Reprinted from Sankhyā : The Indian Journal of Statistics, Series B, Vol. 29, Parts 3&4, 1967

QUALITY CONTROL FOR ECONOMIC GROWTH*

By P. C. MAHALANOBIS

India has large natural resources, and a large and rapidly increasing population which is still mostly underemployed. Rapid economic growth is essential not only for a steady improvement in the level of living but also for defence and national integration. Economic planning, initiated by Jawaharlal Nehru in 1951, laid the foundation for industrial growth and national advancement. With the progress of industrialisation, India, like all other countries, will have to purchase an increasing supply of goods and services from abroad, and must pay for the same through an increasing volume of exports.

It is necessary to make the best possible use of domestic resources for the manufacture of goods of high quality at low cost, substitute such domestic manufactures for imported goods, and sell such products abroad at competitive prices in the world market. This is the only way to overcome balance of payment difficulties, avoid further devaluation of the rupee, and attain self-sustaining growth.

Research and development (or briefly, R and D as it is usually called) is indispensable to invent improved methods and processes for the production of goods or services, of better quality, at lower cost. Statistical Quality Control (or briefly, SQC, or in a still more abbreviated form, QC) is indispensable for the most effective use of any given technological process or system of production. R and D, therefore, is not a substitute for SQC. Neither is SQC a substitute for R and D.

SQC helps in obtaining maximum benefits from the results of R and D, and sometimes also gives indication of the need for further R and D in industry. SQC and R and D are complementary ; and used in proper combination, are a powerful means of increasing productivity per person or per cent of capital engaged ; to do this is the task of management.

*Inaugural address at the Fourth All-India Conference on Statistical Quality Control organised by the Indian Statistical Institute, in Madras from the 7th to the 9th December, 1967.

ORIGIN OF SQC

The aim of SQC is to eliminate, to the largest extent possible, wastage of materials, of labour, and of machine capacity in the process of production, and to maintain the quality of the manufactured products at the desired high level.

The basic principles of SQC are simple, and can be easily appreciated from the origin of SQC. The Western Electric Co. of America, which manufacture the largest volume of telephone and associated equipment in the world, found in the early nineteen-twenties that a large proportion of their products was being rejected, at the stage of inspection, because of poor quality. Dr. Walter A. Shewhart, known as the 'father of SQC', was working at that time as a young research physicist in the Engineering Department (which was renamed in 1925 as the Bell Laboratories) of the Western Electric Co. In 1924 Walter Shewhart was asked to find out how the high proportion of rejections could be reduced. On the basis of his investigations he submitted a report in 1924 in which the method of SQC was described in a sufficiently developed form for use in actual practice. Shewhart subsequently gave a detailed exposition of the subject in his classical book called *Economic Control of Quality of Manufactured Product* which was published in 1931.

SPECIFICATION AND TOLERANCE LIMITS

Consider the case of a very simple manufactured product, namely, narrow rods of a desired length turned out by a machine tool. These rods must be of a suitable length to serve any given purpose, for example, as component parts of a particular equipment. Experience shows that however good may be the machinery, measurements of the length of the rods turned out would not be identical.* The length, as measured, varies from one rod to another. It is, therefore, necessary to specify the average length of the rod; and in addition, also the maximum length and the minimum length, or the permissible range of variation, that is, the tolerance limits, within which the rods would be acceptable as component parts of the given type of equipment. Any rod with a length falling outside the permissible range of variation (that is, outside the tolerance limits) would have to be rejected, and would have to be re-worked, or when this is not possible, would have to be treated as scrap, to be sold at a low price or used for less profitable purposes.

Exactly the same considerations would apply to each component of more complicated equipment. In every case, rejections would imply wastage of materials, of labour, of machine capacity, and also unproductive wear and tear, and unnecessary interest charges on capital engaged during the unproductive part of the work. In every case the aim must be to reduce the proportion of rejections. How this could be done in the case of equipment manufactured by Western Electric Co. was the problem which Shewhart started investigating in 1924.

* It may also be pointed out that repeated measurements of the length of the same piece of rod also would not be indentical but would vary from one measurement to another, usually, however, within narrow limits. All statistical methods, including SQC, are ultimately based on measurements or observations which are subject to variations.

Assignable or specific causes

In studying variations in the quality of products, such as the length of rods in the present example, Shewhart observed that there was a tendency for the length of successive rods produced to become shorter sometimes or longer sometimes or to change by a very large amount from time to time. In such cases it would be reasonable to think that some fault had developed in the machinery which would require adjustment. Shewhart made a significant contribution in classifying such variations as a special type which could be ascribed to "assignable causes", or specific factors or defects, and which could be identified and remedied in some suitable way. The first stage in SQC is to identify and remove such assignable causes.

First stage of control : residual variations

After the assignable or specific causes have been removed, successive rods, as turned out by the machinery, may have approximately the same average length, but individual rods would still have a residual variation in length due to chance or random fluctuations. The word 'chance' or the word 'random' does not explain any thing, but simply registers the fact that such variations have to be accepted as a part of the production process itself.

If the magnitude of the random variations is not much greater than the permissible range of variation, then the machinery would be 'under control', and would turn out rods or other products which would be initially acceptable. Experience, however, shows that in practice all machinery tend to develop, in time, specific defects which require adjustment. It is, therefore, necessary to keep a continuing watch to guard against the appearance of new defects. The second stage of SQC supplies, in the form of the "Shewhart Control Chart", an appropriate visual signalling system to serve this purpose.

Second stage : Shewhart control charts for danger signals

Shewhart made a second significant contribution in using the residual random variations of the products as a valid yard-stick to detect any future tendency of the machine to get out of order. He introduced, for this purpose, the concept of 'rational sub-groups of observations' which, for the time being, would supply the magnitude of the residual or random variations. On the basis of observations on such 'rational sub-groups', it is then possible, with the help of the theory of probability, to calculate the range of variation within which ninetyfive or ninetynine per cent (or any suitable fraction) of the observations, such as, length of rods, or physical dimensions of products, would be expected to fall. It is now possible to construct the 'Shewhart Control Chart' with three parallel lines, of which the one in the middle would represent the average value of the measurements, and the upper and the lower lines would represent, respectively, the limits within which, say, ninetynine per cent (or, a suitable fraction) of the future observations would lie. Estimates of range of variation, according to the theory of probability, would vary from one set of observations to another. If these estimates are plotted on a graph paper against time, one would get a band of fluctuating width.

Shewhart's third great contribution was to replace the estimates of range of variation of fluctuating width by an expected range of variation of constant width, within which an assigned proportion say, ninetynine per cent (or a suitable fraction) of future observations would lie. The chance would be one in hundred (or some other appropriate odds) that the length of a rod, as measured, would fall either above the upper control line, or below the lower control line. Any observation falling outside the control limits can be then treated as a danger signal that some specific or assignable defect might be developing in the machinery under operation. When this happens, it would be proper to take more frequent observations, and in case the danger signal is confirmed, to search for assignable or specific defects, and remedy them, if possible.

USER-ORIENTED CONTROLS

Shewhart started his investigations from the consumer-end of the products, and laid down certain principles of a basic nature. First, there must be clear and precise specification of the level of 'quality' of the product (often in terms of physical dimensions, like the length of rods, in our illustration ; or, in terms of non-quantitative assessments) which must be attained in order to serve the purpose of the user. In a quantitative form, specification would mean stating the desired average size, or the average physical dimensions, together with the permissible range of variation, that is, the tolerance limits in the form of the maximum permissible deviation from the average in two directions, one above and the other below the average. Secondly, appropriate arrangements must be made to manufacture the product in conformity to specifications. This is essentially a task for the production manager ; SQC helps by giving danger signals of possible deviations and defects. And, thirdly, appropriate programmes of (usually, sampling) inspection must be formulated to ascertain to what extent the manufactured products in practice conform to the given specifications. The focus of attention is on the quality of the products, on purposes for which the products would be used by the consumer, and on controls which would eliminate waste, and would lead to economic gains. Shewhart's aims were clearly indicated by him in the title of his classical book of 1931 as "Economic Control of Quality of Manufactured Product." It is worth pointing out that Shewhart had used the phrase "economic control" instead of "statistical control" in the title of his book. This distinction is important in indicating that the aim is economic gain which must ultimately decide how the statistical method, which is a means, should be used to attain the economic end.

SQC AND DESIGN OF EXPERIMENTS

It is possible to have a proper appreciation of Walter Shewhart's work if it is considered in the wider background of the advancement of statistical methods. Shewhart completed his work in 1924. In the course of 1922 and 1923, Ronald A. Fisher in England published his earliest papers on the powerful method of design of experiments and analysis of variance to deal with the results of agricultural field trials. These tools, one developed in connexion with agriculture and the other in connexion

with industry, were the two greatest contributions to statistics as a key technology after Karl Pearson's formulation of the Chi-square test in 1900.

The point to be stressed is that Fisher's design of experiments and Shewhart's control charts were both concerned with applications to practical problems in the world of reality as distinguished from the theory of logical and mathematical relations in the world of abstraction. Both methods used statistical variability as the yard-stick, to test the significance, in one case, of differences in the effect of treatments in agricultural field trials, and in the other case, of variations in the quality of manufactured products. Furthermore, design of experiments is an indispensable and powerful tool for R and D in industry.

SQC: EARLIEST EXAMPLE OF STATISTICAL CYBERNETICS

Shewhart made two significant contributions on the logical side. The mathematical theory of probability can deal adequately with a stationary system which retains its characteristics permanently. No machine in real life behaves in this way; the characteristics of the products always change over time. Shewhart recognised the essential need, as a first step, of eliminating "assignable causes" of variability in the manufactured products, which may be compared with Fisher's approach in eliminating the fertility gradient of the land in agricultural field trials. Secondly, Shewhart introduced the crucial concept of "rational sub-groups" of samples of items which are produced in such a short time that changes in the machine are likely to be small; and the variability within such rational sub-groups of samples may be expected to supply valid estimates of the inherent variability of the machine. Observed deviations from specifications, of a future sample, can be then assessed in terms of the estimated inherent variability to decide whether the machine was under control or required adjustment.

Shewhart provided a simple control chart consisting of a central line of average specification, and two parallel lines of fixed interval, as control limits, within which any assigned percentage of observed average values in future samples would be expected to lie, so long as the machine is under control. The need of adjustment would be immediately indicated, without further statistical analysis, when a sample observation falls outside the control limits. The Shewhart Control Chart is, I believe, the earliest example of a feed-back or a Cybernetic System based on statistical principles.

HOMAGE TO THE MEMORY OF WALTER SHEWHART

I have dwelt on the contributions of Walter Shewhart himself in such detail on this occasion for three reasons. First, because he had laid the foundations of Quality Control single-handed and yet in a practically complete form. Secondly, because he had organized the first All-India Conference on Statistical Methods in Industry nearly twenty years ago in February 1948 which gave the first impetus to SQC in India; and thirdly also because he had continued throughout his life to take a deep personal interest in the progress of SQC in India, and in the affairs of the Indian Statistical Institute. Walter Shewhart was born on 18 March 1891; he died on 11 March 1967. It is proper, on this occasion, to pay our homage to his memory.

STATISTICAL QUALITY CONTROL IN AMERICA

It will be useful to make a brief review of developments of SQC in three countries : America where it had originated, Japan where it has made the greatest progress, and India because of our special interest.

I have already mentioned that SQC was first formulated in a form ready for practical use in a report submitted by Walter Shewhart to the Western Electric Co. in 1924. Progress in the beginning was very slow even in America. Shewhart's classical book on "Economic Control of Quality of Manufactured Product" was published in 1931. A little later Shewhart gave a series of lectures on SQC in London at the invitation of the British Standards Institution. Very slowly SQC began to be used in Great Britain and other countries.

In America a spectacular advance began during the Second World War, round about 1940, owing to urgent needs of expanding defence production. The work had to be organised very quickly, on a very large scale, with great decentralisation of the manufacture of a large number of component parts, and fitting together of these parts, at a later stage, sometimes in different places. It was essential that the components should fall within their respective tolerance limits. Components falling outside the tolerance limits could not be used, or if used, would lead to a high proportion of rejections at other stages of assembly. Such rejections would be not only wasteful of material and labour resources but, what could be even more disastrous, would slow down the war production.

During his original investigations in 1924, Walter A. Shewhart and Harold F. Dodge, a colleague from the Bell Laboratories, had found that 100% inspection of products was less effective than the inspection of a small fraction taken out in the form of random samples. For war production in America, 100% inspection was simply not feasible because there were not enough experienced inspectors to undertake such a task. The Federal Government was, therefore, forced to adopt sampling inspection. In 1941 and 1942 a small number of universities and institutions arranged courses in SQC with Government support. A little later, the War Production Board began to organise short training courses, on a very large scale, in different parts of the country. By the summer of 1945, over 8000 persons from industrial establishments had received SQC training, averaging 57 hours of instruction per course, in institutions of higher education; some thousands more had received training at a less technical level in courses given by their own companies. Similar courses continued to be given later in educational institutions and also in factories.

After the war, SQC began to be used on an increasing scale in non-military production in America, to improve the quality and to lower the cost of production. The large scale of SQC activities may be easily appreciated from the fact that the number of members of the American Society for Quality Control was about 20,000 about a year ago, and must be many more now. America's achievements in war production and rapid industrial progress after the war would not have been possible without the widespread use of SQC. The points to be noted are that a large

scale training programme, involving thousands of trainees, was an essential first step in promoting SQC in America. Also that the SQC movement in America is being sustained, continually, by large scale training and educational programmes, journals, conferences etc., bringing about the active participation of many thousands of people.

Statistical quality control in japan

I should now like to refer briefly to developments in Japan. During the war the Japanese economy was completely disrupted, and Japan was in desparate conditions. The first task, immediately after the war, was to restore industrial production. Before the war, Japan had become known as exporters of extremely cheap goods of very poor quality. After the war, the Japanese Government and industrialists had the wisdom to recognise that Japan could not get a hold on foreign markets on the basis of its old image of cheap exports of poor quality. For survival, Japan reversed its old policy, and decided to establish a new image and reputation for exports of high quality at low prices.

SQC was the ideal tool for this purpose. In 1950, through the efforts of Dr. Edward Deming, the SQC approach was introduced in Japan, and was taken up enthusiastically by engineers and plant managers at the operating end in the factory, and, also, by top management in the country. In all, 500 qualified engineers attended 8-days courses in 1950; hundreds more attended every year thereafter. A large scale training programme was the first step to secure several thousands of persons with a working knowledge of SQC. Such trained personnel began to be employed in large numbers in an increasing number of industries. By 1960, in the course of 10 years or so, the proportion of industrial enterprises using SQC and associated methods had become larger in Japan than that in America or in any other country of the world. Also, among enterprises which used SQC, a larger proportion of products were covered by SQC in Japan in comparison with America. There was a spectacular improvement in quality, coupled with an appreciable reduction in the cost of production, of Japanese manufactures, which made it possible for Japan to enter the world market on competitive terms and become a major exporting country in a very short time.

Training of SQC personnel is essential but not enough. Japan has shown that it is necessary and posssible to make SQC a truly mass movement. Dr. K. Ishikawa of the Tokyo University has given in his paper on "Quality Control in Japan" an illuminating account of the educational and promotional programmes in Japan and has referred to :—training courses at various levels; research meetings in scientific institutions, discussions in small local QC circles of factory workers; lectures; seminars; conferences; publication of books; articles in journals and magazines; and wider programmes for the public. In 1967 there were 11,000 registered, and 60,000 unregistered, QC circles in factories. In October 1967, about 40,000 copies were printed of the monthly magazine "Gembato-QC", or, "QC for the Foreman". QC education courses were overfilled with applications. In November 1967, attendance at All-Japan Conferences on QC were very large; 220 for Top Management; 1600 for Middle Management and QC Staff; and 2500 at the Conference for Foremen. The "National

Quality Month" was started in November 1960, and since then has been observed every year in November for wide participation of the general public in the QC movement.

It is only because of the colossal scale of organization of educational and promotional programmes, and also the involvement of the general public on a large scale, that QC has developed, and is gaining in strength, in Japan more than in any other country of the world, and is bringing about a continuing improvement of quality, and lowering of cost, of Japanese goods in both domestic and export markets. The wide-spread and increasing use of SQC and associated methods has been an important factor in the phenomenal rate of economic growth of 9 or 10 per cent per year, or doubling of the national product roughly in seven or eight years, which Japan has achieved during the last 12 or 15 years. Per capita income and the level of living in Japan had fallen very low immediately after the war. In the course of 20 years, the per capita income in Japan has increased, roughly, four times. During the same period, per capita national income in India increased by less than 20 per cent. The level of living in Japan is rising very much faster than that in India.

STATISTICAL QUALITY CONTROL IN INDIA

I may now recall briefly the history of SQC in India. Having read a note in *Nature* about Walter Shewhart's lectures on Quality Control in London in 1931, I obtained from America a copy of his book on this subject which had been published in 1931. I was so deeply impressed by his achievements that I submitted, I believe, in 1935, a note to Sir Frank Noyce, then Member of the Viceroy's Executive Council, on the need of using SQC and associated methods in India. In 1942 I again wrote to the Government of India pointing out the advantages of using SQC in war production. Time was not yet ripe.

Professor A. V. Hill, then Secretary of the Royal Society, came to India in 1944 to give advice on the organisation of scientific research. On his recommendation the Council of Scientific and Industrial Research (C.S.I.R.) appointed a Committee on Statistics, Standards, and Quality Control of which I was Chairman. This Committee met on 3 or 4 occasions. It was decided to prepare an introductory pamphlet. A special course of training in SQC, the first of its kind in India, was given in the Indian Statistical Institute in 1945-46. The course lasted for several weeks and was attended by 12 persons. Practically nothing else happened. Statisticians had no contact with industry. Industrialists were making large profits and were not interested in Quality Control.

In 1946, during my first visit to the U.S.A., I met Walter Shewhart 'the father of SQC', and Edward Deming, who was greatly interested in SQC and who helped later in promoting SQC methods in a significant way in Japan. Deming made a short visit to India and did some pioneering work. Walter Shewhart came to India, as a guest of the Indian Statistical Institute, on the first occasion for three months, in the winter of 1947-48; and initiated the SQC movement through visits to factories, personal discussions, lectures etc. He was the prime mover in organizing a one-week Conference on Standardisation and Industrial Statistics in Calcutta, February 8 to

14, 1948. About 190 persons, including representatives of industrial management, engineers, Government officers, statisticians etc., attended this conference from different parts of India. Shewhart also helped in establishing the Indian Society for Quality Control in 1947, and gave an impetus to the work of the Indian Standards Institution which had been started a little earlier. He visited India, as a guest of the Institute, on three subsequent occasions.

Progress was slow. A team of SQC experts from abroad came to India in 1952 in a joint project sponsored by United Nations and the Government of India. On the recommendation of the C.S.I.R., one small SQC Unit was established by the Indian Statistical Institute in Bombay in 1953. To give an authoritative lead, the Government of India established in 1954 the SQC Policy Advisory Committee under the Chairmanship of Shri C. D. Deshmukh, then Cabinet Minister of Finance of India, who had been taking a keen interest in SQC since Shewhart's first visit to India in 1947-1948, and who continued to be the Chairman of this Committee for about ten years. Shri Pitambar Pant, now Member of the Planning Commission, was the Secretary of the SQC Policy Advisory Committee for a long time, and helped in promoting SQC in India in many significant ways. Shri S. C. Sen, Joint Secretary of the Indian Statistical Institute, supplied the driving force to the SQC activities of the Institute until his death in 1964.

On the recommendation of the SQC Policy Advisory Committee, 9 operating units for SQC were gradually established, under the sponsorship of the Indian Statistical Institute, at Bangalore, Baroda, Bombay, Calcutta, Coimbatore, Delhi, Ernakulam, Madras, and Trivandrum; a special unit is also working at headquarters since 1964 for training and promotional work. The activities of SQC units consist of training and consultancy service within the factory; organisation of conferences, seminars and lectures; and the publication of technical and expository literature. Three All-India conferences were organised, the first one, on the initiative of Walter Shewhart, in Calcutta in February 1948; the second in January 1954; and the third, sponsored jointly by the Productivity Council and the Indian Statistical Institute, in Calcutta in December 1958. This present conference in Madras in December 1967 is the fourth one in the series.

Perhaps the most important part of the activities has been the organisation of training programmes of various types, from short-term courses of a few days up to a post-graduate Diploma Course in Quality Control. About 130 training courses of various types have been organised between 1953 and 1967, and a total of about 3000 persons have attended such courses; out of them about 80 persons have been trained in the post-graduate Diploma Course at a professional level.

The SQC units have also helped in establishing SQC methods in 200 industrial organisations, mostly in the private sector, and are at present giving professional services to over 70 plants covering a wide range of industries; such as, light and heavy engineering, chemicals, electrical, textiles, paper, cement, iron and steel, mining etc.

The Indian Statistical Institute has been instrumental in securing the help of foreign specialists from other countries, among whom were Dr. Walter A. Shewhart, Dr. Edward Deming, Professor E. R. Ott, Professor Knowler, and Dr. W. R. Pabst,

(U.S.A.); Dr. G. Taguchi and Professor M. Masuyama (Japan); Professor G. A. Barnard and Mr. D. J. Desmond (U.K.); Professor A. Linder (Switzerland) and Professor Hald (Denmark). The foreign specialists have helped very much in promoting SQC by transferring their know-how to India.

Interest in the use of SQC and associated methods in industry is increasing generally, and to a larger extent in the private sector, in India. Every year a number of enterprises are establishing SQC and statistical units of their own. Outside the Indian Statistical Institute, individual SQC consultants have started providing advisory services on payment of fees. SQC and statistical methods are receiving more attention in connexion with training for management. These are hopeful signs but progress made so far is not adequate. In a planned economy, with high protection and a sellers' market, it is necessary that Government should give large scale support for the promotion of SQC in every possible way.

CONCLUSION

Attempts were made in India much earlier than in Japan to introduce SQC. The first log-rolling had started in 1935, however, without any success. The first training courses in SQC were organised in India in 1944-45, only about 3 years later than the first courses given in America, but 5 years earlier than the first courses in Japan. There was rapid growth of QC in America from about 1940, and a spectacular explosion in Japan from roughly 1950; but progress was very slow in India. However, it is of interest to note in this connexion that in America, by 1945, over 8000 persons were given SQC training in higher educational institutions and several thousands in their own factories ; possibly fifteen or sixteen thousand persons were trained in order that SQC could set off in America. In Japan, from 1950, several thousands of persons were trained in higher educational institutions and many others in other places. The number of trained personnel required to get SQC off the ground was probably of the same order of fifteen or sixteen thousand in both America and Japan. In India only about 3000 were trained up to this year through the efforts of the Indian Statistical Institute. If other training courses are included this number possibly would not exceed 3500. The number trained in India is still very small in comparison with Japan and America and has not, evidently, reached the critical level for a rapid development of SQC.

There is a second aspect. In America there is continuing participation in SQC discussions, meetings, publications etc. by a very large number of persons ; the size of membership of 21,000 or more, of the American Society for Quality Control is one index. In Japan the involvement is much wider as indicated by an attendance of 2,500 persons in a QC Conference for the Foreman, or a circulation of 40,000 copies of the 'QC-Journal for the Foreman', and also by even wider participation by the general public in the National Quality Month which is being celebrated in November every year since 1960.

India is completely lacking in large scale participation of the above type. And yet India is in much greater need of SQC than either Japan or America. For rapid progress of SQC in India, training programmes and promotional activities must be organized on a scale comparable with that of Japan or America. India must make this effort for survival.