# QUALITY CONTROL

# IN

# INDUSTRY

by

W. A. Shewhart
Bell Telephone Laboratories

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Not only
How to detect
but also
How to finger print
The Demons of Chance

# SOME PRELIMINARY COMMENTS

## Some Definitions

It has been said that:

Physicist is one who has a clena mind and works with dirty things,
Chemist is one who has a dirty mind and works with clean things,
Engineer is one who has a dirty mind and works with dirty things.

I might add:

Mathematician is one who has such a clean mind that he must work only with the abstract symbols of clean things.

"Mathematics is the subject in which one never knows what he is talking about nor if what he says is true".

Not so long ago a well-known physicist defined a mathematical physicist as one who among physicists is considered a mathematician and among mathematicians is considered a physicist. In the same way, it might be said about a mathematical statistician in the engineering field that he is one who among engineers is a mathematician and among mathematicians, is an engineer.

# INTRODUCTION

## Historical

. **England** "Student" (W.S.Gosset). Brewing, about 1900. First company report 1904.

. **Germany** Karl Daeves. Metallurgy. First known publication, 1922. I first leanned of Grosszahl-forschung about 1924.

. **United States** E.C.Molina. Telephone trunking theory. Malcolm Rorty memo 1903. Molina began internal application 1905; first patent 1906; two important contributions Dec., 1907; publication, 1913.

## Contrast

| | | | |
|---|---|---|---|
| Student | Beer | Error theory and elements of design of experiment | 1. Error of the mean.<br>2. Elements of design of exp. |
| Daeves | Steel | Causes of variability in metals. | 1. Practical importance of evidence of multimodal freq. curves. |
| Molina | Telephone switching ~~problems~~ | a priori design | 1. Telephone trunking theory. |
| Quality Control | Manufactured articles | Applications in three fundamental steps: specification, production, inspection. | 1. Sampling plans to meet consumer and producer risks<br>2. Operation of statistical control |

3. Theory for seeting tolerance limits.

4. Criteria for study ing variation produced by matter in microscopic and even atomic quanti- ties.

5. General theory and technique for con- trol of manufactur process as an <u>operation</u>.

## HISTORICAL [illegible]

Slide #16062 Mass production upon interchangeability is in its infancy.

Slide #17802

March of technique in step with:

1. Need for coordinated effort as in WAR.
   - 1.1 8000 ? B.C. Bows and arrows
   - 1.2 1787 Interchangeability (muskets)
   - 1.3 1917+ standardization (World War)
2. March of ideas
   - 2.1 Exact science 1787
   - 2.2 1924 - Probable science Statistics

Slide ______

Growth of standardization result of World War #1.

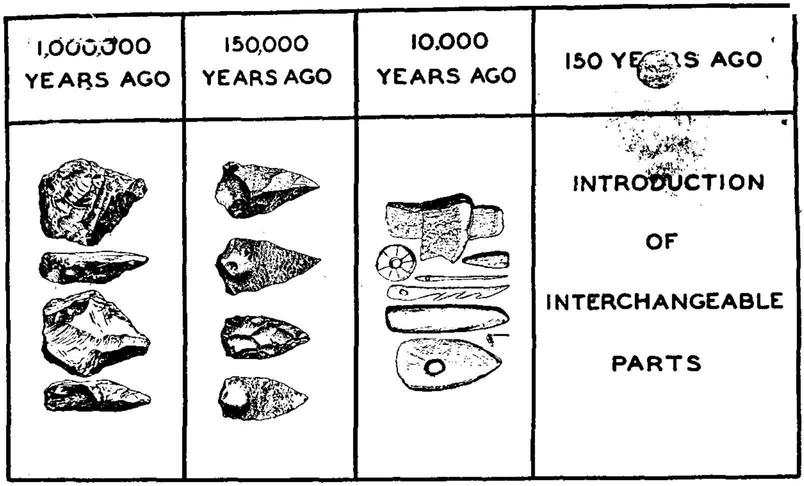
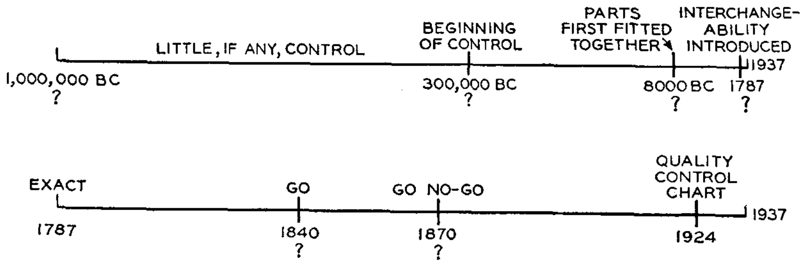
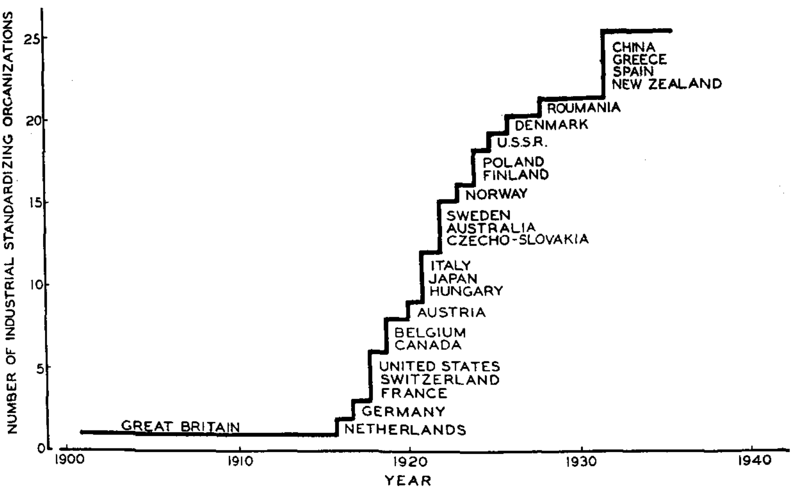

1,000,000 YEARS AGO
150,000 YEARS AGO
10,000 YEARS AGO
150 YEARS AGO
INTRODUCTION OF INTERCHANGEABLE PARTS

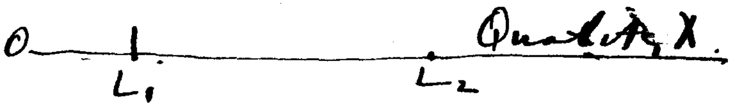
FIG. 2.


LITTLE, IF ANY, CONTROL
BEGINNING OF CONTROL
PARTS FIRST FITTED TOGETHER
INTERCHANGE-ABILITY INTRODUCED
1,000,000 BC ?
300,000 BC ?
8000 BC ?
1787 ?
1937
EXACT
GO
GO NO-GO
QUALITY CONTROL CHART
1787
1840 ?
1870 ?
1924
1937


NUMBER OF INDUSTRIAL STANDARDIZING ORGANIZATIONS
YEAR
0
5
10
15
20
25
1900
1910
1920
1930
1940
GREAT BRITAIN
NETHERLANDS
GERMANY
UNITED STATES
SWITZERLAND
FRANCE
BELGIUM
CANADA
AUSTRIA
ITALY
JAPAN
HUNGARY
SWEDEN
AUSTRALIA
CZECHO-SLOVAKIA
NORWAY
POLAND
FINLAND
U.S.S.R.
DENMARK
ROUMANIA
CHINA
GREECE
SPAIN
NEW ZEALAND

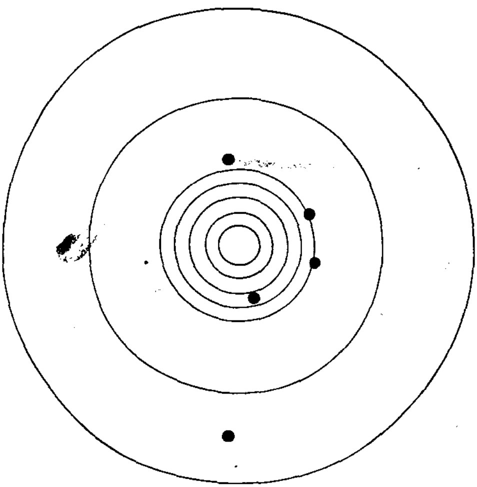
# FUNDAMENTAL PROBLEM

Develop an operation that will produce a thing with a quality characteristic that will hit its mark - the Tolerance Range if repeated 1 or n times.




Case of 2 qualities $X_1$ and $X_2$

Like shooting at a mark



More important yet Are there any assignable Causes present?

is made in the method of shooting

2.

Case of n quality Characteristics (

Instead of a circle our mark
is an element of volume in
n space

$dx_1\, dx_2, \dots dx_n$.

WHAT DOES STATISTICIAN DO?

1. Helps minimize failures to hit target. Rejections

2. Help minimize cost of inspection

3. Help minimize tolerances

3.1 To save material that is scarce.

3.2 To attain a desired quality at any cost as to maximize lifting power of plane.

# CONTRIBUTION OF STATISTICS TO SCIENCE OF ENGINEERING

| Three Steps in Process of Control | Corresponding three Steps [redacted] | [redacted] ution of [redacted] istics |
|---|---|---|
| Specification | Hypothesis [redacted] | [redacted] hypothesis |
| [redacted] ction | Experiment | Statist [redacted] ly design [redacted] exper [redacted] |
| Inspection | Test of hypothesis | Statis [redacted] test of [redacted] Hypothesis |

| | Exact Science | Statistical Science |
|---|---|---|
| Hypotheses | Constant<br>Mathematical limit<br>Mathematical relationship<br>Continuity | statistical variable<br>statistical limit<br>statistical relationship<br>Quantum jump |
| Design of Experiment | Control all but one variable | Do not attempt to control all but one variable. ~~But~~ Instead, measure ~~interaction~~ |
| Test of hypothesis | yes - no | Rule of action that works in the long run ... two sources of Error. |

## [illegible]UNDAMENTAL CONCEPT

Mass production = <u>repetitive [illegible]eration</u>

Let X be a quality c[illegible]ic of the thing produced. Se[illegible]petitions of an operation gives[illegible]

$\{X_i\}_{i=1}^{\infty}$ = [illegible], $X_2$, ..., [illegible] ... [illegible] . . (1

Desire control of causes [illegible]y in X's.

Repetitive Operation (under Same Essential Con

1. Flipping a coin - heads 0, tails 1.

   0 0 1 0 1 0 0 1 1 0 1 - - - - - -

   Throwing a die

   1, 3, 1, 4, 2, . . . . . .

2. Weighing man, (measurement of "Physical const

   $X_1, X_2, \ldots X_n, \ldots$

## FUNDAMENTAL CONTROL HYPOTHESES

Hypothesis I - Some repetitive operations exist in nature that obey mathematical laws of probability.*

Hypothesis II - The maximum attainable degree of validity of prediction** that an operation will give a value X lying w within any previously specified tolerance range is that based upon the prior knowledge that the probability of this event is q' or more generally, upon the prior knowledge of the mathematical law of chance underlying the operation.

Hypothesis III - The maximum degree of attainable control*** of the cause system underlying any repetitive operation in the physical world is that wherein the system of causes produces effects in accord with a mathematical law of probability.

Hypothesis IV - Some criterion or criteria may be found and methods developed for their application to the numbers obtained in a sequence of repetitions of any operation such that whenever a failure to meet the criterion or criteria is observed, it is worthwhile to look for and try to revove an assignable cause of variability from the operation. As these causes are removed, a

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* For example, drawing from a bowl is such an operation.

** Or, in engineering terms, maximum quality assurance.

*** Hence minimum tolerance limits and most efficient use of materials.

state of statistical control is approached where the results of repetitions of the operation behave in accord with a mathematical law of chance.

It is not the object here to discuss th available evidence supporting these physical hypotheses because that has been done elsewhere, but rather to show the prominent part played by mathematical laws of probability in the fundamental assumptions and to emphasize the point that the testing and use of these hypotheses implies that the engineer must keep his eyes on the physical operation as well as on the mathematics.

1939 book inserted here (6)

# CRITERIA OF CONTROL

## 1. Relative Effects of Causes

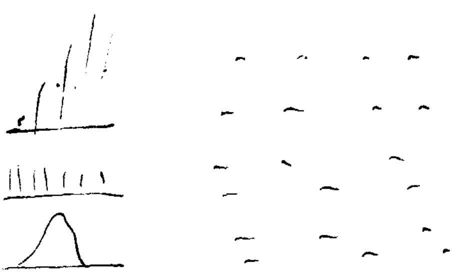
Criteria based upon frequency distribution of variable X in terms of elemental effects of system of m elemental causes in a constant system of chance causes.

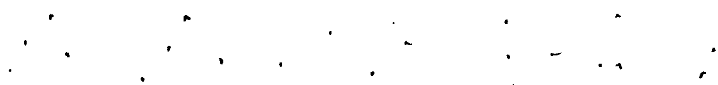
If one of the m causes produces a very large effect in comparison with that produced by any one of the (m-1) remaining causes, it may be possible to find and remove it and the presence of such a cause will likely be revealed by bimodality of the distribution.

## 2. Lack of Constancy in Probability

Criteria based upon order of occurrence in the sequence (1) revealing lack of constancy in the cause system, i.e., lack of constancy in the probability f(x)dx.

This may result in muctimodility that may be detected and will always modify runs in a wqy that can likely be detected.





Random order independent of numbers in bowl if all

# Proof of the Pudding

Minimize rejections
S 8836

Minimize cost of inspection

Minimum tolerances
Dodge Design S 18845

Maximum assurance
Fuses 16047
Vel. of light 17798

8

How?

5 Steps in control S 21879

704 observed values of resist S 7809

704 obs. values of resist show lack of control S 8837

Angel Slide showing importance of sample of 4 S 22369

Find Nature of Cause

2. Need for New Technique of Research

Three difficulties arise when the scale of physical and chemical operations is reduced:

1. New physico-chemical hypotheses
2. New methods of laboratory operations.
3. New techniques for analyzing data and testing hypotheses.

New technique embodies principles, points of view, and objectives that make it differ from classical technique sufficiently to make it a new kind of analysis.

Examples

a) Newtonian vs. quantum mechanics.
b) Quantitative vs. microchemical and micro-gas analysis.
c) Classical statistical criteria ignoring order vs. criteria based on order.

# E B Ferrell Problem

10

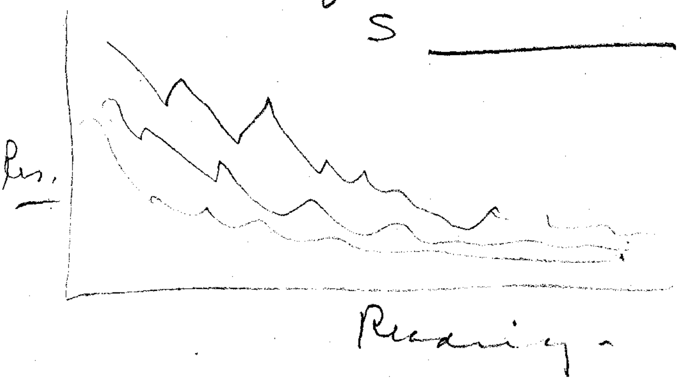
(1) 144 obs. values of thickness
521612

(2) Order of drawing vs order when drawn from a bowl. 521613

3) Control chart indicates assignable cause 521616

(4) Runs tell us something about the cause.
521617
521613

# Nature of Cause




| Length | Number of runs up and down Sept – | Sept – | Oct + | Theory |
|---|---|---|---|---|
| 1 | 9 | 10 | 8 | 8 |
| 2 | 9 | 7 | 8 | 8.41 |
| 3 | 2 | 2 | 4 | 3.03 |
| 4 | | | 1 | .77 |
| 5 | | 2 | | |
| 6 | | | | |
| 7 | 1 | | | |

# W. E. Campbell

## Locates Cause of Trouble

① Problem as Stated

one value to
represent resist

② 40 readings on single contact
S 22458

③ 40 random points
S 22447

④ 40 random - new apparatus
S 22450

⑤ Single Contact S 22452

Design of Experiment 15

Show Sample terminals and brushes

S ____

S ____

War substitute materials.

Jm Finch (Analysis of Variance

S [redacted] 22

Routine Analysis

S 22546

# Thickness [redacted]aper in mils

## Horizonta[redacted]Across sheet

| Type of Paper | Method of Measure-ment | B.T.L. Ave. | B.T.L. Variance Areas | B.T.L. Variance Sheets | B.T.L. Resid-ual | [redacted] W. [redacted] Co. Ave | [redacted]iance Areas | [redacted]iance Sheets | Resid-ual | Manning Ave. | Manning Variance Areas | Manning Variance Sheets | Manning Resid ual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .001" | Ratchet | 1.28 | .0016 | .0149* | .002[redacted] | 1.26 | [redacted] | .0212* | .0014 | 1.32 | .0072* | .0172* | .0017 |
| | Dial | 1.29 | .0013 | .0151* | .00[redacted] | 1.29 | .0009 | .0174* | .0015 | 1.29 | .0007 | .0125* | .0015 |
| .00125" | Ratchet | 1.63 | .0064 | .1135* | .0050 | [redacted] | [redacted] | .0987* | .0063 | 1.64 | .0075 | .1250 | .0678 |
| | Dial | 1.60 | .0084 | .0958* | .0050 | [redacted] | [redacted] | .1068* | .0062 | 1.61 | .0084 | .1101* | .0058 |
| .0015" | Ratchet | 1.81 | .0071 | .0854* | .0040 | [redacted] | [redacted]093 | .0825* | .0057 | 1.80 | .0075 | .0475* | .0052 |
| | Dial | 1.80 | .0081 | .0993* | .0045 | 1.[redacted] | [redacted]114 | .0711* | .0059 | 1.80 | .0058 | .0769* | .0053 |
| .00177" | Ratchet | 1.92 | .0049 | .0053 | .0025 | 1.9[redacted] | .0027 | .0138* | .0022 | 1.99 | .0031 | .0146* | .0029 |
| | Dial | 1.98 | .0044 | .0137* | .0018 | 1.9[redacted] | [redacted]058 | .0138* | .0027 | 1.98 | .0038 | .0144* | .0023 |
| .002" | Ratchet | 1.92 | .0020 | .0080* | .0016 | 1.[redacted] | .0122* | .0100* | .0025 | 1.93 | .0138* | .0072 | .0034 |
| | Dial | 1.91 | .0092* | .0072* | .0020 | 1.[redacted] | .0069* | .0051* | .0021 | 1.92 | .0081* | .0020 | .0022 |
| .0035" | Ratchet | 3.66 | .0029 | .0023 | .0030 | 3.6[redacted] | .0[redacted] | .0065 | .0052 | 3.57 | .0220* | .0082 | .0080 |
| | Dial | 3.63 | .0057 | .0054 | .0033 | 3.6[redacted] | .00[redacted] | .0085 | .0044 | 3.66 | .0048 | .0075 | .0043 |

*Significant difference between areas [redacted]sheets as heading indicates

November 14, 1940

Turned over to Mr. Finch
12/4/40

Setting Tolerance Limits

S 16920

S 22021

| | Average out off by 40 ranges | Minimum percentage | MMax. | R |
|---|---|---|---|---|
| m = 1 | .9967 | .9923 | | |
| m = 30 | .9922 | .9624 | | |
| m = 100 | .9732 | .8186 | | |

Contrast $m\bar{X} \pm \sqrt{m}ts$ with $m\bar{X}' \pm \sqrt{m}3\sigma'$

# CONCLUSION

Statistics + Mass Production = New Tool of Peace

STATISTICAL THEORY PLUS MASS PRODUCTION PROVIDES A MEANS OF MAXIMIZING OUR PHYSICAL COMFORTS IN TIME OF PEACE AND OUR STRATEGIC FACTORS IN TIME OF WAR

About 175 present. Several from Buffalo and surrounding cities. Very active discussion.

The Application of Statistical Methods to Industrial Standardization and Quality Control by E. S. Pearson, published by the British Standards Institution, 1935.

Z1.1-1941, Guide for Quality Control
Z1.2-1941, Control Chart Method of Analyzing Data

Published by the American Standards Association.

An Engineer's Manual of Statistical Methods by L. E. Simon, published by John Wiley and Sons, 1941.