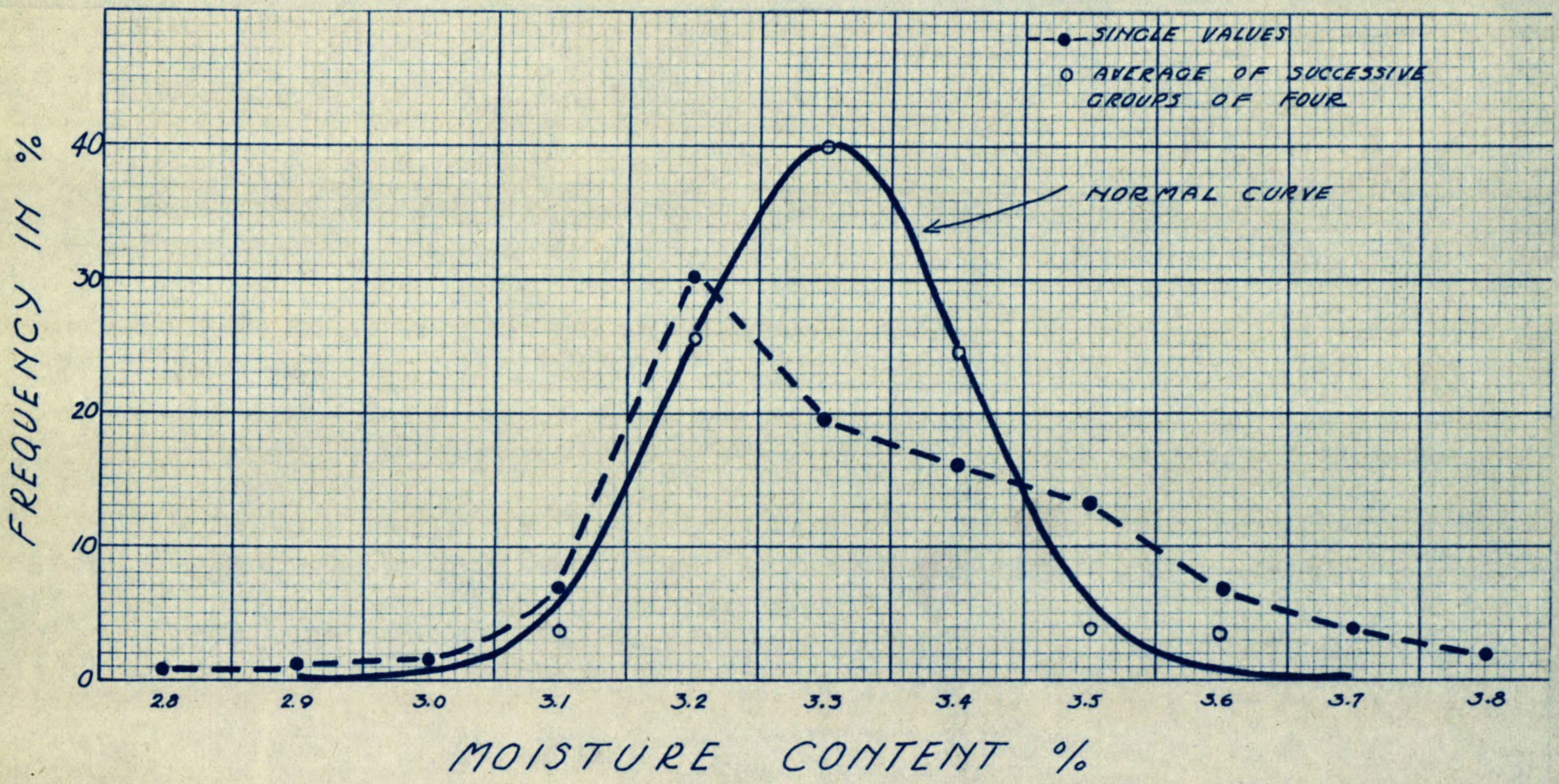
Each process is characterized by limits of properties of the product which are inherently fixed by the nature of the process. Statistical methods determine these limits so that the manufacturer can know exactly how the process is going.

Rational Subgroups:

The previous example was simplified in order to demonstrate the principle of Quality Control, which, of course, depends upon normal distribution of test values. However, (Rational Subgroups, cont'd) -

a normal distribution does not always prevail, and for this reason the grouping system was developed. This system requires that successive samples be considered as groups of four or more and the average of each group is plotted as well as the standard deviation of each group or the range of each group (highest value--lowest value). Page 10 shows the amazing power of this simple method to transform a skewed distribution to the normal curve. Note that when single values were recorded the line representing the frequency with which each class of results occurred is very irregular. That is, the frequency distribution is very definitely skewed. Now, should the method of the previous example be applied to such data, using single values, the control limits (plus or minus three standard deviations) do not serve as an accurate guide to the presence of assignable causes of variation. However, when each successive group of four results was averaged and the frequency distribution plotted as is shown on Page 10, it was found that the shape of the curve fitted the normal curve of error very closely. Therefore, by the simple technique of taking groups of test data it is possible to make use of the information which is available regarding the normal curve of error. It should be noted here, however, that this operation is only possible with data produced from controlled operations. There are cases of test values occurring in such irregular manner that no predictions can be based on them. However, irregular data are a characteristic of the development stage of manufacture and the causes of irregularity are gradually eliminated as time goes on. They can be

# EFFECT OF GROUP SIZE ON THE DISTRIBUTION CURVE



(Rational Subgroups, cont'd) -

estimated by the use of correlation technique. By the time any operation has reached the mass production stage it is generally found to be susceptible to the statistical quality control system.

Interpreting Control Limits:

After it has been estimated that the data exhibit characteristics approximating those of the normal curve of error it is then possible to interpret the significance of each group of test values, as follows: "If the process remains unchanged, then results exceeding average plus or minus three times standard deviation (three sigma limits) will occur three times in one thousand. The occurrence of a test result outside of three sigma limits therefore is a strong indication that the process has changed. The possibility that the product has changed can be deduced (assuming that the normal curve of error exists) quite accurately by determining the deviation of the value from average.

Example:

GIVEN Quality Level = Av'ge 9.18
Sigma 0.39

QUESTION Of what significance is the value 9.50?

ANSWER

$$t = \text{deviation} = \frac{9.50-9.18}{0.39} = \frac{0.32}{0.39} = 0.82 \text{ sigma.}$$

(From table of areas under normal curve of error) Frequency of this deviation = 2 x 0.2939 = 0.588

ODDS THAT QUALITY OF PRODUCT HAS NOT CHANGED ARE 0.588 to 0.412 (approx. 6 to 4).

Thus by using the past to evaluate the present, that is, by recording in chronological order, the significance of each test can be estimated.

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## AN EXAMPLE OF FUZE TEST DATA PLOTTED ACCORDING TO QUALITY CONTROL.

| Group No. | Average, $\bar{X}$, of each group | Range, R, of each group |
|---|---|---|
| 1 | 8.55 | 1.71 |
| 2 | 8.75 | 0.24 |
| 3 | 8.92 | 1.36 |
| 4 | 8.70 | 0.89 |
| 5 | 8.95 | 1.05 |
| 6 | 8.55 | 1.67 |
| 7 | 9.09 | 1.23 |
| 8 | 9.01 | 0.43 |
| 9 | 8.61 | 1.10 |
| 10 | 9.15 | 0.59 |
| 11 | 9.31 | 0.71 |
| 12 | 9.41 | 2.26 |
| 13 | 9.41 | 1.13 |
| 14 | 9.57 | 0.86 |
| 15 | 9.78 | 0.66 |
| 16 | 8.88 | 1.41 |
| 17 | 8.65 | 1.00 |
| 18 | 9.18 | 1.60 |
| 19 | 9.23 | 0.58 |
| 20 | 9.85 | 2.45 |
| 21 | 9.21 | 1.00 |
| 22 | 9.47 | 0.87 |
| 23 | 9.94 | 0.94 |
| 24 | 9.33 | 1.26 |
| 25 | 9.21 | 0.69 |
| 26 | 9.62 | 0.51 |
| 27 | 9.45 | 0.84 |

$$\Sigma \bar{X} = 247.77 \qquad \Sigma R = 29.04$$

$$\bar{\bar{X}} = \frac{\Sigma \bar{X}}{N} = 9.18 \qquad \bar{R} = \frac{\Sigma R}{N} = 1.08$$

The values given above represent burning time (in seconds) for tracer fuzes. Groups of five have been recorded, with the following results:

(Continued on next page)

(Example of Quality Control Applied to
Fuze Test Data, cont'd) -

Control Chart Lines.

| | Central Line | Control Limits |
|---|---|---|
| For averages $\bar{\bar{X}}$ | $\bar{\bar{X}} = 9.18$ | $\bar{\bar{X}} \pm A_2 \bar{R} = 8.56 - 9.82$ |
| For averages $\bar{R}$ | $\bar{R} = 1.08$ | $D_3\bar{R}$ and $D_4\bar{R} = 0 - 2.28$ |

The central lines, of course, are the averages of averages and ranges respectively. The factors used in calculating control limits,

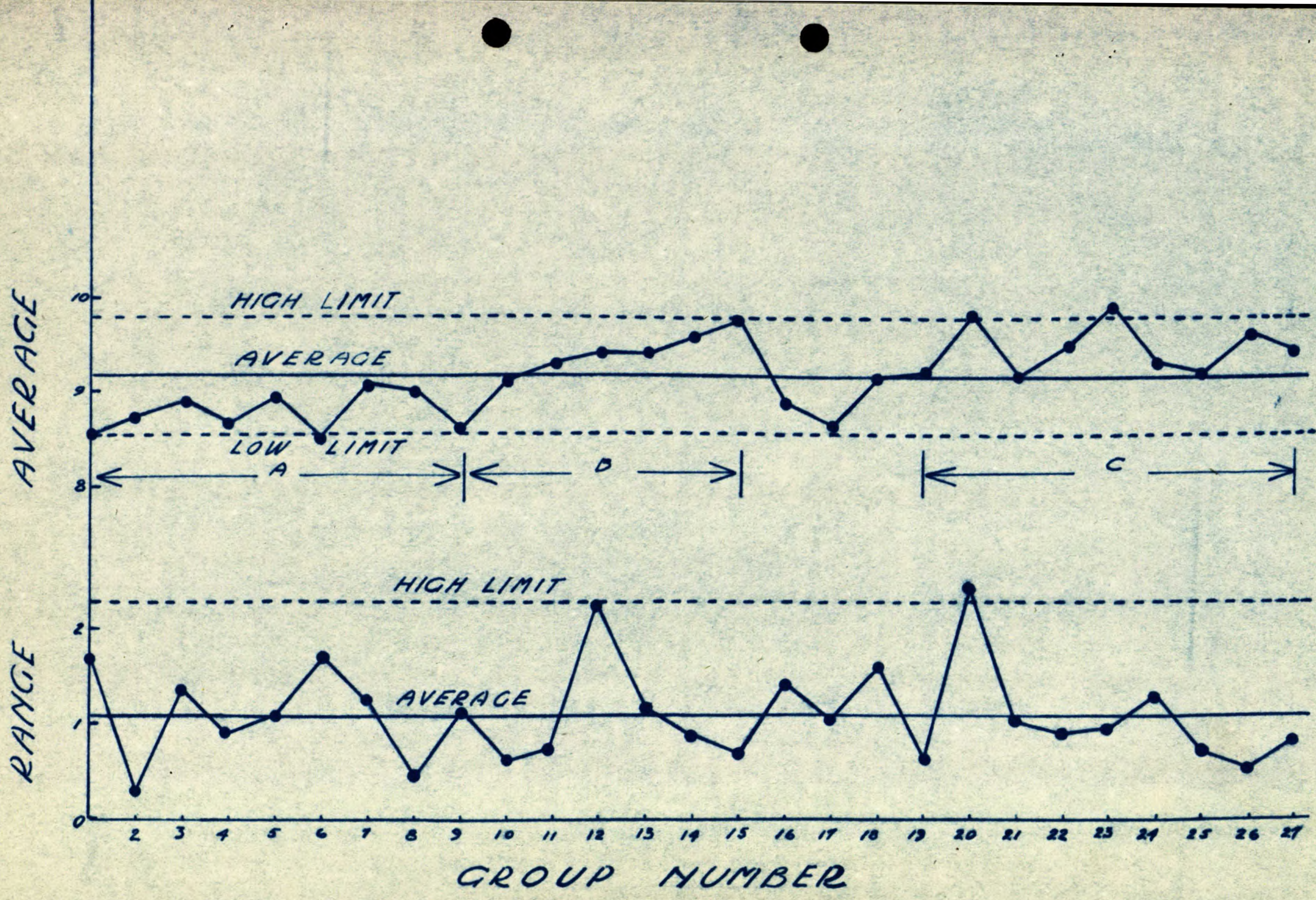
$A_2 = 0.577$

$D_3 = 0$

$D_4 = 2.114$,

are to be found in the A.S.T.M. "Manual on Presentation of Data."

(Page 14 shows the control chart for the above values.)


HIGH LIMIT
AVERAGE
LOW LIMIT
A
B
C
AVERAGE
RANGE
HIGH LIMIT
AVERAGE
10
9
8
2
1
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
GROUP NUMBER

(Example of Quality Control, cont'd) -

Interpretation of Quality Control Chart -

Seven or more points on the same side of the central line or in a continuous trend upward or downward are sufficient to indicate a shift or trend in quality level. Note that in Period A average values were consistently low. In Period B a gradual trend upward occurred. In Period C average values were consistently high. Therefore, A, B and C represent three periods in which production conditions were different.

Groups 1, 6, 20, and 23 show apparent lack of control, and therefore should be investigated.

Conclusions -

The control chart method applied to a test of fuze performance has indicated that the manufacturing processes, raw materials, or testing procedures were characteristically different for Periods A, B, and C. Also, assignable causes of variation were present in Groups 1, 6, 20, and 23. Thus, the control chart method shows the production engineer the exact nature of the variation and where and when to look for definite "out of line" procedure.

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(End of Example)

Number of Test Results Necessary for Determination of Quality Level:

It is recommended that at least twenty-five groups be used to determine quality level. Experience has shown that conclusions based on fewer results than this number may be erroneous.

Periodic Revision of Quality Level Limits:

In keeping a continuous record in chart form it will be found advisable to calculate control limits from time to time. This may be done at arbitrary intervals, such as one week, one month, etc., or by visual examination of the record.

Application of Statistical Methods:

Lieut.-Col. L. E. Simon, of the Ballistic Research Laboratory, Aberdeen, Maryland, has stated that in the inspection of explosives, fuzes, cartridges, and any other munitions product, the statistical system makes it possible to get more information on products with less work than is required by old-fashioned sampling and inspection systems. At Piccatinny Arsenal it was found that better control over explosive pellets was obtained by taking a group of five at regular intervals, weighing very accurately, and plotting control charts. The previous method required that every single pellet be weighed. Captain Cohen's comment on this was that five accurate measurements are worth more than one thousand rough measurements.

At the Westinghouse Electric and Manufacturing Company, Springfield, Mass., M110 bomb fuses are made and 60 per cent of the dimensions controlled are reported on Quality Control charts. Mr. A. L. Atherton stated that

(Application of Statistical Methods, cont'd) -

sampling by dimensions tells more by far about the product than does 100 per cent Go-Nogo inspection; the value of the quality control is apparent when defective work occurs. If control charts have been kept, the causes of defective fuzes can be quickly detected and eliminated. Without the control chart data the causes of defective fuzes are unknown and must be looked for. In the latter case the manufacturer is working in the dark.

The importance of this new development in inspection technique may be judged from the fact that the U. S. Ordnance has adopted it and several of the British Ordnance reports have been given over to the statistical phase of inspection. On Wednesday, April 15th, 1942, a meeting was convened jointly by the Institutes of Civil, Mechanical, and Electrical Engineers to discuss Quality Control. This meeting (in England) was described in the April 24th issue of THE ENGINEER (28, Essex Street, Strand, London). It was reported that "the Chief Inspector of the A.I.D., Mr. Lucas, made it clear that the inspection department of the M.A.P. is honceforward prepared to judge the quality of a manufacturer product on the evidence provided by the control chart.

Following is the editorial comment of THE ENGINEER (London, England) April 24th, 1942:

QUALITY CONTROL

The success of last week's joint meeting of our three leading engineering institutions augurs well for that closer collaboration on matters of common engineering interest for which we have always pleaded so strongly. Some eight hundred members drawn from the ranks of industry, as well as from the Services, both Armed and Civil, gathered in the Great Hall of the Institution of Civil Engineers to hear several authoritative and first-hand accounts of quality control and its applications to wartime production--a subject to which we referred in our issue of January 30th. Sir Noel Ashbridge, President of the Institution of Electrical Engineers, was in the chair, and among those present was Sir Andrew Duncan, the Minister of Supply.

The proceedings were opened by Dr. C. G. Darwin, who, as Director of the National Physical Laboratory, went to the United States about a year ago on an important mission from which he has just returned. Among other things, Dr. Darwin saw the extensive use to which the American arsenals and armaments factories are putting this technique of quality control in assisting the national productive effort, and he illustrated his explanation of quality control by a well-chosen example from this important field of production. Sir Frank Gill, who followed Dr. Darwin, laid stress on the fact that in applying quality control what was needed most was not statistical knowledge, but simple and practical operating instructions. Anyone interested may study the statistical fundamentals and will be the more expert for so doing, but is is wrong to think that nothing can be done to apply this technique until statistical experts are available. Many factory engineers are competent to follow the simple directions given, for example, in B.S.S. 1008--1942, to which both Dr. Darwin and Sir Frank Gill made reference in their introductions to the subject before the meeting. A further publication, an interim revision of B.S.S. 600--1935, dealing exclusively with quality control charts, was later mentioned by Mr. Good, Director of the British Standards Institution, as a more extensive text on the subject which would be available very shortly. Several of the subsequent speakers either referred to or explained the application of quality control, not only to munitions manufacture as suc., but also to the manufacture of mechanical components. Dr. Dudding gave an interesting and amusing demonstration of quality control charts based on the method of defectives; whilst Mr. Rissik described in some detail how the use of quality control founded on measurements had in a certain case succeeded in reducing the man-hours wasted on scrap and repairs in the machine shop by some 50 per cent. over a period of six months.

It is abundantly clear from the available evidence that, considered as a technique, pure and simple, quality control is an extremely powerful preventative of defective production. On this score alone it is bound to commend itself to all concerned with the maximising of our war effort. At the same time, considered as an aid to production, quality control is an extremely powerful lubricant. By and large, it enables one to maintain throughout a smooth and regular flow of product uninterrupted by excessive rejections. It also provides for the first time a reliable basis for judging quality from samples instead of from the product as a whole, with obvious savings in inspection costs. Finally, considered as an integral part of production organisation, quality control imparts an entirely new character to the relations between manufacturer and purchaser, the nature of which is of great and far-reaching

(Application of Statistical Methods, cont'd) -

significance. This new relationship is reflected in the change of policy announced at the meeting by the Chief Inspector of the A.I.D. Mr. Lucas made it clear that the inspection department of the M.A.P. is henceforward prepared to judge the quality of a manufacturer's product on the evidence provided by the control chart and, if that evidence is satisfactory, to leave inspection to the manufacturer. It is to be hoped that the inspection departments of the other Production Ministries will follow this timely lead in the direction of economising in governmental inspection effort and man-power.

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SUMMARY:

By applying scientific methods to present inspection practice it has been found that more knowledge of the product could be obtained, with a 50 per cent, or more, reduction in staff; also, it is claimed, production flows more smoothly and defects are reduced.

If claims made have any basis of truth, then all those engaged in mass production industries or the inspection of mass-produced goods should give serious consideration to the introduction of this method.

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