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IMPROVING PRODUCT QUALITY IN SMALL INDUSTRIES IN DEVELOPING COUNTRIES[1]

by

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quality product requires that it is made that way. There are several other advantages.

Obviously if the product is made with more than 95% good, then outgoing quality will be better than the product considered above. In fact, if it is known that the "as made" quality is satisfactory, no further inspection is required at all. This would completely eliminate all scrap and re-work becsuse none would be sought. However this happy situation never arises completely and there is always some doubt as to the actual quality made. Further there can be long periods during which the product is made to a satisfactory quality, but, for no apparent reason, it deteriorates from, say, 2% defectives to 10% or more and this can continue for several hours or even days. The object of quality control is to detect such changes in a minimum of time.

In many cases, the customer is another part of the same firm where the components are assembled to make the products. If all components are made to the specification, then they can always be assembled and this is still true if the components have been sorted by 100% inspection. However, the ease of assembly and the time taken will depend upon the actual sizes of the components <u>inside</u> the specification. If there are many near the top limit, producing a tight fit, then assembly takes longer and this will occur with a batch originally containing 5% or more defectives. At the other extreme, loose fits from components near bottom limits are inclined to have inferior performance or life, or both. This is now defined as inferior reliability and is characteristic of the assembly of batches which have been required to be screened because they are not good enough as made.

Better quality "as made" is therefore associated with reduced inspection requirements and easier assembly. However it is not known in advance just how good the quality is, so some inspection is always required to estimate this quality as well as give customer protection. The former aspect is greatly influenced by other knowledge particularly the measurement of quality previously obtained by the same process working under what are believed to be the same technical conditions.

Typical figures quoted in the UK show that costs due to inspection and quality failures amount to about 7% of the gross turnover with another ½% spent on creating and controlling quality. However, when this effort is doubled to cost 1%, it has the effect of reducing inspection and failure costs to about 4%. The net saving of 2½% of gross turnover applies to the quality obtainable from existing resources without any substantial technical changes in operation. It is likely that somewhat larger savings would result from similar methods in small companies.

There will be situations where the available facilities are still inadequate to produce a quality acceptable to the market without a sorting process. This occurs in a factory making glass containers where 85% good product is considered commercially satisfactory although 15% defectives cannot be passed straight into the market. Here sorting is regarded as part of the production process but an efficient glassworks will establish controls to ensure that defective bottles are not produced at a rate exceeding 15% for any extended period. It is so easy to permit quality to slide when there are always so many defectives. This 85% output can be used for planning to estimate delivery dates and costing to be competitive in tendering. Any deterioration will delay delivery, increase costs (loss on a contract) and run a greater risk that excessive defectives are delivered to customers despite the sorting.

3 Definition of Quality

The quality of a product can be defined as the degree with which it satisfies the purpose for which it is intended. It starts with design which establishes the level of performance required and this applies to every item. However there are differences from unit to unit so that some will be found to satisfy the purpose while others will not. For example, a ceiling fan is designed to rotate at a speed of at least 180 rpm. However, the variation from fan to fan amounted to ±12 rpm so that the worst had a speed of only 174 rpm even when nothing had gone wrong. About one fan in 16 failed to rotate at the minimum specified speed and hence they could be said to be of inferior quality. Nevertheless they still circulated the air round the room so they still possessed some quality as ceiling fans and it is difficult to state how much lower their value is because of the inferior performance.

On the other hand, the best fan would rotate at 198 rpm which is much better than the required specification. About one fan in six would have speeds in excess of 190 rpm and again it is difficult to state how much higher value they have. It is quite certain that the customer would not be prepared to pay more when the specified value is 180 rpm. The company has to decide what the quality level should be, how it should be interpreted and then how it should be designed to give that quality. These are all related to cost and generally management must decide what market it is trying to attract, how large that market is, what proportion it will obtain and, thus, the level of manufacture. This decides methods which can be employed with subsequent effect on quality and cost. There is then a relationship between selling price and share of market leading round the whole cycle again. All this depends upon compliance with the design quality; any failure to do so will affect everything so we are naturally led to the more important quality of conformance.

As another example, an automobile is basically a device for conveying people from one place to another but the speed, comfort and safety with which this can be accomplished depends upon the quality designed into the product. Other factors of economy, capacity, manoeuvrability, ease of parking, noise, etc. are also important design features. A luxury limousine will be much more expensive than a "People's car" and will certainly be regarded as being of higher quality. Some customers are prepared to pay the additional cost,so much so that in the UK the most expensive car costs 30 times as much as the cheapest. However it does not mean that its quality is 30 times as high. In fact, it is almost impossible to give a quantitative comparison of their qualities. Such relative values of quality are purely subjective and they will be influenced to a large extent by the confidence that actual manufacture will conform to the design. There can be no certainty that the most expensive product will conform to its own design as well as the least expensive.

The description of any product gives some definition of its quality but it is well known that different examples of the same product are of different qualities. This variation gives rise to ideas of product performance for which minimum values may be specified in National Standards and other ways - ceiling fan to rotate at a minimum of 180 rpm. Thus the customer is able to purchase a product with a specified performance which may extend to a large number of characteristics including appearance and other subjective features such as taste, smell.

The reliability of a product is another aspect of its quality. Although there are complex mathematical definitions, it can be thought of as a measure of the maintenance of performance throughout life. Most products are subject to wear and require regular servicing to maintain an acceptable performance. This is obvious for complex products like aircraft but it is also necessary for commonplace products like garments. The ease with which the servicing can be carried out and the availability of spares and other materials to enable it to be accomplished have a profound effect on overall product quality.

The quality performance of the final product depends upon the quality of the components and materials from which it is constructed. These also require to have their quality performance specified. Materials usually have minimum (or maximum) values of various physical and/or chemical properties specified and these must be verified by small samples.

The quality of components is specified by a number of dimensional sizes usually shown on a drawing with tolerances which have been chosen so that the product can always be assembled and will function satisfactorily if all components satisfy their specified limits. Product quality then depends upon component quality but it often happens that unnecessarily tight tolerances are specified for components to make sure. This causes more expensive manufacturing processes to be used or 100% inspection to sort "good" from "bad". However it is not generally known how far and how frequently these tight limits can be violated without detrimental effect on the final product. This is another problem to be investigated by quality control methods.

It is not sufficient to specify qualities of materials and components and performances of products. It is also necessary that actual production conforms with these qualities and performances. This can only happen if the methods used for manufacture are capable of producing the desired quality and that technical control is maintained to ensure that these methods are operated as planned. These features are the quality of conformance which is evaluated by quality control techniques discussed in the following sections.

4 Methods to Improve Quality

Quality can only be obtained from technology. This is true even in the craft industries where technology has to be defined as the ability to repeat methods time and time again on materials with constant physical characteristics. In practice, completely uniform material is never obtained, neither is it possible to have exact repetition of any process. A super craftsman would be able to predict how the material will vary before he processes it and automatically he makes adjustments to his methods so as to balance the effect of the variable material. This is an impossible task but some degree of balance is achieved and the ultimate uniformity is a measure of the craftsman's skill.

Variation is particularly true of "natural" materials but modern technology has developed methods to produce a more uniform material to enable standard processes to be used in later stages of manufacture. For example, there is enormous variability among the individual fibres of cotton. The preparatory processes are designed to blend these fibres and produce laps and then slivers which are proportionally much more uniform. The doubling and spinning processes continue this blending so that ultimately each square centimetre of a piece of woven cloth is very similar to every other square centimetre even though a microscopic examination would reveal the original variation from fibre to fibre.

The obvious way to improve the quality of a product is to improve the technology used in the manufacture. This could be achieved by better methods or more efficient use of current methods. An initial step must consist of evaluating the efficiency of existing methods. This is best done by measuring the quality of the output over a sufficiently long period so that all normal variation has an opportunity to occur. Analysis of the data then shows whether it is stable, relative to its own measured variation, or not. If it is stable, then improved quality will require better technology, but otherwise some improvement can be obtained by better utilisation of existing methods.

Technical improvements usually incur capital expense and this is likely to involve foreign currency difficulties in developing countries. All efforts should be made first to ensure that the best use is being made of current plant before ordering new. Further, estimates should be made of the period over which the best use of current plant will continue to provide sufficiently high quality to satisfy the market. It often happens that although existing quality does not satisfy the market, a proper quality control plan would enable present resources to do so for a few more years. There is an example of a cotton mill in South India which was interested in re-equipping its spinning shed because efficiency was 12% lower than the standard expected for the frames being used and count being spun. It is well known that spinning efficiency is positively correlated with yarn quality, so improved quality would also result from increased efficiency. It was estimated that new foreign plant would save the 12% loss but it involved scarce currency with a delay of several months for delivery.

A provisional order was placed and at the same time a study of the losses was initiated. This showed that most of the variation occurred from time to time rather than from frame to frame and that the observed variation was too large to occur by chance. A quality control plan was introduced to reduce the incidence of unstable operation and this had the effect of increasing the efficiency by 14% over a period of six months.

A similar study was carried out in the weaving shed of a jute mill and in this case there was so much variation from loom to loom that it was not possible to detect time to time variation. The study was based on quality control interpretation of activity sampling. The results of one section were:

looms	number	stoppages in 30 rounds	estimated efficiency
"good"	47	323	77.1%
"bad"	3	49	45.5%
total	50	372	75.2%

The three bad looms were overhauled to bring their efficiencies up to the remainder of the group and a repeat study then showed a slight improvement in the overall shop performance to 77.5% efficiency. An increased output of better quality cloth was obtained from the same plant by overhauling only 6% of it. Very little extra improvement would have been obtained by overhauling every loom. Six "intermediate" ones had an average estimated efficiency of 65.6% and these same looms gave the higher estimate of 76.7% in the second study without any technical change in their operation at all.

This example has been quoted to illustrate how productivity and quality are improved by the selective overhaul of plant. This can be regarded as a technical change without any great capital expense. However it does use, in developing countries, scarce skilled labour so the importance of choosing the right plant for overhaul cannot be over emphasised.

This study was part of the initial investigation to determine the quality standard for the loom shed before setting up a routine quality control system. The standard was provisionally set at 77.5% and the object was to maintain the efficiency at this level. Maintenance of quality is just as important as improvement.

Improved quality is often obtained in industrialised countries by using completely new methods but these are based on extensive Research and Development programmes quite beyond the scope of small industries in developing countries. Mostly the impetus for such improved processes comes from the desire to save expensive manpower and again this is not a usual problem in developing countries. Nevertheless, it may be economic for some small firms to operate new and improved methods especially when they have technical collaboration agreements. The decision should be made from a study of the economics of the situation; it should not be a matter of prestige.

The obvious remedies for poor quality are new or improved plant, better materials or methods but these are not necessarily the solutions even in large organisations. If new plant is operated as badly as the old, improvements in quality and efficiency will not be as large as they could be by working the old plant as well as possible. Further, the initial improvements obtained with the new plant would not be maintained. This leads naturally to the alternative, but not exclusive, method of improving quality by better management.

Detailed objectives of better management are different in industrialised and developing countries. Both are concerned with higher efficiency, but cost and labour productivity are predominant in the former group. Plant and material utilisation (productivity) are much more important in developing countries. Cost, of course, is also important but a good case can be made for subsidising labour costs - this is discussed in Section 6.

The fundamentals of good quality management are not difficult. First, the operator must know what is required and given facilities to enable him to perform the task. Then he must have sufficient training so that he understands what he has to do and he is capable of doing it. Next the materials he uses must be available in sufficient quantity at the time they are required and there must be simple means of disposing of the finished work without damage. The workplace must be well lit, heated (or cooled), ventilated with sufficient space to move with heights and distances arranged to enable him to continue for the whole of the work period without undue fatique. It should be kept clean and free from accident hazards such as fire from cotton waste.

The required quality must be specified on a document (which is often a drawing) with facilities to measure the quality actually produced in the same units. Ideally this should be done immediately after the item has been processed either by the operator or by an inspector who makes his observations available to the operator. The operator must understand that he is responsible for the quality he produces even if somebody else measures it.

Consistent high quality is impossible without paying due regard to the factors given above. However they do raise a number of queries which are soluable by quality control methods. The major query is concerned with the relationship between the specification and process capability. Initially it is assumed that the specification is correct and inviolable. Processes are chosen which are believed can satisfy the required specification economically and then it is necessary to measure their capability to do so. This involves making many items and measuring their quality and interpretation of the results. Somebody in management must be capable of this interpretation objectively and then decide whether the process matches the specification. If it does, production can proceed as long as it is controlled but otherwise either the process or specification must be changed. In many cases it is the latter and the easement of pressure on the process operator often has the effect of improving quality although not to such an extent that the initial specification would be satisfied.

Changed processes may consist of altering operating conditions (temperature, pressure, speed, etc.) or adding further operations (sorting) or working with different (more uniform) materials or adding jigs and fixtures to prevent errors or a complete change such as was considered above under technical improvements. The decision as to what change is likely to be most beneficial, taking account of economic factore, will be determined from technical considerations but the magnitude of the improvement can usually be gauged only by interpretation of observations leading once again to the use of quality control techniques.

5 Measurement of Quality

The simplest measurement of quality of an individual item is merely to inspect it to decide whether it possesses the required attributes or not. For example, the major requirement of a bucket is that it should hold water without leaking. If this is satisfied it is acceptable but if it leaks, no matter how slowly, it is defective. There can be little doubt about the accuracy of this measurement and it suffices for a particular bucket. The user is only concerned with his bucket.

The manufacturer is more concerned with the quality of all his buckets and he cannot deduce that all are satisfactory just because the first one is. Conversely he should not adjust all his processes whenever he finds one that leaks. His decision must arise from consideration of the inspection of many items and he must distinguish between the quality of an individual bucket and that of the product as a whole.

Suppose he finds that over a period there are 2% leaking buckets and he cannot detect any differences in the way the buckets were made over the whole period. Then the occurrence of a leaking bucket is a matter of chance arising from an unpredictable combination of conditions all coming within the normal range of variation in manufacture. The operator has not made a defective deliberately, nor even by allowing his attention to wander; he is trying just as hard to make good buckets when the defective occurs. Clearly the quality of the product cannot be judged by measurement of one unit.

Since the defectives occur at random, it is quite possible for there to be runs of 100 acceptable buckets (frequently) and even 230 about once in 100 runs. These would not imply any improvement in quality any more than finding 2 leakers out of 8 proves the quality is worse.

The measurement of product quality by counting attributes is therefore subject to large sampling errors and it is necessary to inspect large numbers to obtain reliable estimates. Somewhat smaller numbers will suffice if the standard quality is poor, say 20% defective. The essential quantity is the total number of defectives in all the samples.

The bucket is also subject to other defects, capacity, weight, dimensions, dents, surface scratches, etc, any one of which makes it defective although it is still marketable. The overall quality can be measured by the total number of these defects. Sometimes they are classified as major, minor or incidental with a combination of these to give a demerit score as a measure of quality.

Counting of defects also measures quality in products made continuously such as woven cloth or enamelled wire. It can be quoted as the number of defects per square metre even though the samples may consist of much smaller areas. The sampling errors associated with counting defectives still apply to the counting of defects but,as the numbers are usually larger, the effect is not so important. Again the important quantity is the total number of defects over all the samples providing the variation follows a random pattern.

Verification of product quality requires much less measurement. For example, if it has been established earlier that the normal quality is 2% defective, then a sample of 10 units without any defectives confirms it. It is also confirmed if the sample contains 2 defectives. 20% in the small sample verifies 2% in the product! This is dealt with in considerable detail in Section 7 under quality control.

Many products, particularly engineering pieceparts, are designated as effective or defective when it would be possible to measure the actual size. This is done after checking with Go No-Go gauges which are very simple to use but it is important that their accuracy is checked frequently. Their use implies that, if a component has all its dimensions inside the tolerance, it is perfect, but if any dimension is outside the limits then the component is useless. This has already been mentioned in Section 3 with some doubt as to its validity.

It is common practice for the "first-off" to be checked with such gauges by a competent inspector and, after his clearance, the job is allowed to run subject to periodic sampling checks with the same gauges by the inspector or by the operator. This cannot guarantee that all the pieceparts comply with the drawing and a "small" percentage of defectives is usually accepted. Although "small" is not properly defined, it does imply that the degree of defectiveness will also be small and the incorrectly sized components will have no practical detrimental effect on the quality of the ultimate product.

It would certainly be better to measure actual sizes to know what margin exists inside the tolerance and such measurements also give estimates of the dispersion among component sizes. Simple dimensions like the diameter of a bolt may be measured with a micrometer but unless the component is an exact circular cylinder, there could be variations due to ovality and taper apart from errors introduced by the way the observer uses the instrument. These should be small relative to the tolerance but this is not necessarily true. Examples can be quoted where random errors of measurement can exceed the tolerance occasionally.

The choice of measuring instrument will be influenced by the tolerance and the speed with which observations can be made. There is little point in measuring a diameter as 0.7497" when the drawing limits are 0.745" - 0.755". In general the unit of measurement should be between 5% and 10% of the tolerance. If this diameter is measured to the nearest 0.001", a recorded value of 0.755" means that the observer believes that the true value lies between 0.7545" and 0.7555"; the upper part of this is outside the limits although the piecepart would be accepted.

An entirely different kind of quality measurement occurs in determining the physical and chemical properties of materials such as steel, moulding powders, rubber, jute, etc. These will be delivered to an agreed specification and will require that a sample be analysed or tested. The sample will consist of a few grammes to represent the whole consignment; it is impossible to test every gramme. There are approved methods of selecting such samples to give a good estimate of the average quality but they do not measure the variability in the material over the whole consignment. The material is never used in the same way that the sample is selected so variability in the material appears in the ultimate product.

A small user can never determine accurately the properties of the material he uses and he seldom knows how variation in these properties affects the quality he produces. His best protection comes from the purchase of material supplied under a Certification Mark scheme operated and licensed by the National Standards Institution. This is discussed in some detail in Section 10.

6 Quality in Developing Countries

Quality problems in developing countries stem primarily from the low level of education among the bulk of the population. This is associated with a low standard of living and no massive demand for goods and services which would permit the use of advanced technical methods of production. Since such methods have been developed in industrialised countries with labour shortages, they have often concentrated on automatic and semi-automatic machines with jigs and fixtures in labour saving devices. All of these tend to produce greater uniformity as long as they are correctly adjusted and hence better quality is obtainable. These adjustments require highly skilled labour with long and expensive set ups so that advanced methods are only economic with long runs. When such a machine goes out of adjustment, the quality of the product deteriorates rapidly and can be detected with very simple inspection and quality control procedures. This is very necessary to avoid making excessive scrap.

Many firms in industrialised countries who have automatic machines also use many simple machines for the same purpose because of their flexibility especially when small quantities have to be produced. Despite increased labour costs, this is the cheapest method of manufacture but the quality produced will not be so uniform. Also when a simple machine goes out of adjustment, the quality deterioration will not be so great making it of less importance but more difficult to detect. The best firms in industrialised countries use quality control schemes to detect these changes in a minimum time. The simplest procedures are not suitable for this purpose but developments of the control chart technique first proposed by Shewart in 1924 can be very valuable. These are given in Section 6.2.

There are two main reasons why developing countries do not use the most modern automatic machines. These would not be economic with the required quantities and there is no object in saving unskilled labour when it is very plentiful. Shortages of foreign currency and of skilled labour for setting up are contributory causes but they can be overcome for a limited part of industry in which advanced automatic plant has to be used to obtain the required quality. When this is done, it is important that the plant is used efficiently. An example from an engineering firm in a developing country working with technical co-operation from a large British company will illustrate this.

It was required to make a pin to a tolerance of 1.00 ± 005 mm and a watchmaking automatic lathe was available for this purpose. Measurements of the capability of the machine showed that it could hold an overall tolerance of 0.006 mm with perfect material. A study of the components actually made showed a variation of 0.038 mm which could have been reduced to 0.031 mm with a sound quality control scheme. The difficulty arose from the use of indigenous material which was very variable but the best available without further expenditure of foreign currency. Management was inclined to blame the setter for the rejects and he spent most of his time on the impossible task of balancing the material changes, just before they occurred, by setting adjustments. The result was a dispersion of 0.036 mm as quoted above; this corresponds to 40% defectives. The best he could have done with the available material was 32% defective but there would have been practically zero if material had been imported from a suitable source. As the defectives are produced at random, they have to be removed by a sorting operation. The machine downtime for setting was over 60% to give a useful output of about only 20% of that planned when the machine was purchased.

Apart from the rare use of highly advanced technical plant, there is quite a range of simple to intermediate technologies available to developing countries which are suitable to use with their size of market. Generally as technology becomes more sophisticated it requires:

larger capital investment
more accurate tooling
more skilled labour to set up
longer set up times
long runs to balance high set up costs
more frequent monitoring of operating conditions and product quality

but less operator skill and attention. Fixed costs per unit are minimised but total costs are greatly dependent upon run quantity.

Consider the manufacture of a small phenolic moulding. This can be made one at a time on a simple mechanical press or in multi-impression tools on a hydraulic press with an automatic timer. The latter method is capable of better quality at lower costs for large enough batch quantities as long as operating conditions are set and maintained at optimum levels. These include:

temperature distribution
over the tools
pressure
cure time
breathe time
pellet weight

together with accuracy in making all tools alike.

Optimum operating conditions can be determined from industrial experimentation on the shop floor. This will also give the range of levels which can be permitted without substantial worsening of quality. These must be matched against technical possibilities in the firm. It is useless to know that the optimum cure temperature is 157°C unless it is also known how far it can depart from this without detriment. If it is also known that a tolerance of ±7°C can be permitted, there must still be technical facilities - measurement, thermostats, etc. - to ensure it is obtained. The figures quoted are within the capability of any reasonable moulding shop, but, if the tolerance had been ±1°C, then the necessary controls would be beyond the scope of the small firms for which this paper is prepared.

Statisticians can be trained to design and interpret the necessary experiments over a wide range of industries. The success of their efforts will depend upon the co-operation they receive from the technical personnel. Training of the statisticians and the way they can help industry in developing countries is discussed in Section 11 under Assistance.

The simple mechanical press will require an operator to load the correct quantity of powder into the mould and maintain specified temperatures and pressures. These will not be as simple to achieve as in a large hydraulic press but there is likely to be more latitude. However there is great dependence on the human factor and a larger proportion of defective mouldings must be expected from time to time. After unloading, each item must be inspected and this is best done by the operator while he is handling the piece. It would require accurate work measurement and strict adherence to a standard work pattern for him to look after two such presses without loss of output and certainly when there is surplus manpower, it is not desirable to do so. There should be plenty of time for the necessary inspection.

Comparison of the two methods shows that the hydraulic press involves much greater capital expense and its six impression tool will cost more than six times as much as the simple tooling in the mechanical press. It will also require more skilled labour to set up but the operator can be quite unskilled and it is easy for him to look after two such presses to produce about 14 times the output per manhour. Further the product will normally be of better quality although if anything does go wrong, there will be a lot of expensive scrap. Inspection by the operator as he unloads will show up any defectives produced but it will not indicate whether there should be other technical action or not. In particular, one impression may become faulty to make a scrap moulding in every lift. Management must then decide to:

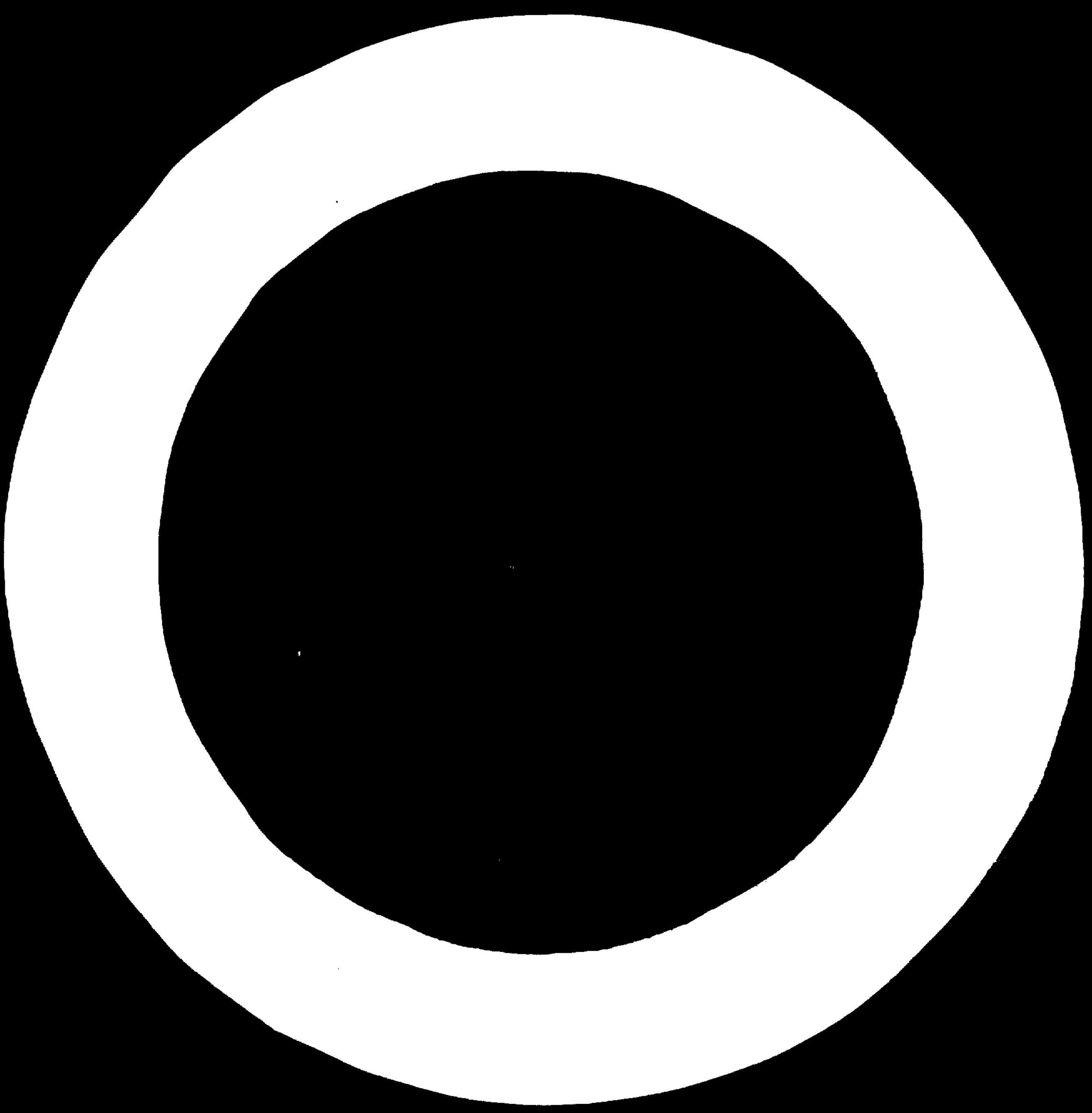
continue and remove the scrap mouldings

or blank off the faulty tool with any necessary adjustments

or close down the press and correct the fault.

This decision is not so very simple as there will also be a small number of defectives produced by the random and uncontrollable variations in the process. The necessity for skilled and professional manpower may prevent the more advanced press from being used.

The "best" method of manufacture will be the one with the minimum standard cost for the product. This would assume availability of all necessary resources including skilled labour and foreign currency. Developing countries have large numbers of unskilled people many of whom are unemployed. Nevertheless all of them consume the food, goods and services which come into or are produced in the country. As far as the nation (not the government) is concerned, it does not matter whether a firm employs 20 men efficiently out of 100 available or all of



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IMPROVING PRODUCT QUALITY IN SMALL INDUSTRIES IN DEVELOPING COUNTRIES

Summary

Quality can only be created by technology and better quality depends upon improved technology or better use of current facilities. Small industries in developing countries can do little to improve their technology but they can manage their businesses more efficiently.

Better management may require redeployment of resources with changes in emphasis on the relationships between men, machines, material and money. Developing countries are short of all of these except manpower which is abundant but mostly unskilled. It is often in the national interest that greater output should be obtained from plant or that material should be saved by the use of increased labour which would otherwise be unemployed. This should be subsidised by the State.

Greater efficiency will come from the use of scientific management techniques of which Quality Control is appropriate here. The literature and published case studies are nearly all concerned with mass production but the principles are equally applicable to small industries even those engaged on small scale production. The details of application may be very different and small industries with simple technology require quite sophisticated control systems for optimum use of resources. The necessary trained personnel are not generally available but considerable improvements can be obtained with suitable simplified methods. Some general purpose quality control plans

have been designed with this object. Step by step procedures for installing and maintaining these systems are given in the appendices.

The forms of assistance available to small firms from extension service agencies, large plants and national bodies are discussed. These lead to the use of the international sampling plan (best known as MIL-STD-105D) and other forms of certification for materials supplied to, as well as by, the small firms. A programme of international technical assistance is proposed in the conclusion with the object of training local graduates so that they can train others and hence lead to a self sustaining quality programme for the nation.

1 Preamble

The standard of living in any country depends largely upon what it is able to produce. It may be fortunate enough to be naturally rich in minerals, such as oil, when production consists primarily of extraction from the earth. Under such conditions there are always more advanced countries being very willing to help in the exploitation with some kind of sharing arrangement between the companies of the several countries. However, many developing countries are not so lucky and they have to rely more upon their own efforts. The United Nations technical assistance programme is designed to help them to help themselves. This paper tackles one aspect of the problem.

A fundamental difference between the industrialised and developing countries is in the number, skill and education of the labour force. The industrialised nations have a higher standard of living with a larger proportion of skilled and educated people who are expensive to employ. There is great pressure to use them as efficiently as possible and this has led to more advanced technology with the completely automated factory as the ultimate aim.

On the other hand, developing countries are comparatively short of skilled men and have large numbers of untrained and poorly educated people for whom it is difficult to find any kind of employment. Basic industries certainly exist in developing countries but generally these require large capital expenditure for each person employed. These are often quite efficient and provide the materials on which other domestic industries depend but they are seldom competitive enough to be able to export surpluses. Their contribution to national prosperity is largely indirect and most of it must come from the small industries which employ the majority of the people. These lack the technical co-operation from industrialised countries with their associated management skills so it is not surprising that they are not so efficient.

Many books have been published describing these management techniques with case studies relating to large scale or mass production. It is not immediately obvious that these techniques can be adapted for use in small companies. Nevertheless the principles are just as valid for small scale production although the detail of use may be very different from that used in mass production. An understanding of these principles is necessary but the actual shop floor operation can be simplified to a sufficient extent for useful techniques to be applied even by personnel with limited education.

Management in small companies may consist of only one or two people and it is clearly impossible for them to become expert or even learn about every technique which may be offered to them. However the principles of control are applicable to many techniques and this paper shows how they can be applied in the quality field.

Improvement in standard of living will be achieved by producing goods in larger quantity or of higher quality or preferably both. Many of such goods can be produced in excess of domestic requirements so that they can be exported in exchange for food, consumer goods, industrial materials and plant.

Export customers have a world wide choice of suppliers so obtaining orders requires that price, delivery and quality are all competitive. These can be specified in a contract but unless the conditions agreed are met, repeat orders will not be forthcoming and the whole standard of living will collapse. Excessive rejects will increase costs, delay delivery and raise doubts as to quality even after 100% inspection. On the other hand, improved quality makes the supplier more competitive even if any cost saving is not passed to the customer. The importance of being able to forecast accurately how facilities will work in practice cannot be over emphasised. This depends upon knowing what is truly possible and instituting controls to ensure that they are realised. This is one of the proper functions of quality control.

2 Advantages of Improving Quality

The Public Image of improved quality is better customer satisfaction with goods that perform as expected at the time of sale and continue to do so for the whole of a specified or implied guarantee period. This is generally associated with final inspection of the product but there are still complaints from users which may be due to premature failure. Some arbitrary limit is set for such complaints and when it is exceeded, even for short periods, there are demands for more and more final inspection to make sure! This will then take place at a later time when quality being made is quite unrelated to the batches which gave rise to the complaints. The additional inspection will not serve its intended purpose.

Any industrialist knows that, if his firm makes 5% defectives, some will pass through any inspection screen. For example, 100% inspection of such a product will probably remove 80% of the defectives but there will still be 1% in the screened work. In addition the inspection is likely to reject at least 1% and probably much more of good product! A further 100% inspection would double inspection costs and may be 70% effective, still leaving 0.3% defectives among the goods delivered to the customer. Even a third stage of 100% inspection will not find every defective and cannot guarantee satisfaction at all times. The question then arises that if 300% is not sufficient, what should be done? This question is just as valid in the small industries of the developing countries as it is in the most sophisticated technology of space exploration. The answer is that quality cannot come from inspection and that a high them less efficiently if the total output is of equal value and there is no useful work for the surplus 80. In practice this would not happen and the output value should rise as the number employed increases either by greater output or better quality or both.

All developing countries have some textile industry and a small firm may have a weaving shed with 24 simple power driven looms. An immediate problem is to decide its manning. Suppose the looms run at the rate of 10,000 picks per hour but that each loom is stopped for an average of 12 minutes per hour for mending yarn breaks and shuttle changes. Then, if each loom has its own weaver, it will run for 48 minutes per hour to give 8,000 picks or 80% efficiency. The weaver should only be busy for 20% of his time so he could certainly attend to another loom. If he does so it is possible that the second loom will have a yarn break or require a shuttle change during the time he is attending to the first loom. The probability of this occurring can be calculated and tables are available to give the amount of down time due to this interference. In this particular shed, the possibilities are:

Number of weavers	Looms per weaver	Picks per hour	Shed efficiency
24	1	192 000	80.0%
12	2	187 680	78.2%
8	3	181 728	75.7%
6	4	173 532	72.3%
4	6	148 932	62.1%
3	8	119 265	49.7%
2	12	80 000	33.3%
1	24	40 000	16.7%

Taking cost per metre of cloth (or 1,000 picks) as a criterion, the shed should have 8 or 12 weavers, the actual figure being decided by relative cost of labour and plant. However the national outlook would require maximum production from the shed and this will need the employment of 24 weavers if they are available. Weaving is not highly skilled and it should be possible to obtain the required numbers by simple training.

The quality of woven cloth depends largely upon the time that the loom continues to run after a break has occurred. Many looms have automatic stops in which case any increase in the number of weavers can only have a marginal effect on quality. The improvement can be quite substantial on looms without them.

This example shows how an excessive number of unskilled people with limited training can be used to obtain better plant utilisation. The moulding shop example showed how a similar deployment of unskilled labour, also with limited training, could use simpler plant saving currency and skilled personnel for set ups. In both cases, factory costs may be higher but it could be in the national interest to incur such costs. Standard quality would scarcely be affected but departures from standard operating conditions are not so serious. Further, the more skilled labour released could then be used for products where quality is more important or has greater value.

The same principle can be applied in the control of quality. This depends upon the maintenance of standard technical operating conditions which is usually verified by inspection of the product. The amount of inspection depends upon the confidence that technical control is maintained and the actual inspection methods used. This confidence will in turn depend upon the inspection results; it will be high only if all of these confirm expected quality. This seldom occurs; all industries have some inspection results which indicate departures from standard. These are likely to form a larger proportion in the smaller industries of developing countries. Such industries require more frequent inspection or more efficient inspection or preferably both. More efficient inspection involves measurement rather than gauging and this requires better trained labour. When this is not available better control will mean more frequent gauging immediately after manufacture employing more unskilled labour to avoid poorer quality for too long. This may not be economic for the firm but it could well be in the national interest. Firms should be encouraged to look into this possibility and, if it is found to be true, then the additional net cost should be subsidised.

There are some industries where it is not possible to measure the quality of the product during manufacture. However it is still possible to determine optimum operating conditions and control will then be exercised on the input variables. Quality can only be maintained if these are kept within the specified intervals. For example, the properties of moulding sand have a large effect on quality in a foundry. The castings themselves can only receive a cursory inspection when first made - blowholes and inclusions will only become apparent at a later stage - and even if some adjustment has to be made to the process, it will apply to the input variables which could have been measured without reference to the ultimate product. In fact, they can be treated as if they were the product of an earlier process in the same way that component dimensions are controlled during manufacture. This even applies to such abstract "products" as metal temperature.

It is now clear that developing countries have to make use of simple to intermediate technologies particularly for their smaller firms. The designed quality which they are able to offer is also simple to intermediate but this is no reason why the quality of conformance should not be high. It is most important that they should make the best use of all their resources which are generally limited in every respect except for unskilled manpower.

7 Principles of Quality Control

The basic principle of Quality Control is very simple. It is merely the systematic comparison of current achievement against experience and this can only be done scientifically if both achievement and experience are expressed on a numerical scale. The first step then requires the evaluation of experience and this must be observed over a sufficiently long period of time so that all normal variation has an opportunity to occur. This experience contains some degree of variation in the quality produced and it is important to decide whether this variation is inevitable with existing technology.

The decision depends on the observed pattern of variation and statistical (mathematical) techniques have been devised to compute whether this observed pattern could "reasonably" be obtained by chance. An arbitrary definition is given to "reasonably" and it is often associated with a chance that a more variable pattern would be obtained once in 100 times that such a set of data is collected from a stable process. Other definitions are also used instead; the simplest merely relates to the acceptance of the most extreme values.

On some occasions the initial investigation shows that the process is stable over the whole period and then it is deduced that technical operating conditions remained the same throughout the period. Further it may be deduced that the quality obtained is the best that is possible with current technology.

More frequently, the initial investigation shows that over part of the time, the quality is inferior to the average by amounts which cannot reasonably be due to chance taking account of the variability during the whole period. This implies that normal technical operating conditions were not maintained and it would be possible to achieve better quality if they were maintained. The achievable quality level can be estimated by averaging the results over the stable period. This is clarified by an example.

Fifty-two cartons, each containing 168 glass bottles, were inspected over a month to examine the quality of the sorting process. It was found that there was a total of 231 defectives corresponding to 2.64% but 90 of these occurred in 5 cartons. Such a pattern of variation is extremely unlikely to occur by chance so it can be deduced that the process was not being operated as well as it could be for about 10% of the time. The figures can be summarised in a table:

Period	Number inspected	Number defective	Percentage
Stable	7896	141	1.79
Unstable	840	90	10.7
Total	8736	231	2.64

It is clear that elimination of the unstable period would show an improvement in outgoing quality but, more important, it would avoid the very poor quality in about 10% of the cartons dispatched. As sorting is a manual operation which depends only on the skill and attention of the operator, this would be possible with suitable motivation for him to maintain his standard.

Standard quality for sorting this glass bottle will be based on the observed defectives in the 47 cartons which formed a stable group. The average is 3 defectives per carton but they contain various numbers between 0 and 7. It would therefore be expected that future production will also contain up to 7 defectives or even 8 occasionally but not as many as 12 which was the best result of the five cartons packed in the unstable period. Control then consists of verifying that the process is working normally as long as all sample results are in accordance with stable experience while requiring that appropriate technical action is taken to restore normal operating conditions whenever a sample result is outside stable experience. This is achieved by placing a control limit at a value sufficiently unlikely to occur by chance when the process is working normally and accepting all smaller values as confirming that the process is working as well as possible. However, any sample giving a value which reaches or exceeds the control limit will be accepted as evidence that the process is not working normally.

The position of the control limit can be computed or read off from simple tables and in this case it must be larger than 8 and certainly not as large as 13. It is always a compromise between unnecessary (and detrimental) adjustment to a process and failure to do so when technical control has truly slipped. The value used in the British Standard 1313 corresponds to a chance of less than one in 200 but there is nothing sacrosanct about this; some firms in the UK use one in 100 or one in 1,000 limits while others follow US conventions and use a more complex formula to compute the limits.

Somewhat similar results were obtained for the whole group of bottles with comparable physical characteristics. The figures are:

Period	Number inspected	Number defective	Percentage
Stable	29,460	647	2.20
Unstable	3,132	444	14.2
Total	32,592	1,091	3.35

These results were typical of the whole factory over the month during which nearly 540,000 pieces of ware were inspected with 2.77% defectives. However the stable level was 1.98% defectives and instability occurred for about 13% of the cartons. The stable level was considered to be just satisfactory but improved quality would obtain a larger share of the market. No further improvement could be expected without a technical innovation which had to affect the sorter's application to his job without loss of output. This was achieved by designing a quality incentive bonus scheme based on a quality control plan with pre-set initial targets for each type of ware. These quality targets were set at higher levels than had been obtained previously but were still considered to be achievable with sufficient motivation. The weighted average of these targets was about 1% defectives and the actual quality achieved after nine months was 0.7% defectives.

The purpose of the initial investigation is to determine the quality which can be obtained over a sufficiently long period of time so that all normal commercial variation has an opportunity to occur. This is then defined as the Quality Standard for the process and it is not necessary for this to be expressed as a proportion defective. It is preferable for it to be given as an objective average level together with a measure of process variability. After this is done, quality still cannot be controlled unless the firm believes it knows how to create the necessary technical operating conditions to make the product to this quality standard. There must never be any doubt about this belief!

In practice, technical control cannot be maintained indefinitely and departures will occur from time to time even though there has been no conscious effort to change anything. The effect is seen as a change in quality and, if the specified technical operating conditions are correct, this change can only be a deterioration. Any quality control plan is designed to detect the change as soon as possible taking account of its magnitude and importance. Generally large changes can be detected sooner than small changes but the true purpose is to know whether standard technical operating conditions still apply or not. It is accepted that they do unless there is sufficient evidence on a control chart to the contrary.

It must be emphasised that once an out of control situation has been observed, it is vital that appropriate technical action is taken to restore normal operating conditions. There can be no information about the quality that the process is producing until this action has been taken. There will be knowledge about the individual items in a sample which are measured but no knowledge about the much larger quantity which are not measured. Even if later samples give results coming well within the control limits, it must not be assumed that the process is working normally again; it is unlikely to correct itself without suitable technical action. On the other hand, when standard technical operating conditions do apply, there is considerable knowledge about all the product including those not measured and even those not yet made. One cannot say what the quality of an unmeasured item is but it is possible to assert what proportion of the product will have qualities within specified intervals.

Sometimes the initial investigation gives a stable quality which is better than the market requires and this can occur even when the overall quality is unsatisfactory. For example, a multi-spindle automatic lathe was found to be capable of working to limits of ±0.001 in while producing a component with a tolerance of ±0.002 in. Usually this tolerance was met but there were extensive periods when 20% or more of the product failed to comply.

In such situations it is always possible to achieve some cost reduction or similar advantage providing that the process is controlled to the stable quality level. The more uniform quality may have some value by:

providing an easier assembly
or reducing work at a later operation
or producing a better performance
or producing a more reliable product, etc.

If there are no such advantages, then it might be possible to:

use a cheaper material

or work towards a limit to save material

or run the process faster, etc.

In the example from the glassworks, feed back was obtained by the financial incentive but generally this is not necessary nor is it very desirable in developing countries. However, the principle of feed back is vital in any quality control plan; it is useless to know that the process has become unstable unless something is done about it. In the wider sense, feed back is used after the initial studies have given their estimates of process capabilities. These provide information for:

1 the designer to quote realistic tolerances
2 process planning to assign appropriate machines
3 purchasing to obtain economic plant for products being made and planned
4 maintenance to assess wear and need for overhaul
5 tool and gauge room for checking and measuring
6 sales to specify achievable performances.

This is still true even in small firms of developing countries where one or two men have to look after all these functions. They should work with the best available information.

Failure to achieve these capabilities will show up on the control charts from which information is fed to:

1 supervision for appropriate technical action, setting, etc

2 production planning to ensure correct quantities despite losses

3 costing to assign excesses

4 inspection and quality assurance to ensure customer satisfaction

5 service.

Field complaints and market enquiries show what the customer wants and what he thinks of the product. This should be fed back for consideration by designs, specification and through the whole cycle back to production, quality control, etc. It is truly said that "Quality is everybody's business" and quality control gives the axis on which all other aspects revolve.

8 Techniques of Quality Control

It is now accepted that Statistical Quality Control covers three main areas, sampling plans, control charts and industrial experimentation. A sampling plan is a set of rules to decide whether a batch of material of consignment of components should be accepted or not. The control chart is used to ensure that the achievable quality standard is maintained. This implies that technical operating conditions are normal which should be true most of the time. The chart will detect changes in these operating conditions when they occur and this should be rare. Industrial experimentation is required when the achievable quality standard will not satisfy market requirements. It aims at determining optimum operating conditions and often uses quite sophisticated statistical methods to achieve this objective.

8.1 Sampling Plans

These are used by producers of goods to give themselves an assurance that the quality will satisfy an agreed or implied level. They are also used by consumers for a similar purpose. Great ingenuity has gone into the design of some sampling plans and generally they fall into one of two types. In effect the first assumes that a batch is unacceptable unless the sample results are considerably better than the required quality while the second accepts batches in sequence unless the sample results are considerably worse than the required quality. The both serve their purpose and relate to different situations.

Dodge and Romig's well known tables illustrate the first type. For example, they may wish to avoid acceptance of a batch of about 2000 items if it contains 2% or more defectives. Their simplest sampling plan requires that a sample of 440 items has less than 6 defectives for acceptance of the batch. This corresponds to something better than 1.36% defectives in the sample. In fact, if the producer supplied a batch with exactly 2% defectives, the consumer would still have a one in 10 chance that he will accept it.

These plans are rather severe on the producer who finds that even when his batches contain only half the maximum allowable proportion of defectives, he will still have well over a quarter of them rejected. This is far too frequent so he has to supply goods of a much higher standard for which he obtains little reward. Nevertheless this type of sampling plan is the best for isolated batches in which there is little or no background knowledge of quality.

The second type has more universal use and there is now an internationally agreed standard set of sampling plans with the title ABCA-ARMY-STD-105A. This is the result of collaboration between USA, UK and Canada each of whom issues the set with its own title.*

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* This is MIL-STD-105D in USA, DEF-131A in UK and CA-C-115 in Canada.

This is a development of MIL-STD-105 first used in USA for acceptance of military stores and soon extended to all official purchases when it was suitable. It exerted great pressure on many firms to improve quality and led to a wide extension in the use of statistical quality control. Subsequently it was widely used in Europe leading to compatible tables being published in UK. The latest tables incorporate the best features of all that have gone before.

The simplest plans in these tables for batches of 2000 items requires that samples of 125 units are selected and inspected. If the acceptable quality level (AQL) is 1.5% defective, then up to 5 defectives are permitted in the sample without rejection. This corresponds to 4% defectives in the sample.

The basic thinking behind these plans is that no producer can afford to have many of his consignments rejected so that he is economically forced to work to an agreed or imposed AQL. They are most suitable when long sequences of batches of the same material are submitted for acceptance. If the producer supplies goods at the AQL of 1.5% in this example, then he will have about one batch in 80 rejected which is considered satisfactory to both parties. On the other hand, if he presents an occasional poor batch with 4% defectives, it will still have a 50% chance of being accepted by this particular plan.

Small firms in developing countries have to purchase goods and materials. If they require regular supplies of the same goods, they could use the MIL-STD type of sampling plan at an agreed AQL but they are unlikely to be able to impose adequate penalties if bad quality is presented to them in the same way that large firms and government departments can. The

Dodge-Romig plans give better protection against really bad quality but require much more inspection. In either case, there must be agreement as to both sampling plan and quality level; the small firm can expect to be at a disadvantage in making such agreements. Their best protection comes from using material supplied under a Certification Mark Scheme where the sampling of the product and examination of routine quality measurements is the responsibility of the National Standards Institution. This is discussed in Section 10.

The problems are substantially the same when small firms supply the goods they have made. Certainly they should not rely upon sampling plans for quality assurance. This will come from the proper use of control charts during manufacture. These will give the quality levels which they know they can achieve consistently to form the basis of any sampling plan which their customers intend to use. Control charts also give evidence of quality for official Certification Mark Schemes and in disputes with customers.

8.2 Control Charts

These are used to give systematic monitoring of the quality of the product during manufacture. They usually require that samples are taken from the process and inspected but can be used with 100% inspection if desired. In either case, the items are inspected to decide whether the process is working normally or not. The decision will be the best on the available evidence but there can be no absolute guarantee that it is correct. The process will produce some satisfactory items when it is out of adjustment and conversely, it will produce items of doubtful quality when it is operating perfectly.

There are rules for deciding whether the process should be allowed to continue running or whether a technical change is necessary to restore normal operating conditions. These rules depend upon the values of control limits and are chosen so that the process will have a long uninterrupted run when it is working normally but any change from standard operating conditions will be detected in a minimum of time. These objectives conflict with one another and emphasis is usually placed on a long run when conditions are normal. Detection of disturbed conditions depends upon the number of items inspected and the type of control chart. Very simple methods can be used if there is high confidence that normal technical operating conditions will be maintained, but more complex methods are required or much more inspection if this confidence does not exist.

This can be illustrated by an example of the simplest kind of control chart. Samples of 20 items are taken from the process which is known to produce 2% defectives in the long run when properly adjusted. The control chart is based on the number of defectives found in the samples and it is clear that most samples will contain 0 or 1 defective (about 94% of them). It would be possible to set the control limit at 2 defectives when the process would only run for about 17 samples without unnecessary and detrimental adjustment. A higher value for the control limit would be better and it could be 3 when the average run length (ARL) would be 140 for standard quality or 4 with an ARL of 1600. When technical control is lost, it will be assumed that the defectives increase to 10% and the ARL for a control limit of 3 will then be 3.1. The ARL is 7.5 if the control limit is set at 4.

If technical control is usually maintained for long periods, an average wait of 7.5 samples to detect the change is not very important and it is preferable to set the control limit at 4. On the other hand if quality deteriorates frequently, say once per week or more, then the control limit is better set at 3. In either case, the time to detect the change can be reduced by more frequent sampling and this may be the best method in developing countries with a surplus of labour.

This problem becomes more acute when higher quality is necessary and is normally obtained. If the standard quality is 0.2% defectives and it is desired to detect a change to 1% defectives, then the samples should be ten times the size, viz 200 items, for the same sensitivity. This is not often practicable so more frequent samples are taken and it still takes a long time to detect the required change when it occurs.

The reason for this poor sensitivity is the small amount of information contained in the knowledge that an item does or does not satisfy some requirement. This is all that is possible with true attributes such as leaking buckets or correct colours. However quality is often determined by counting defectives for simplicity when it would be possible to measure actual values of quality characteristics. The additional information contained in actual measurements can give much improved sensitivity by using control charts for variables. The standard type of chart assumes that all the process variation occurs within the samples. This is not necessarily true and these control charts will not always work without modifications which are not explained in standard quality control books. Unfortunately these difficulties are more likely to occur with the simpler technologies available in developing countries. However the simpler number defective chart with its limited sensitivity will always work.

There is no doubt that better control is obtainable with properly designed measurement charts which take account of all the variability in the system due to machine, material and men. This requires skilled statistical knowledge which should be made available to small firms on a subsidised consultative basis. Once such a chart is set up, it looks just the same as any other mean and range control chart and works in exactly the same way.

The choice then comes to a smaller amount of more skilled inspection by measurement, together with some simple calculations, or more inspection by attributes without any calculations. There is little difference in operation or routine interpretation of the charts. However the former requires more knowledge to set up and the charts can be used to provide more information for quality development later.

There is an intermediate type of chart which was developed in

1942 but, after an initial surge of enthusiasm, has had limited application. This is the Compressed Limit method which can be used instead of control by variables. In effect, it requires that the items in the samples are gauged to limits which are stricter than the specification. The values of these compressed limits are computed from the process variability and they are used only to decide whether technical operating conditions are maintained or not. They should never be used to estimate product quality when technical control has slipped. Used in the right context, gauging of 7 items to optimum compressed limits will be about as sensitive to changes as actual measurements of 5 items whereas 100 or more would have to be gauged to specification limits for high quality products. Although approximate formulae are given in published tables, compressed limits really require some statistical skill for efficient use.

Many additional rules have been proposed to increase the sensitivity of control charts at the expense of simplicity. The simplest is to add Warning Limits between the central line and control limit which then becomes an Action Limit. The occurrence of two successive samples on or beyond the warning limit is regarded as being equivalent to a single sample result violating the action limit. Sometimes the rules require that a second sample is taken immediately when one reaches the warning limit. Applying either set of rules will certainly detect a change with less inspection but they also reduce the ARL when standard quality is maintained. No allowance is made for this undesirable reduction in published schemes but, if it were, warning limits would still show some useful improvement in sensitivity.

Alternative rules have been proposed which can be used as well as, or instead of, warning limits. These relate to runs of 9 or 10 successive points on the same side of the central line of a chart or a trend of 9 or 10 successive points all of which are higher (or lower) than the preceding point. These rules correctly indicate that a change in technical operating conditions has occurred but interpretation by unskilled personnel may be misleading. They should be used with care by small firms or under expert guidance.

Somewhat better results are obtained if warning limits are modified so as to apply to the average of two successive points instead of comparing each point separately against a limit. Consider an example in which the objective mean is 100 with the upper action limit at 130. Then the ordinary warning limit would be at 120. The modified warning limit for the average of two successive points would be 121*. It can be shown that if the true mean increases above 100, then the average of two successive samples is more likely to reach 121 than both of them reaching 120.

The use of warning limits for two successive samples can be extended to three or more samples with improved sensitivity as the number of samples is increased. However the chart soon

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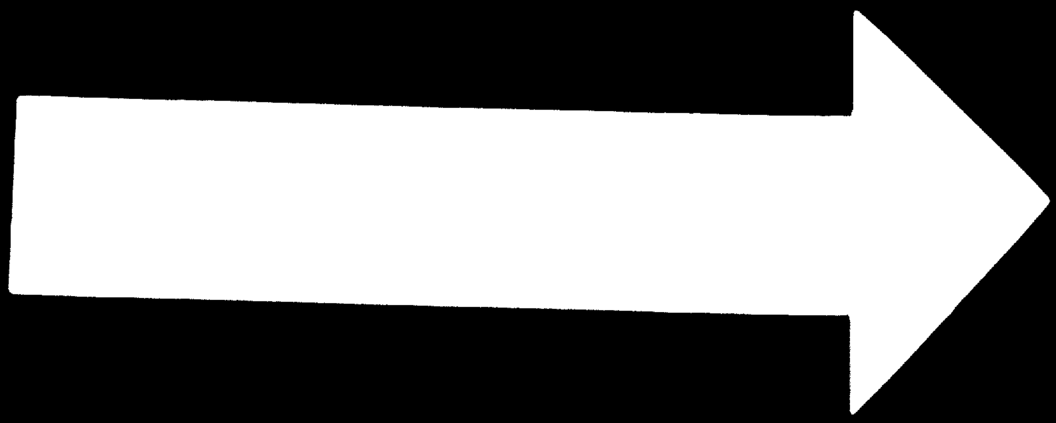
* These are '3-sigma' and '2-sigma' limits for individuals together with '3-sigma' for the mean of two items.

becomes very complicated and there is no record of anybody using more than three pairs of control limits.

During recent years another technique has come into use which, despite its mathematical origins, is essentially a control chart with an adjustable number of these modified warning limits to give maximum sensitivity to change. As each new sample is obtained it is compared against a limit while at the same time, it is combined with the immediately preceding 1, 2, 3, 4 .. etc. sample results and compared against appropriate limits. This gives the most sensitive statistical control available and a simplified version of this technique can be used by unskilled personnel in small firms even with small scale production.

The technique is most versatile and can be used for control by attributes or variables with any sample size and any summary measure and it can be applied to any sequence of samples. It is called the Cumulative Sum Chart, conveniently abbreviated to Cusum Chart, and as its name implies it requires that the cumulative sum of the deviations of the control statistic (summary measure) above a predetermined Reference Value be formed after each sample result becomes available and compared against a kind of control limit called a Decision Interval. This continues until either the cusum becomes zero or negative when it is deduced that the process is working normally or it reaches or exceeds the decision interval which is taken as sufficient evidence that technical operating conditions have changed.* The cusum can start at any sample and there are



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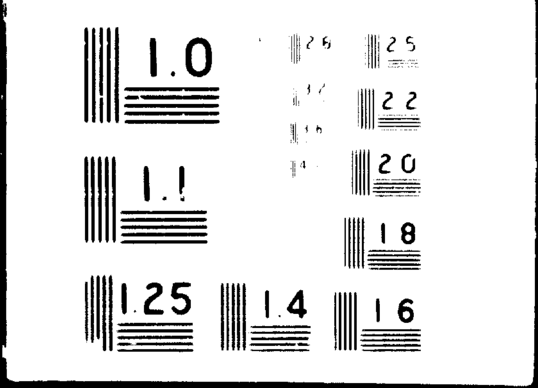

very simple rules to decide optimum starting points.

The characteristics of any cusum plan are determined completely by the two parameters, reference value and decision interval, once the sample size and control statistic have been decided. These are chosen so that there is a large ARL when conditions are normal and a small ARL when they have changed by an undesirable amount. Many papers and some books containing tables and nomograms have been published to enable suitable plans to be designed for any particular situation. There are some points of particular interest to small firms which will be elaborated here. These lead to definite recommendations of cusum plans which can be used by such firms.

A very valuable property of cusum schemes for variables is that their sensitivity is almost independent of sample size. This means that if samples of 5 items are used to give an ARL of 400 at standard quality falling to 3 at rejectable quality, samples of one could be used instead with suitable changes of parameter to give an ARL of 2000 at standard quality when the ARL at rejectable quality will be almost exactly 15. The number inspected is the same for the same sensitivity of control. A cusum plan should therefore use the natural sample size and in small industries this is nearly always one. The actual

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* When worsened quality gives a decrease in the value of the control statistic, the decision interval will be negative and the process is considered to be working normally as long as the cusum is positive.

given by the purchaser complete with sampling frequencies and control limits. These are not always successful in the small firm with less skilled labour and supervision. The difficulties which occur from time to time are best resolved by visits from officers of the large plant.

9.4 National Standards Institutions

A National Standard is a specification for a product or material agreed by a committee representing manufacturers and users with impartial members nominated by government departments, universities, etc. It will represent a quality level which can be achieved by nearly all reputable manufacturers. The National Standards Institution provides facilities for committee meetings and the secretariat.

National Standards for materials will usually include test procedures together with required limits for compliance. Any small firm purchasing materials to such a National Standard will know the worst quality it expects to obtain and can arrange its manufacturing processes to make the best use of such quality. However small firms may not have the facilities to perform the specified tests in which case they will not have the same guarantee that the material supplied truly conforms. The actual quality supplied will not be altered by the user's failure to perform the recommended tests!

This difficulty has been recognised in several countries over many years and a solution obtained by a Certification Mark Scheme whereby the National Standards Institution shares responsibility for the quality of 'certified material'. This scheme is fully discussed in the following section. Small firms should always ask for certified material if it is available.

National Standards for products are somewhat similar but they require performance specifications as well as dimensional accuracy. They also include minimum life requirements for consumable products such as electric lamps. Life tests can only be carried out on samples which are always too small to detect small deteriorations in quality, particularly by the user. The manufacturer will have other background information. Again consumer protection is best obtained by the Certification Mark Scheme.

The remaining National Standards apply to nomenclature, test procedures including quality control and standardisation of sizes such as screws, bricks, etc. These can provide the basis for commercial contracts and small firms can easily take advantage of the facilities once they know that they exist. They should certainly purchase all National Standards relevant to their own manufacture (for materials and products) to know what can be expected with good commercial practice in their own country. Quality studies undertaken as in previous sections will then indicate how they will be able to face their competitors. Improved quality must result from all firms doing their best.

10 Certification

In its simplest sense, quality certification consists of the producer sending a record of his final inspection results to his customer with the batch to which the certification relates. This would be part of the purchasing agreement and would include all the test procedures and the sampling plan used for the final inspection. The producer can scarcely dispatch any batch which fails to satisfy the required conditions unless he falsifies his report. The consumer will require some safeguard against such a possibility and he would reserve the right to carry out verifying tests on any batch. He is not restricted to using the same sampling plan for this purpose.

These certification plans are very suitable when there is regular production and delivery of the same goods providing that no disputes occur as to the quality of any batch. If any such disputes should occur, they reduce the confidence in all the other batches which have been accepted recently. There can never be any great confidence in the quality of an isolated batch without support from other evidence. This could come from complete inspection, which would have to be done by the consumer, but maximum confidence comes from the integrity of the supplier.

In fact, the consumer wishes to save the trouble and expense of goods inwards inspection and he would like to think that all batches presented to him will be free of all defectives. In practice, there will be some agreed maximum proportion of defectives and the sampling plan should reflect this acceptable quality level (AQL). However some batches of AQL will still be rejected by the producer by the chance of selection of the sample. He will salvage what he can of the batch by 100% sorting and sometimes he will find the rejection is not justified. This should not occur frequently as it increases costs which the consumer will have to bear in the long run.

A small firm is more likely to be the producer in this kind of certification plan rather than the consumer and he will have to accept an imposed AQL. This will probably be obtained from the international sampling plan - ABCA-ARMY-STD-105A - but more commonly known as MIL-STD-105D. Some account of this was given in Section 8.1. Experience, even in the large plants of industrialised countries, has shown that the required AQL, imposed by state industries and ministries, is only satisfied economically if an efficient quality control scheme is in operation. The rapid expansion of quality control methods in USA during the decade following the war has been largely attributed to the public sector's insistence of purchasing to MIL-STD-105. Small firms have a lesson to learn from this background but they obtain little assistance from certification plans when they have to provide the quality certificate.

The other aspect of certification occurs when the small firm purchases its requirements which will be called material. It will not be strong enough by itself to insist on the supplier giving quality records relating to the actual batch. This is not so important as long as all batches are of substantially the same and acceptable quality. The small firm is not in any position either to insist upon this or to verify it. It is here that the Certification Mark Scheme mentioned in the preceding section gives the necessary protection and assistance.

In many countries the National Standards Institution owns a registered Trade Mark which it is prepared to license to manufacturers who are able to satisfy it that they consistently supply goods to the appropriate National Standard - say NS 123. The goods and containers can then carry a stamp with the registered Trade Mark "NS 123" in some distinctive design. Such a licence gives a guarantee of quality for the whole product not merely the items or test pieces which have been inspected. The responsibility for maintaining the guarantee is shared between the manufacturer and the National Standards Institution (NSI) but it does not imply that there will never be an item which does not comply with NS 123. It is unusual for any National Standard to specify the actual quality directly. It does give rules for acceptance from which it is possible to compute the quality level which will almost certainly lead to acceptance. The occasional defective will occur and any replacement will be subject to normal commercial practice. The Certification Mark Scheme would be stronger if it specified the compensation to be given for an occasional defective.

It must be emphasised that the Certification Mark Scheme is much stronger than the National Standard by itself. For example, a typical acceptance clause may read:

"Take a sample of 3 pieces and test them in

> accordance with clause 4. Accept the consignment as conforming to the Standard if all 3 pieces satisfy the requirements of clause 4. Reject the consignment as not conforming to the Standard if 2 or 3 pieces fail to satisfy the requirements of clause 4. If there is one piece which fails to satisfy these requirements, take another sample of 3 pieces for a further test. The consignment will then be accepted as conforming to the Standard if all 3 pieces satisfy the requirements of clause 4 but will be rejected if one or more pieces fail to satisfy these requirements."

It can be shown that there is at least a 99% chance of accepting a consignment with less than 3% defectives but a batch with 30% defectives will still have almost exactly an even chance of acceptance.

A scrupulously honest firm will only claim compliance with such a Standard if it is able to work consistently with less than 3% defectives. However, some firms lacking in technical ability will not be able to produce goods to such high quality and their samples will still satisfy the acceptance clause on some occasions but not always. This will occur merely by the chance of selection of the samples even when the true quality of a number of consignments remains constant. Such a firm can justly claim to have complied with the Standard on these fortunate occasions although the consumer does not obtain better quality. This is certainly not the spirit of a National Standard. The Certification Mark Scheme provides protection to the consumer even when he has no testing facilities himself. It also has the effect of safeguarding the better firms against unfair competition from others who are not always supplying goods satisfying the Standard.

The NSI has three main responsibilities in the issuing of a licence to use the Trade Mark in connection with its Certification Mark Scheme. They must be satisfied that:

1 the firm has adequate facilities to test whether the product is in conformity with the Standard,

2 it makes routine tests on the product which are kept in a proper manner and are available for inspection by the NSI,

3 these records truly represent the quality which the firm is supplying.

The first two of these conditions must be satisfied before the licence is issued and the firm is at liberty to propose any method of maintaining its routine records as long as the NSI is satisfied that the quality of the product can be deduced from these records.

The continuance of the licence requires the third condition to be satisfied as well. This truly involves a higher level of quality than that corresponding to NS 123 because the NSI will take samples of the firm's products either from its warehouse or purchases on the open market. These samples will then be measured by a testing authority or by the NSI's own laboratory if it has suitable facilities. It is then not sufficient that the sample results are acceptable to the Standard; it is also necessary that they are in agreement with the routine test figures supplied by the firm. This can be clarified by an example.

The tensile strength of test pieces made from a particular grade of phenolic moulding powder are required to have an average value of 7500 lb/sq in. in the long run while the average value for the three test pieces made from a single batch of powder must exceed 6500 lb/sq in. Routine factory records will show values in excess of 6500 and they may well cover a range from 7400 to 8200. If the testing authority obtains a value of 7200, such a result would satisfy the acceptance clause of the Standard but it could not be considered as being in agreement with the firm's official records. The NSI would then have the right to withdraw the licence to operate the Certification Mark because there can be no reliance in the figures quoted by the firm. Further no testing authority can ever carry out sufficient tests to guarantee the quality of a product if it does not believe, in advance, that the firm supplying the product will always maintain the quality. Withdrawal of a licence should be a very rare occurrence but it should be given maximum publicity when it does happen. It should only be re-issued after the manufacturer has proved that the quality of his product is definitely superior to that required by the Standard.

It is obvious that it is in the firm's best interests to present reliable figures to the NSI on all occasions and it should never claim to supply a better quality than it is, in fact, supplying. It may be added that it is very difficult to "cook" the results in such a way that a professional industrial statistician will be misled.

The best method by which the manufacturer can maintain routine quality records is the quality control chart. These can establish levels of quality throughout the manufacturing processes in addition to the Factory Quality Standard for the final product. This will demonstrate that the firm is capable of making the product in conformity with NS 123 which is strong supporting evidence when making application for a Certification Mark licence.

There is still one difficulty which must be resolved before the Certification Mark Scheme can operate to everybody's satisfaction. No matter how careful they are in the manufacturing unit, there will be rare occasions when quality deteriorates. This will be shown up on the quality control chart and suitable technical action will be taken to restore normal operating conditions. However some items of poor quality will have been made and it is important that these do not get into the main stream of proper quality production. Disposal of suspect work is important in any certification scheme. The most satisfactory method is complete segregation to be sold later down graded as "not certified" or "seconds" possibly at reduced prices.

Any small firm can insist upon purchasing only certified materials when it is available in its own country. The cost should be no higher for certification and it does give an assurance that the quality is in conformance with the National Standard. No licensee can afford to take the risk of losing his licence in a properly operated scheme.

Certification schemes are not confined to National Standards Institutions; some are operated by consumer associations. These may give a certificate of the actual values they have obtained after testing open market purchases but the numbers involved are too small to give a fair representation of the whole of a manufacturer's production. Nevertheless these reports are widely read and the general public places a great deal of reliance in their unbiassed tests. They provide a strong incentive for any firm to present better quality to the public to increase sales. These associations may also initiate propaganda for higher quality than has been agreed by the NSI committee. This higher quality will be obtained on some occasions because factory standards are generally better than national standards but it cannot be guaranteed without changed methods and increased costs.

Consumer associations also look into the reliability and performance of products over the whole of a normal life. This will include the frequency and cost of maintenance and repair with the ease of obtaining any necessary spares and consumable parts. Again the numbers involved cannot be large enough to give accurate estimates of product reliability although differences between competing brands may be well established. They may invite the general public to contribute their own experiences of these products but these comments will be largely subjective.

The range of activities of some consumer associations is even wider than that of the corresponding national standards institution. They can extend from simple objects and materials like tennis balls and soap powders to complex products like automobiles. They also devise their own performance tests to assess quality which are used in addition to those given in national standards.

The least attractive part of their activities is the suggestion in many reports that quality problems can be solved by more final inspection. This is in direct conflict with the old cliche "You cannot inspect quality into a product unless it is already built into it". Nevertheless it is fair comment that if a defective is found in a market purchase of ten items, the product as a whole will almost certainly contain at least 0.5% defectives and probably many more. On the other hand, they serve a very useful purpose in drawing attention to design features, both good and bad, which can be expected to be repeated throughout the whole of the product.

Another kind of certification has existed in industrialised countries for many years. There has been legal requirement that pharmaceutical products should have their composition stated on the labels of the containers. The objective has been the protection of public health and some countries now require that similar measures are taken for manufactured foods especially those which will be exported.

Export certification has become a legal requirement in some developing countries in recent years. It is realised that the standard of living of the nation is greatly affected by its export performance which in turn depends upon the customers' confidence that quality will be maintained. It is particularly necessary that non-traditional exports, such as engineering products from Africa and Asia, should be of adequate quality to sell in competition with similar goods made in Europe. Any industry is at liberty to propose a procedure which will give the Export Certificate of Quality and the simplest schemes make use of MIL-STD-105D for products made in batches of 500 or more. These will cover most small industries who are encouraged to improve their quality performance above the AQL imposed by the ministry to obtain an export certificate.

11 Conclusions

This paper has reviewed the value of improving product quality and the methods which are available to small industries in developing countries to achieve this objective.

The first step must be to persuade the proprietors and managers of small businesses that their best interests are served by improved efficiency. This is accepted fairly readily and they must see greater financial rewards from the changes they are asked to make. It is not at all obvious that improved quality will accomplish this. The traditional outlook is that quality is associated with inspection which is a necessary but undesirable overhead cost. They understand that greater rewards will come from increased output and they believe this conflicts with improved quality.

They must be persuaded that this conflict does not exist in a well run firm and that quality control is concerned with making the best use of all resources. There are situations where current resources should be re-deployed with a small investment in quality control to reduce both scrap and rectification. This may entail engaging more staff, purchasing measuring equipment and even employing consultants to establish a simple system. This latter course should be subsidised in a developing country. The best propaganda will be supplied by the management of other small firms who have shown substantial profits by tackling their quality problems.

Once there has been acceptance that quality should be measured for an extended period, it will be obvious that any method of control must improve quality. These methods have been discussed in Section 6.2 and step by step procedures are given in the appendices for the simplest of them. These will be found to be very useful for those processes which come close to satisfying product specifications when working as well as possible. They can be expected to reduce defectives by 20% or more even when operated by unskilled personnel in small industries of developing countries. Improvements of this order of magnitude may or may not be really useful to an individual firm but they can be repeated over most of a country with little concentrated effort. The total effect will be very considerable.

Very many firms would benefit by using more advanced quality control techniques but it is impossible to generalise as to how great any improvement will be. Each project has to be judged on its own merits. Some improvements will be negligible while the optimum scheme in others could be 4 or 5 times as good as the general purpose plan. Certainly all control charts should be scrutinised occasionally by a more skilled quality control officer. He is likely to be a local graduate who has been trained to a higher level by visiting experts. He should then be able to design a better scheme which can be understood and operated by the factory personnel without his supervision. It need not be the absolute optimum but it must save more than it costs.

Major quality improvements, which will make a significant contribution to raising the standard of living, will only come if a genuine demand for it is created over the whole population. This depends upon a full programme of education and all developing countries are trying to achieve this. It is a slow process and international agencies can help particularly in training to build on the education already obtained locally or in industrialised countries. Ultimately training for the mass of the population must be given by indigenous personnel and first it is necessary to create these trainers. They will normally be local graduates who are selected to work with visiting experts.

The quality control pioneers in USA and UK were not statisticians. They were engineers, scientists and technologists who found that they could understand and solve their technical problems by the application of statistical methods to their observations. It was natural that similarly educated people should be given the initial training in statistical quality control (SQC) in developing countries. This was not found to be so successful in India where the maximum quality control effort has been made among these countries. Although many of them attended the first group of training courses given by UN experts with the object of creating "teacher-trainees", no engineer or scientist was found to be both suitable and willing to undertake this work.

A major reason was that engineers, scientists and technologists were offered much higher salaries in their own subjects than in SQC. Further there are excellent training facilities for statisticians in India but insufficient employment opportunities. The large proportion of quality control engineers there have had their basic training in statistics mostly with Master's degrees. The few engineers and scientists who have made a career in SQC have been outstandingly successful. It would appear that most of the trained engineers in developing countries serve their nation best by working in engineering although they would be better engineers with an understanding of SQC. Experience shows that there is no great difficulty for them in learning sufficient statistics once they are convinced that SQC is a valuable technique. Similarly a statistician who works in a particular industry will have no great difficulty in learning sufficient of this industry to make useful quality control applications but he will require much deeper training to make a contribution to the very large number of small industries in developing countries.

The initial objective of any internationally sponsored training programme will be the creation of the necessary indigenous trainers. It is proposed that this should be carried out by a team of 3 or 4 visiting experts whose total experience would cover a wide range of industries of all sizes. They will give a two week introductory course covering the simple techniques described briefly in Sections 8.1 and 8.2. Although this will make use of modern teaching aids to simulate industrial sampling, no course on a practical subject like quality control can truly succeed without laboratory work. Here the ideal laboratory is the factory floor so it is proposed that the initial theoretical instruction is followed immediately by 3 or 4 weeks investigations and applications in a variety of industries. The students will be encouraged to work on these projects by themselves but they will be supervised by the experts. They will reassemble for another week or more after this practical period to report back to the whole group. The discussions which will ensue should consolidate their learning and indicate what their next steps should be. It is not proposed that they should study the subject in greater depth at this stage of their development.

Some of the students will have had industrial experience before attending the course and may have been well established in their particular company. Their project work should take place in their own factory and the success they achieve at these early stages given the widest publicity to encourage others especially the smaller industries. These students are unlikely to become the future trainers.

Other students will be graduates in any discipline with little or no industrial experience. A scientific or statistical background is preferable. Their projects will be their first industrial contacts and they should continue similar work after the reunion period to enlarge their experience. Obviously they must be supported by some public agency to enable them to do so. This will be justified if it is intended that they should become the future trainers.

The whole of this initial programme would be completed in about two months after which the team could move to an adjoining centre which might be a neighbouring country where they would repeat the programme. It would be desirable for one member of the team to stay at the original centre or to adjust his work allocation so that he is available to return there. He would continue to advise the potential trainers and work with them in organising their own first training course involving the simplest techniques. He should act as Course Chairman for its presentation with a minimum of direct participation but plenty of discussions with the trainee lecturers at the end of each day. He should sum up the course at the end and encourage the delegates to try to make some simple applications. At this stage, the course might only cover a period of one week concentrating on simple sampling plans and the general purpose control charts given in the appendices. These would be equally useful to small and large industries.

Further quality improvements would come from the tighter control of more sophisticated schemes. It will take some time before the trainers learn how to use statistical methods to design suitable schemes which take account of all the technical factors involved. This can only come from experience and any technical assistance expert will ensure that the experience is directed into the most appropriate channels.

This method of international assistance was used as a first step in India but the country is too large for it to have succeeded without further assistance. This took the form of longer tours of duty by several international experts covering a total of 13 expert-years. The quality control programme there has concentrated on establishing a group of SQC Units in eight major cities. They give a subsidised consultative service to industry and have a major objective of training their own staff by practical example. Originally each Unit was under the technical leadership of an international expert with a small staff of statisticians who had attended the initial course given by the UN team. These men have now acquired sufficient skill and experience to run all the Units themselves and train their junior staff also by practical example. They all offer short courses for industry to supplement their consultancy and most client firms take advantage of these.

This kind of programme would be suitable for other developing countries with good facilities for basic teaching of statistics. It need not be as large and one or two expert-years would suffice for most countries. The first impact would improve quality in the larger industries but it would achieve the primary objective of training quality control engineers without whom no long term quality programme can be truly effective.

It is difficult to quantify the quality improvement which will be obtained by following the proposals contained in this report. However it is possible to visualise an Index which measures overall quality on a scale between 0 and 100. Perfection would be represented by 100 and must be regarded as being unattainable without enormous expense quite outside the scope of any firm in a developing country. There can be little meaning attached to an Index of 0 but current quality may have an Index of 20. Then the various steps can be expected to increase this as in the following table.

Step	Action	Index
1	Initial value	20
2	Establish specification and provide good working conditions	25
3	Provide facilities for operators to verify quality they have made	30
4	Make use of National Standards, Certified material and laboratory testing facilities	40
5	Use of simple general purpose Quality Control plans	60
6	Analysis of quality data with feed back for small technical changes including instructions for setting	65
7	Shop floor experimentation to determine optimum operating conditions with implementation of an appropriate quality control plan	70
8	Gradual evolution to	75
9	Major technical changes which are likely to be too expensive	80
10	Perfection	100

It can be seen that completion of step (5) after the earlier ones will take most firms about half way to perfection and they can achieve this with current facilities as long as there is the will to do so! It would be easier with help from experienced Quality Control Engineers but it is not vital. This help is necessary for further improvements and would result from a programme of international assistance.

There is often pressure to install new and improved plant - Step (9) - before all the earlier steps have been taken. This action would usually require scarce foreign currency with a considerable time delay. The table shows that the increment on this account is only 5 and it is unlikely to be much greater wherever it is inserted. The Index itself will vary from day to day and initial improvements may be somewhat larger. However experience shows that the whole of a larger improvement will not be maintained without undertaking the earlier steps also.

APPENDIX A

A Simple General Purpose Quality Control Plan Based on Cumulative Sum Technique

1 Control by Counting

This plan has been designed to provide a sensitive control when it is only possible to inspect the product qualitatively and decide whether each item satisfies some requirement or not. It is equally applicable when quantitative inspection would be possible but it is not considered economic or practicable to use it.

The figures quoted apply to a process producing 2% defectives under normal technical operating conditions but these conditions become disturbed on unpredictable occasions thereby increasing the rate of defectives appreciably. Definite technical action is required to restore normal conditions when such a disturbance has occurred.

The object is to avoid making any changes to the process when it is working satisfactorily - the chance of doing so is only about one in 450 per sample - while detecting a change to 10% defectives in an average of 3½ samples.

If the standard quality is not 2% defectives, the plan can easily be adapted merely by altering the sample size so that the expected number of defectives remains as 0.4. For example, use samples of 40 for a standard of 1% defectives or samples of 8 for a standard of 5% defectives. In each case, the change detected in about 3½ samples will be five times the standard proportion of defectives.

Any convenient sampling interval can be used and this will depend upon the degree of confidence that technical control will be maintained taking account of the sensitivity quoted above.

Procedure 1

1 Prepare a cusum table in which the observations and control calculations will be recorded - see Figure 1.

2 Select a first sample of 20 items from the process, inspect each of them and count the number which are defective to the quality characteristic being inspected.

3 Record the number of defectives in column 2, sample 1.

4 If the number of defectives is 2 or more, subtract 1 from the number and record in columns 3 and 4, sample 1. Do not record anything in these cells if there are less than 2 defectives.

5 Accept the process as working at a satisfactory level if there is no entry in column 4 or the number there is less than 3.

Note: There is really no evidence that the process is not working satisfactorily.

6 If the entry in column 4 is 3 or more, it indicates that the process was not working at a satisfactory level for about the period that there have been continuous entries in column 4. Take appropriate technical action to restore the process to standard technical operating conditions, record this action in

column 5, leave a blank line and restart the table at zero for the next sample.

7 Select a second sample of 20 items from the process, inspect each of them and count the number which are defective to the quality characteristic being inspected.

8 Record the number of defectives in column 2, sample 2.

9 If column 4, sample 1 has anything recorded in it, subtract 1 from the number of defectives in sample 2 and record in column 3, sample 2.

10 Add the entries in column 3, sample 2 and column 4, sample 1. Record the sum in column 4, sample 2 if it is positive. Do not record anything in this cell if it is zero.

11 If column 4, sample 1 is blank and there are 2 or more defectives in sample 2, subtract 1 from the number and record in columns 3 and 4, sample 2. Do not record anything in these cells if there are less than 2 defectives.

12 Accept the process as working at a satisfactory level if there is no entry in column 4 or the number there is less than 3.

13 If the entry in column 4 is 3 or more, it indicates that the process was not working at a satisfactory level for about the period that there have been continuous entries in column 4. Take appropriate technical action to restore the process to standard technical operating conditions, record this action in column 5, leave a blank line and restart the table at zero for the next sample.

14 Select further samples of 20 items from the process at about the same intervals as were used between samples 1 and 2, inspect each of them and count the number which are defective to the quality characteristic being inspected.

15 Record the number of defectives for the r^th sample in column 2, sample r.

16 If column 4 of the previous sample has anything recorded in it, subtract 1 from the number of defectives in sample r and record in column 3, sample r.

17 Add the excess recorded in column 3, sample r to the entry in the previous sample at column 4 and record the sum in column 4, sample r if it is positive. Do not record anything in this cell if it is zero.

18 If column 4 of the previous sample is blank and there are 2 or more defectives in sample r, subtract 1 from the number and record in columns 3 and 4, sample r. Do not record anything in these cells if there are less than 2 defectives.

19 Test the process for stability after each sample result is evaluated by following instructions (12) and (13).

(1) Sample number	(2) defectives	(3) excess	(4) cusum	(5) notes
1	2	1	1	
2	1	0	1	
3	0	- 1		
4	1			
5	2	1	1	
6	0	- 1		
7	0			
8	0			
9	2	1	1	
10	1	0	1	
11	3	2	3	reset lower
12	0			
13	1			
14	1			
15	2	1	1	
16	1	0	1	
17	2	1	2	
18	1	0	2	
19	0	- 1	1	
20	0	- 1		

Figure 1

The data in this table were obtained by simulation to illustrate the procedure.

APPENDIX B

A Simple General Purpose Quality Control Plan Based on Cumulative Sum Technique

2 Control by Measurement

This plan has been designed for a process which produces a product whose quality is determined by direct measurement and for which experience shows that the tolerance is often met by over 99% of a batch run. Past results may show periods of excessive rejects and operating the plan will reduce both the frequency and intensity of these unsatisfactory periods.

It is assumed that there is an objective mean, represented by the symbol, μ, together with a tolerance, T, so that:

$$\text{the low limit} = \mu - T/2$$

$$\text{high limit} = \mu + T/2$$

Normally these are imposed by design, commercial or legal requirements but sometimes the specification is one-sided, say at the low limit, while the upper limit can have any value. In practice, there will also be an upper limit imposed by economic considerations so that the problem still reduces to the control of a measured dimension with an objective mean of μ and an overall tolerance of T.

The plan can be operated either by figures in a table or by plotting a cusum chart. Step by step procedures are given for both methods which are exactly equivalent to one another. The tabular form lends itself more easily for further analysis but the graphical method is simpler on the shop floor.

Columns 1 to 6 of procedure 2 are sufficient for the control of the level of working. Columns 7 to 9 are used if it is desired to have some control of variability as well. Similarly steps (1) to (18) of procedure 3 provide the control of level with steps (19) to (28) for control of variability. It is easier to take steps (20) to (23) immediately after step (15) and to compute and plot y_r immediately after x_r has been obtained.

The data quoted in Figures 2 and 3 were obtained by simulation to illustrate the procedures. Samples 1 - 10 show a stable situation with samples 36 - 45 being set at a lower level. This is detected in sample 45 with evidence that it occurred about sample 41.

The plan gives a fair control when the conditions detailed above are satisfied but it is unlikely to be the optimum; neither will it lead to better basic quality. However it should be simple enough to operate, and analysis of the results by an SQC engineer will indicate the next steps for increased efficiency.

The object is to avoid making any changes to the process when it is working satisfactorily - the chance of doing so is only about one in 500 per sample - while detecting a setting 0.2T away from the objective after measuring an average of only 10 items. It will also detect a 50% increase in variability in about the same time.

Procedure 2

1 Prepare a cusum table in which the observations and control calculations will be recorded - see Figure 2.

2 Record the mean, μ, and tolerance, T, of the specified dimension as indicated at the top of the table.

3 Compute $V_1 = \mu + 0.1T$ and record as the reference value for the ascending cusum as indicated above column 4.

4 Compute $V_2 = \mu - 0.1T$ and record as the reference value for the descending cusum as indicated above column 6.

5 Compute $V_3 = 0.3T$ and record as the reference value for the variability cusum as indicated above column 8.

6 Select a first item direct from the process, measure its dimension represented by the symbol, X_1, and record in column 2, sample 1.

7 If X_1 is greater than V_1, compute the excess $(X_1 - V_1)$ and record in columns 3 and 4, sample 1. Do not record anything in columns 5, 6, 7, 8 and 9.

8 If X_1 is less than V_2, compute the excess $(X_1 - V_2)$ and record in columns 5 and 6, sample 1. Do not record anything in columns 3, 4, 7, 8 and 9.

Note: $(X_1 - V_2)$ will be negative.

9 If X_1 is between V_1 and V_2 inclusive, do not record anything more for sample 1.

10 Accept the process as working as closely as possible to the specification if there are no entries in columns 4 and 6 or, if there are any entries, they are all numerically less than T.

11 If the entry in column 4 is equal to or exceeds T, it indicates that the process is set too high. Reset the process about 0.2T lower, record the action in column 10 and restart the table at zero.

12 If the numerical value of the entry in column 6 is equal to or exceeds T, it indicates that the process is set too low. Reset the process about 0.2T higher, record the action in column 10 and restart the table at zero.

13 Select a second item direct from the process, measure its dimension represented by the symbol, X_2, and record in column 2, sample 2.

Note: This could be the second item made or it could be a sample selected after a suitable interval.

14 Record any technical change which occurred between sample 1 and sample 2 in column 10, sample 1.

15 If column 4, sample 1 has anything recorded in it, compute the excess $(X_2 - V_1)$ and record in column 3, sample 2.

16 Add the entries in column 3, sample 2 and column 4, sample 1. Record the sum in column 4, sample 2 if it is positive. Do not record anything in this cell if the sum is zero or negative.

17 If column 4, sample 1 is blank, compute the excess $(X_2 - V_1)$ if it is positive and record in columns 3 and 4, sample 2. Do not record anything in these cells if the excess is zero or negative.

18 If column 6, sample 1 has anything recorded in it, compute the excess $(X_2 - V_2)$ and record in column 5, sample 2.

19 Add the entries in column 5, sample 2 and column 6, sample 1. Record the sum in column 6, sample 2 if it is negative. Do not record anything in this cell if the sum is zero or positive.

20 If column 6, sample 1 is blank, compute the excess $(X_2 - V_2)$ if it is negative and record in columns 5 and 6, sample 2. Do not record anything in these cells if the excess is zero or positive.

21 Compute the difference between X_2 and X_1 giving this difference a positive sign and record in column 7, sample 2.

22 If the difference found in (21) is greater than V_3, subtract V_3 from it and record in columns 8 and 9, sample 2.

23 If the difference found in (21) is not greater than V_3, do not record anything in columns 8 and 9, sample 2.

24 Accept the process as working as closely as possible to the specification if there are no entries in columns 4, 6 and 9 or, if there are any entires, they are all numerically less than T.

25 If the entry in column 4 is equal to or exceeds T, it indicates that the process was working at too high a level for about the period that there have been continuous entires in column 4,

Reset the process about 0.2T lower, record the action in column 10 and restart the table at zero.

26 If the numerical value of the entry in column 6 is equal to or exceeds T, it indicates that the process was working at too low a level for about the period that there have been continuous entries in column 6. Reset the process about 0.2T higher, record the action in column 10 and restart the table at zero.

27 If the entry in column 9 is equal to or exceeds T, it indicates an increase in process variability which has existed for about the period that there have been continuous entries in column 9. Examine the process to determine the cause, take the necessary action to restore normal working conditions, record this action in column 10 and restart the table at zero.

Note: Any entries in column 10 during the unstable period may give a clue to the cause.

28 Select further items direct from the process at intervals similar to those used in instruction (13) and measure the dimension of each as it becomes available. Denote the dimension of the r^{th} item by the symbol, X_r, and record in column 2, sample r.

29 Record any technical change which occurred between two sample items in column 10 of the earlier sample.

30 If column 4 of the previous sample has anything recorded in it, compute the excess $(X_r - V_1)$ and record in column 3, sample r.

31 Add the excess recorded in column 3, sample r to the entry in the previous sample at column 4 and record the sum in column 4, sample r if it is positive. Do not record anything in this cell if the sum is zero or negative.

32 If column 4 of the previous sample is blank, compute the excess $(X_r - V_1)$ if it is positive and record in columns 3 and 4, sample r. Do not record anything in these cells if the excess is zero or negative.

33 If column 6 of the previous sample has anything recorded in it, compute the excess $(X_r - V_2)$ and record in column 5, sample r.

34 Add the excess recorded in column 5, sample r to the entry in the previous sample at column 6 and record the sum in column 6, sample r if it is negative. Do not record anything in this cell if the sum is zero or positive.

35 If column 6 of the previous sample is blank, compute the excess $(X_r - V_2)$ if it is negative and record in columns 5 and 6, sample r. Do not record anything in these cells if the excess is zero or positive.

36 Compute the difference between X_r and X_{r-1}, giving this difference a positive sign and record in column 7, sample r.

37 If column 9 of the previous sample has anything recorded in it, subtract V_3 from the difference found in (36) and record in column 8, sample r.

38 Add the result recorded in column 8, sample r to the entry in the previous sample at column 9 and record the sum in column 9,

sample *r* if it is positive. Do not record anything in this cell if the sum is zero or negative.

39 If column 9 or the previous sample is blank and the difference found in (36) is greater than V_3, subtract V_3 from it and record in columns 8 and 9, sample r.

40 If column 9 or the previous sample is blank and the difference found in (36) is not greater than V_3, do not record anything in columns 8 and 9, sample r.

41 Test the process for stability as each sample result is evaluated by following instructions (24) to (27) applied to sample r.

Specification 45 - 55

Mean = μ = 50   Tolerance = T = 10

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Sample number	obser-vation	$V_1 = 51$ excess	cusum	$V_2 = 49$ excess	cusum	$V_3 = 3$ diff	excess	cusum	notes
1	54	3	3						
2	46	- 5		- 3	- 3	8	5	5	
3	52	1	1	3		6	3	8	
4	52	1	2			0	- 3	5	
5	50	- 1	1			2	- 1	4	
6	52	1	2			2	- 1	3	
7	48	- 3		- 1	- 1	4	1	4	
8	49			0	- 1	1	- 2	2	
9	51			2		2	- 1	1	
10	50					1	- 2		
36	50					2			
37	47			- 2	- 2	3			
38	49			0	- 2	2			
39	51			2		2			
40	51					0			
41	47			- 2	- 2	4	1	1	
42	50			1	- 1	3	0	1	
43	45			- 4	- 5	5	2	3	
44	46			- 3	- 8	1	- 2	1	
45	47			- 2	-10	1	- 2		reset 2 higher
46	50								
47	49					1			
48	46			- 3	- 3	3			

Figure 2

Procedure 3

1 Prepare a chart on a squared background with the horizontal axis indicating the time and date of sampling and with the vertical axis providing values of the measured dimension.

2 Choose a uniform scale for the horizontal axis which is conveniently graduated in sample numbers.

Note: The plan is not confined to sampling; it can be used when every item is measured.

3 Graduate the vertical scale in terms of the measured dimension so that the specified tolerance, T, is represented by exactly 10 sampling intervals on the horizontal scale.

4 Choose an origin about half way up the vertical axis and at the extreme left of the chart.

5 Make a parallelogram mask in a rigid transparent plastic with an angle of 45^{o} between the adjacent sides and the horizontal distance between the parallel sloping sides equal to 10 sampling intervals on the horizontal scale of the chart.

Note: The vertical distance between the parallel sloping sides will also be equal to 10 sampling intervals.

6 Make a groove along the top (or bottom) of the chart in which the mask can slide while always maintaining a horizontal direction for the base.

7 Select a first item direct from the process, measure its

dimension and subtract the objective mean, μ, from this measurement. Denote the difference by the symbol, x_1.

8 Plot x_1 against sample number 1 to give the first point on the control chart. Take care to use the correct sign of x_1 in this plotting.

9 Slide the parallelogram mask over the chart until the latest plotted point comes on the trailing edge. Make sure that the mask is properly located in the groove to maintain its horizontal edges parallel to the sample number axis.

Note: If the latest point is lower than the immediately preceding point, turn the mask over so that the sloping edges indicate a decrease in cusum for an increase in sample number.

10 Scrutinise the chart to determine whether any of the earlier plotted points (including the origin) fall in front of the leading edge.

11 Accept the process as working as closely as possible to the specification if none of the earlier points fall in front of the leading edge.

12 If any of the earlier plotted points fall on or in front of the leading edge, it indicates that the process was not working at standard quality for about the period between the violating and latest plotted points. Take appropriate technical action to restore the process to standard technical operating conditions and restart the chart at zero.

Note: The technical action for this chart is usually resetting and the amount would be about 0.2T.

It is convenient to leave a space equal to two or three samples when restarting the chart at a new origin; the technical action should be recorded in this space.

13 Select a second item direct from the process, measure its dimension and subtract the objective mean, μ, from this measurement. Denote the difference by the symbol, x_1.

Note: This could be the second item made or it could be a sample selected after a suitable interval.

14 Plot the second point against sample number 2 at a height x_1 above the height of the first point plotted. Take care to use the correct sign of x_1 in this plotting.

15 Test the process for stability by following instructions (9) to (12).

16 Select further items direct from the process at intervals similar to those used in instruction (13) and measure the dimension of each as it becomes available. Subtract the objective mean, μ, from each measurement and denote the deviation of the r^{th} item by the symbol, x_r.

17 Plot the r^{th} point against sample number r at a height x_r above the height of the previous point plotted. Take care to use the correct sign of x_r in this plotting.

18 Test the process for stability after each point is plotted by following instructions (9) to (12).

19 Prepare a similar chart with the same scales to examine process variability.

Note: The same chart can be used both for level and variability if the second set of points can be identified by different colours.

20 Choose a convenient origin on a vertical line corresponding to sample number 1.

21 Compute the difference between x_2 and x_1 giving this difference a positive sign.

22 Subtract 0.2T from the difference obtained in (21) with the appropriate sign to measure the excess of process variability over a provisional standard. Denote this by y_2.

23 Plot y_2 against sample number 2 on the second control chart. Take care to use the correct sign of y_2 in this plotting.

24 Use the parallelogram mask as in instructions (9) to (12) to test for stability of variability.

Note: This would not normally be used to look for decreases in variability.

25 Compute the difference between x_r and x_{r-1} giving this difference a positive sign as each value of x_r is obtained.

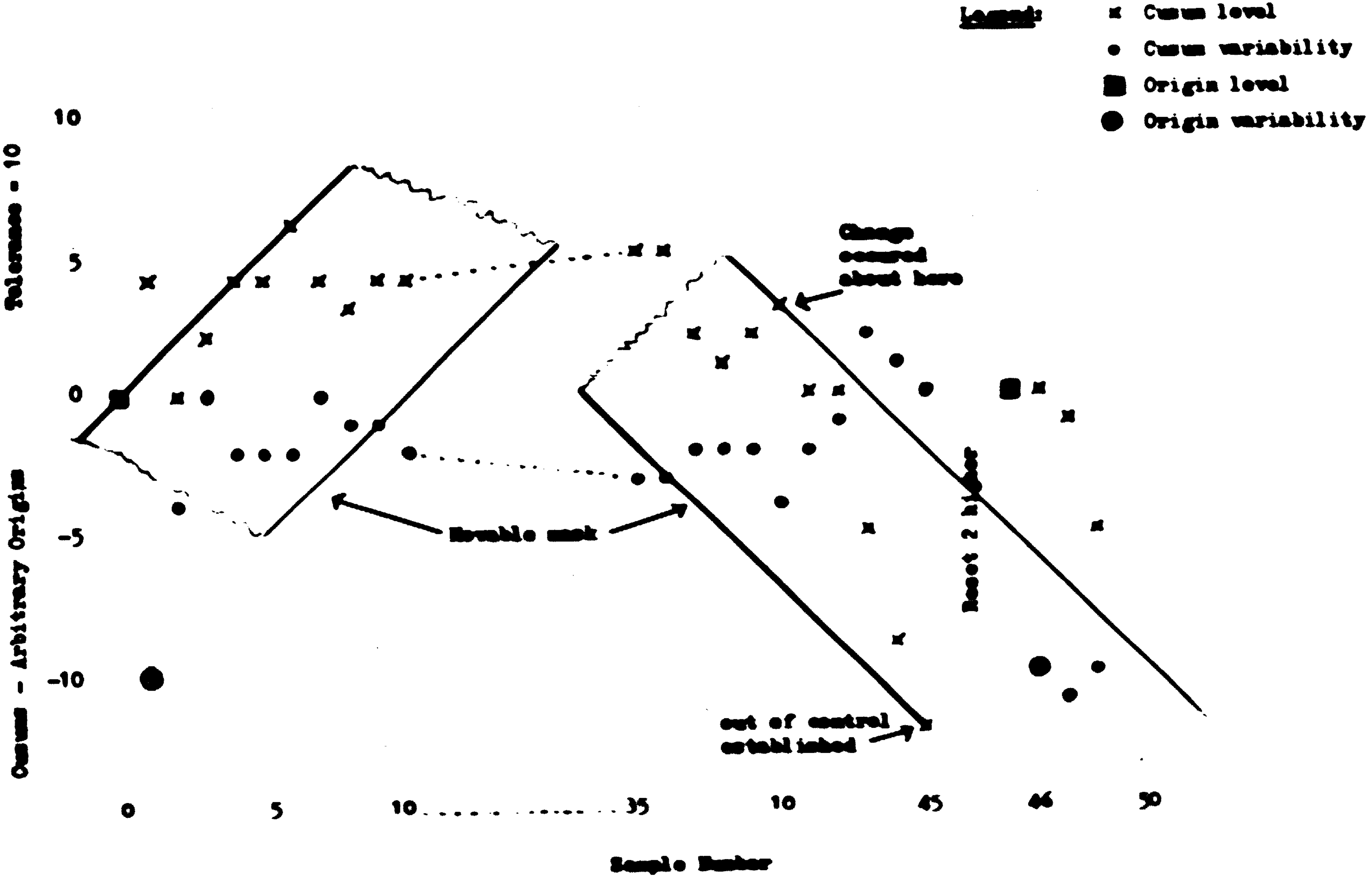
26 Subtract 0.2T from the difference obtained in (25) with the

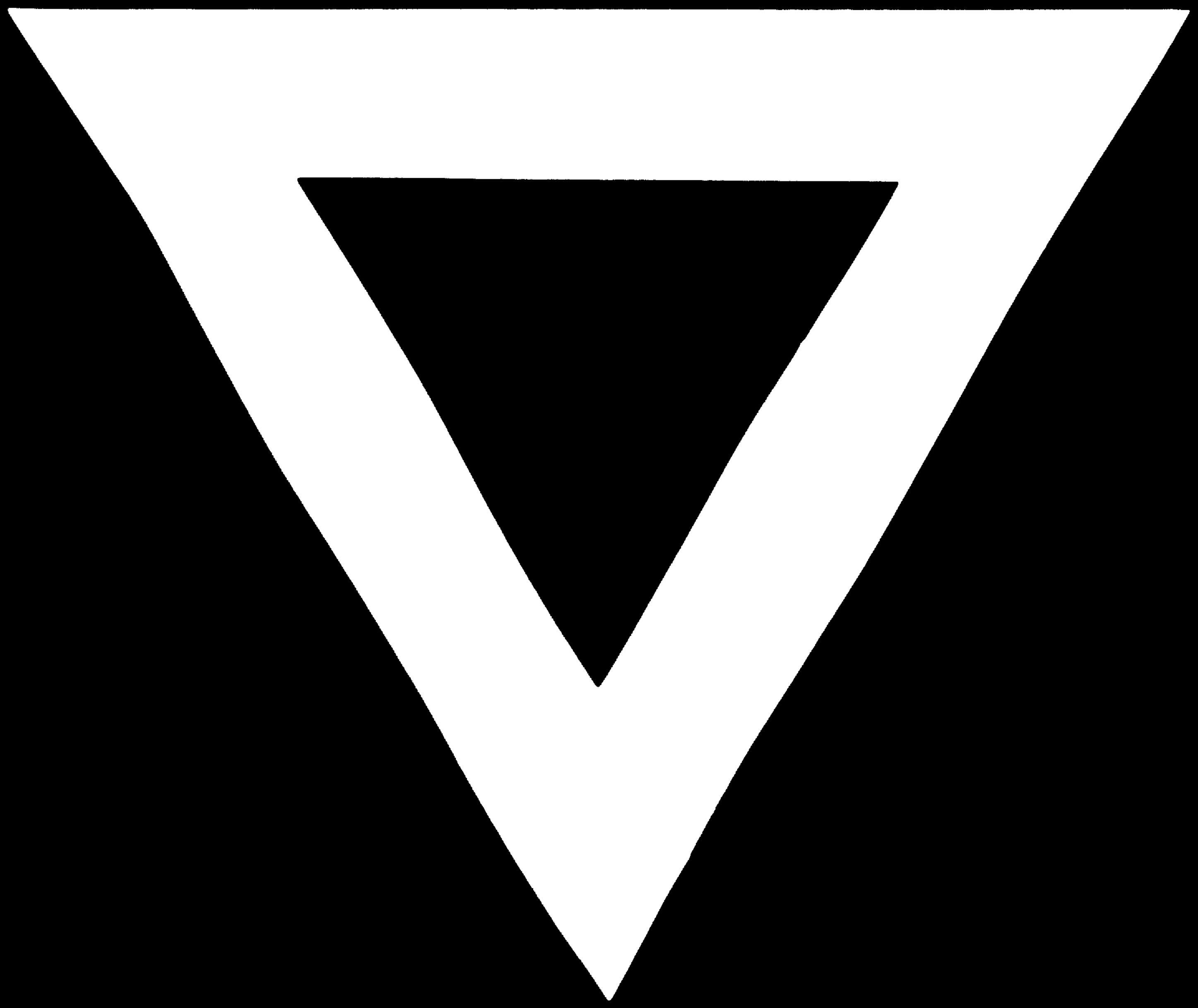
appropriate sign and denote it by y_r.

27 Plot the (r - 1)th point on the second control chart against sample number r at a height y_r above the height of the previous point plotted. Take care to use the correct sign of y_r in this plotting.

28 Test the stability of the process variability after each point is plotted by following instructions (9) to (12).

FIGURE 3


Legend:
x Cusum level
• Cusum variability
■ Origin level
● Origin variability
10
5
0
-5
-10
Tolerance = 10
Cusum - Arbitrary Origin
Change occurred about here
Movable mask
Reset 2 higher
out of control established
0
5
10 35
10
45
46
50
Sample Number



3. 12. 73

measured value is then the control statistic.

Another property of cusum plans is that the most sensitive control is obtained when the reference value is chosen to be halfway between the acceptable and rejectable quality levels. This just leaves a choice of decision interval to design a general purpose plan and it so happens that the decision interval can be made equal to the tolerance if the process is capable of working to the specification. This will not generally be an optimum plan but its simplicity outweighs any small disadvantage on this account. A step by step procedure for operating such a plan is given in Appendix B. It is not suitable for processes which normally produce more than 2% defectives.

This plan has an optional extension to control process variability by examining the difference between two successive samples. It makes no attempt to assign causes to any excessive variability; this is impossible with such a simple plan. They can only come from technical examination when there has been a clear indication that it has occurred.

Alternative methods of presentation are given using a table or a chart. It is strongly recommended that all observations are tabulated, even if the chart is used, and subjected to skilled analysis later to obtain maximum information and hence improve product quality.

The cusum technique can also be used for control when quality is measured by counting the number of defectives in a sample.

These also have a reference value and a decision interval which together with the sample size define the plan completely. In principle it is possible to have samples of one item as recommended for direct measurement but this tends to complicate the application rather than simplify it. Most plans use integral values for both the parameters but this is not essential. One simple pair of values and a convenient sample size have been selected to provide a useful general purpose plan which is given as a step by step procedure in Appendix A. It is designed for use when standard quality corresponds to 2% defectives but it is easily adapted to other quality levels. It can also be used instead of control by variables when standard quality is not good enough for the plan given in Appendix B.

8.3 Industrial Experimentation

Control charts are used to ensure that the achievable quality standard is maintained without reference to whether this will satisfy the market or not. In many cases, particularly for exports from developing countries, this quality is not good enough even when it is maintained. The obvious action is 100% sorting to sell the goods but they can never be as reliable as those which are made to specification. Alternatively the process itself can be examined to determine whether the specified operating conditions are truly optimum or even if it is possible to maintain them within the required limits. It is essential that this is a practical examination which will be applicable to normal production on the shop floor. It is not sufficient to know what can be done in the laboratories of a collaborating company in an industrialised country!

Modern industrial experimentation is designed to give the required information with a minimum of effort and of interference with normal production. This requires the use of statistical methods to determine the combination of input technical factors which gives optimum quality. The input technical factors are obvious and normal operating values, with tolerances, will have been assigned to them. In moulding rubber, these are temperature, pressure and cure time and there may be others. Quality will also be affected by less obvious factors which may be of greater importance. These include batches of material, operators, machines, shifts, etc. all of which produce variability which has to be accepted.

An experiment can be designed to determine how quality is affected by all of these together with any interactions which are considered, in advance, might be important. The experiment can be limited to the ordinary range of variability used in manufacture or some factors can be given values outside their usual intervals. It is important to know just how quality will be measured and whether any other aspects such as productivity or cost are also to be taken into account. It is even more important that the observations are taken after changed conditions have had sufficient opportunity to settle down and that the operator makes no special effort to obtain better quality than he usually exerts. Finally it must be possible to deduce how much variability in product quality would remain if <u>all</u> factors are maintained exactly at specified levels. This is a statistical abstraction but it can be deduced from a properly designed experiment. It is desirable that this statistical "error" can be deduced in more than one way as an overall control on the conduct of the experiment.

Graduate statisticians can be trained in the principles of design of industrial experiments. They must collaborate with the technical personnel and share the responsibility of supervising the operators during the actual performance to ensure that it is carried out as planned. Even so, there will often be discrepancies and a well trained industrial statistician will be able to extract the maximum information from the data collected.

The largest proportional potential improvement in quality and efficiency occurs in small firms with their simpler technology. Their best way of helping themselves is to conduct suitable experiments to determine optimum operating levels for all technical factors which they can control together with estimates of the quality standard which these will produce. They then require a quality control plan to ensure that this quality standard is maintained. Such a programme requires highly trained professional personnel for investigation and installation. Small firms cannot afford to employ such people permanently and would be unable to make use of their skill for more than a small part of their time if they were so employed. Routine control can be exercised by relatively unskilled people with simple training.

9 Assistance

9.1 Extension Services

Possibly the greatest obstacle to improving product quality is inertia. Often this arises because the manufacturer does not know what quality he makes nor how much it varies from day to day. He may truly believe that he cannot do anything about it and that he is only able to satisfy his customers by sorting the work immediately before dispatch. This certainly occurs in craft industries, such as pottery, where material variations are blamed for everything that goes wrong. The attitude is that better material will come to hand later and then quality will recover automatically. He will not have any facilities to test the raw material and he will not know what properties should be measured for him or what values they should have. As long as he buys clay, he is able to make pottery and experience tells him that sufficient of his output will be saleable to stay in business.

This situation improved greatly in industrialised countries with the establishment of industrial extension agencies in the form of Research or Trade Associations. These are supported by the particular industry and often receive grants from public funds. Technical information is available to any member firm and any management technique appropriate to the industry. Some Research Associations also offer training facilities, both technical and managerial, to their members. They will also tackle specific problems for member firms but with full economic consultancy charges.

Developing countries are now following the lead with similar extension services but they require more publicity for wider acceptance particularly by the smaller organisations. These receive government grants and possibly they should be increase if sufficient officers of adequate calibre are available for employment. Their services should always be subsidised even for specific company problems but the magnitude of the subsidy could be related to the value that the solution contributes to the national economy taking account of the firm's size.

A particularly fine example of extension service agencies is the group of SQC Units in India. These provide a limited consultancy service, particularly in quality problems, but require that the actual collection of the quality data is made by factory personnel under guidance. Analysis of the data and subsequent establishment of quality standards and control procedures are performed by the Unit consultant. The whole project is turned over to the factory for routine operation as soon as possible. Maintenance visits are made from time to time to ensure that quality standards and controls are kept up to date.

These SQC Units are also engaged in training at all levels. They offer a full time one-year course in SQC and related techniques at a professional level with continuing employment as junior consultants until such time as the young graduates are capable of independent work. This particular activity is not of particular interest to small firms except that it creates the consultants who can help them occasionally.

There are also short training courses over two or three weeks to which small firm personnel have been sent with great benefit particularly in conjunction with the consultancy service.

9.2 Central Testing Laboratory

These exist in many countries with the primary object of standardising and calibrating measuring equipment. They also make actual measurements of quality when disputes arise and are available for such measurements when the supplier or the customer does not possess the facilities himself. They are often supported by public funds and their charges may not include all the basic overheads. There are similar laboratory facilities in many extension service agencies. Small firms should use this kind of laboratory for the calibration of their test equipment. There should be regular checks, particularly of gauges which certainly change in size with constant use. The amount of change should also be recorded in the laboratory report so that the small user can estimate the rate and hence decide how long an interval it is safe to use the equipment without re-standardisation.

Some factories send samples of their output or test pieces to these laboratories for measurement. These may be to verify the accuracy of their own tests but more often the laboratory will provide the only quality measurements. If these are not satisfactory, the small manufacturing unit may decide not to dispatch the particular batch but frequently it will have been sent before the test results are received. It must be emphasised that, although this may be very useful and should be encouraged, it is <u>never</u> control of quality even if the poor work is scrapped or rectified.

9.3 Large Plants

There are two main areas where small firms can obtain assistance from large plants. The first occurs when they are the customer and the large supplier wishes to maintain or improve his share of the market by providing technical data about his product - the small firm's material - so that it can be used efficiently. Generally this data is only available in instruction documents provided at the time of sale. A very fe large companies are prepared to go further than this and will offer their know-how as part of their sales campaign.

The other area of assistance occurs when the small firm acts as a sub-contractor. Here self interest is often the dominating reason since failure to obtain the right goods of the right quality at the right time can be very expensive to a large highly organised industry. In addition to providing detailed specifications with drawings to show exactly what is required, many firms will also explain in great detail how the components should be made and supply special tools and fixtures to help to achieve this objective. They may also indicate how they will verify that the quality of the goods is satisfactory and propose that the sub-contractor should use the same sampling plans. This, by itself, will not ensure that the components are made correctly and some form of quality control during manufacture is also required. Suitable plans are sometimes