Chapter 15
The Culture of Statistical Quality Control

15.1 Fulfilling the Prerequisites: Culture and Expertise

The purpose of this chapter is to explain how small and medium enterprises (SMEs) can gain the advantages statistical quality control (SQC) can offer. The text is written in a way that bigger firms, too, may use it, particularly those who do not yet have but contemplate installing a statistical system for quality assurance.

On the hypothesis that many small to medium enterprises have not in operation SQC, I start by outlining the prerequisites, foremost among them the change in internal culture regarding product assurance. Skill, too, is important but it can be acquired from outside the firm both to help in starting an SQC system and to train the company's people on how to use and manage it.

Culture cannot be acquired from the outside. Section 15.2 provides the reader with a real-life case study on how much cultural change counts. SQC calls for discipline and in a number of companies this is in short supply. To be successfully implemented SQC also requires homogeneous systems and procedures throughout the organization. Frequently, this is assumed to be the case, but is not documented by the facts.

In addition, because one of the important characteristics of SQC implementation is the change from 100% inspection to sampling inspection, the company's management and all of its professionals must appreciate statistical inference. This cultural change is not as easy as might seem because not all schools teach causal inference as they should do.

Whether by attributes or by variables, statistical plans imply randomization and they include causative factors which assist in data interpretation. Causal analysis may be complicated by the fact that in many cases there are several causes, some of which may be interrelated—hence the need for experimental design discussed in Chap. 11.

In the background of the approach to quality control in the large and in the small this book described, lies the fact that, in the real universe, there are no fixed sets of *self-evident* truths or theoretical definitions, axioms, and postulates. Researchers, and

D. N. Chorafas, *Quality Control Applications*, Springer Series in Reliability Engineering, 295
DOI: 10.1007/978-1-4471-2966-0_15, © Springer-Verlag London 2013

indeed all scientists, typically operate on the basis of assumptions which they have accepted as being sufficient up to a point, but:

- They continue being eager to challenge the "obvious" and
- They are open-minded about discovering that some of their assumptions might be false, or that some other principles they had not appreciated are the determining factors.[1]

I bring all these notions to the reader's attention because while SQC is a powerful scientific tool, it will not be effective if its implementation clashes with the company's culture. The wrong way of looking at science is to believe that scientific proof is a matter of showing formal consistency with a set of what are treated as being *self-evident* truths because they are based on prevailing theories. Not only is this false, but also the effect of believing in it:

- Impacts in a negative way the mind of people and
- Leads to denying the existence of anything outside the bounds of that system whose "laws" make it practically deterministic.

By contrast, the concept of causal inference is synonymous to a state of mind characterized by the quest for answers which are *stochastic* rather than "certain". In real life the notion of being "certain" answers rarely if ever research requirements. Expecting things to come your way is an illusion. Stochastic answers involve uncertainty about a measurement, an observation, an event, an outcome. But that is how science (and to a considerable extent business) works. What I just said is valid whether the answer concerns:

- A description,
- An observation, or
- An explanation.

The existence of an open mind able to think in terms of statistical inference is so fundamental that it underpins the entire field of statistics. This statement is valid whether we talk of tests of hypothesis, sampling, $\overline{x}$ plots, $\overline{R}$ plots, percent defective p, fraction defective c, tests of significance, statistical tables, or a graphical exposition of trends and conditions.

Measures of central tendency and of dispersion, frequency curves, regression analysis, covariance, correlation, and a long list of statistical tests, or presentations, evidently including SQC are all based on causal inference. This is also true whether our measurements are experimental or observational, but in quest of description and explanation.

The problems to which these notions apply are not only industrial or scientific. They may as well be economic, demographic, or many other fields where causal inference is at a premium. The reader who went through the first 14 chapters of this

[1] Everything changes, said Herodotus the ancient Greek philosopher.

book will appreciate that the outlined approach to the analysis of cause and effect rests on three pillars:

- Statement of the hypothesis,
- Estimation of parameters, and
- Testing of the hypothesis.

To analyze data statistically the hypothesis must be expressed in a mathematical form, as a model with two components: assumptions and random events influencing the subject under study. Assumptions are outlined in a cause and effect duality. Random events are essentially responsible for deviations between observed and expected values—unless there is a bias in the system.

The test of hypothesis takes the form of testing the results of statistical analysis against other knowledge some of which is derived from causal inference. In the medium to longer run, however, confrontation with new data derived from operations is the ultimate test of hypotheses. Even when it is verified, the hypothesis remains a tentative statement which might be upset by new facts.

Any SQC plan, including the simplest ones, which does not start with the statement of hypothesis and follows up with testing will not worth its salt. Sampling plans, too, have rules which must be observed. In addition, the right methodology must be established for an SQC implementation.

These are, in a nutshell, the elements of the new culture a company will need to acquire in order to successfully implement scientific tools in its management, SQC being one of them. This leads to the next prerequisite: How well trained are its human resources in terms of stochastic inference and statistical tests.

A company which starts with implementing SQC will require an experienced person, usually an outsider to train and to provide technical assistance to the internal quality control group. My recommendation is that this SQC specialist starts his work in collaboration not only with manufacturing but also with engineering, to assure that the inherent quality of a design is fully observed in the manufacturing operations.

Consultants, however, should be on tap not on top. The company will need to develop internal SQC resources, and to appoint an able person to be in charge. His *job description* should include checking all parts used in fabrication, to ascertain that all components have correct tolerances and acceptable failure rates. This evidently requires establishing and carrying out a program of acceptance testing for all incoming parts; as well as a program of production level tests to be applied to the fabrication lines.

Together with the SQC consultant, design engineers and manufacturing engineers (also field maintenance personnel, if field maintenance chores are applicable) the SQC manager should initiate a program to study the company's specific mechanism of failure. The details of this effort will be carried out at the functional group level. More often than not, the aforementioned effort will require a thorough reliability evaluation of the production equipment to be made through special tests.

- These tests should yield an accurate measure of both the inherent equipment reliability and accuracy in observing engineering specifications and
- Because manufacturing may have conflicts of interest in evaluating its present machines, such tests should be performed by an independent, unbiased group with some outside assistance.

Also part of the SQC manager's *job description* must be the investigation of the current state of the art of testing for quality. By monitoring failure reports the SQC manager is in a position to inspect, at frequent intervals, the behavior of equipment used for production. To perform these tasks in an able manner, the SQC manager will do well to follow the advice by the father of Admiral Chester W. Nimitz to his son:

- "The sea—like life itself—is a stern taskmaster."
- "The best way to get along with either is to learn all you can."
- "Then you do your best and don't worry—especially over things you have no control [1]."

If the word "sea" is replaced by quality and reliability, *then* what Nimitz' father said fits hand in glove stochastic inference—and therefore the premises necessary to successfully implement an SQC system.

15.2 Restructuring System and Procedures

The president of GAMMA, a mid-sized manufacturing company, expressed as follows his opinion on the projected implementation of SQC: "We are concerned with the problem of quality inspection, but somehow it has been difficult to introduce statistical tools in our firm. Discussions along the line of a statistical methodology have taken the last 4 years. We now wish to introduce the necessary systems and procedures, but both our factories must be in accord on common standards."

In the opinion of the executive VP/Manufacturing, GAMMA was missing an analytical culture. The way he put it: "What we do today is very largely empirical. We do not really know 'why' in an analytical sense, we just do so. In some aspects we lack coordination in quality control. But our competitors, too, are confronted by this problem."

A preliminary study showed that the lack of common standards on quality inspection prevailed not only between the company's two factories, but also between different shifts in the same plant. The second shift, for example, had higher percent defective than the first because it employed only foremen. There were no engineers present in the second shift as they all worked in the first shift. Quality simply received a different handling. (From my experience with other companies I can say that the second shift almost always gives lower quality results.)

Because several incompatible standards could be found in the fine tissue of the manufacturing process, it was important to account for them at a certain degree of precision in order to establish the appropriate quality control methodology. Factory I, for example, had installed at the production floor a quality control template which permitted the supervisor to easily decide whether adjustment is necessary.

Factory II was not following this (recommendable) practice. What is more, there existed certain confusion between what was called "screening test" and fully fledged quality control. That screening test had little if anything to do with inspection at the production floor. Quality control was done on a 100% basis at the "banks" between two production lines where semi-manufactured goods were stored.

The differences between the two entities went down to a level of detail. Factory I did electrical tests for resistance. Within Factory I operations, however, there existed substantial disagreements on the importance of the electrical resistance tests, as opposed to weight and diameter measurements.

Factory II did not believe in these tests. At the headquarters, some of the manufacturing engineers like one approach; others follow exactly the opposite one. Testing methods varied so much from one factory to the other that products which passed the test in one factory could be rejected in the other, and vice versa.

Rejection meant that the product will not be outright scrapped but will be (probably) sold at a discount. Or, in case the factory was out of stock of products which passed the test, rejected products will be reworked and sold.

Another example has been that of tests destined to give indications on minimum and maximum weight which is important for GAMMA's second product line of manufactured goods. In Factory II, ten units were taken out of a box and controlled for weight. Factory I took a sample of five units out of each box for quality inspection purposes. From this sample of five, Factory I computed the mean weight. Corrective steps were taken if the mean weight exceeded specified limit.[3]

The flaws in the two factories' quality control procedures do not end there. The inspectors assigned to the job were not properly trained. They had a cookbook in which a quarter of the values of control ranges were missing. Going through the cookbook I found some control data were written in pencil. The answer to my question *why* has been that they were tentative (!).

To make matters worse, the inspectors were thought as being able to know by heart the different control ranges. Out of five tests one of them did in front of me, he passed one test but failed the four others he could not exactly remember. This is how GAMMA built quality into its products.

Even when and where mathematics of sorts was used, the methodology necessary to improve inspection procedures and practices was missing. In one of the production lines of Factory I, sampled lots were checked through the kind of tests which were disavowed by Factory II as being irrelevant; and when sampling inspection was practiced, the sample size varied.

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[3] This, however, was characterized as "tentative".

The statistical plan in that particular product line of Factory I, where a semblance of SQC was used, run as follows: If one, two, or three defects were found, the lot was accepted. If four or five defects were found, the inspector drew another sample. For six defects or more the lot returned for 100% inspection. Three things can be said about this approach:

- Superficially, it looked as if it were a reasonable sampling plan. In reality, this sampling was invalid because no study has taken place to document its mathematical/statistical foundations.

As a result, the acceptance/rejection of lots worked like a roll of the dice, without confidence limits being placed on the (accept/reject) decisions.

- The quality control plan lacked even a tentative corporate acceptance by senior management.

The director of marketing said that *if* this were a sound quality assurance program, it would have been adopted throughout GAMMA's operations. Marketing wanted to have a homogeneous basis for quality judgment, but then several of the company's engineers challenged the validity of that plan.

- The difference of opinions among manufacturing engineers and design engineers, at headquarters, was such that no sound SQC plan could be developed.

The contradictions characterizing the different quality control opinions at the home office were such that wherever quality records existed they were incompatible with one another, hence impossible to examine them in a dependable manner. It comes therefore as no surprise that the mission given to the consultant was to come up with a firm plan for SQC able to integrate the different practices and assure that sound quality control principles are first established, then followed by a thorough revamping of systems and procedures.

Three alternative sampling plan solutions were elaborated by a working group which included designers, manufacturing engineers and the consultant. Testing each one of them, the group came to the conclusion that, given the company's product line, the better method to adopt was sequential sampling with lot templates (Sects. 15.4 and 15.5). A cost/benefit analysis was made prior to presenting this quality control plan to GAMMA's management board for approval.

Integral part of the proposal has been an intensive training program involving key personnel from headquarters, and the two factories. Both engineers and marketing people participated in an effort to induce a cross-departmental cultural change.

Regarding the implementation mechanics of the quality control system, the first options of starting with one of the factories was disregarded because of the risk of inter-factory friction. Instead, it was decided that the better approach was to be implemented SQC simultaneously at Factory I and Factory II at properly selected production lines.

Based on lot templates and sequential inspection, the methodology of the SQC plan which was adopted, allowed switching from normal to tightened inspection

procedures as quality worsened. Then, back to normal and eventually to reduced inspection as quality improved.

The consultant insisted on the fact that the new systems and procedures being elaborated for quality control, as well as the statistical methodology underpinning them, should be followed throughout GAMMA's operations without "ifs", "buts", and deviations. This required extending the original training program beyond quality inspectors and salesmen to include management personnel at headquarters and the factories. The aim was to assure:

- The full understanding of the SQC method and
- The need to observe all prerequisites of an effective statistical quality assurance.

The consultant further suggested a number of experimental studies aimed to establish the exact nature of defects and their background reasons. Apart from the benefits these studies were expected to bring in better understanding of quality problems, the proposed plan bet on a reduction of inspection time by eliminating repetitive work. One of the plant managers had provided evidence that in the course of a month 23.403 h were spent on inspection and control.

In conjunction with the SQC methodology, the question was raised about defect patterns by the plant. In that same factory, the cumulative rejection rate for all types of products has varied between 12.6 and 26.2%. Worse yet, 8% of these rejections precisely were non-identified—a vague reason being given was: "early processing".

The cultural change effort progressed in parallel to the SQC methodology. As one of the factory directors was to comment "I am many years in manufacturing. There are many things which are *very* necessary. We have to do them. In deciding 'what' we must study expected results and check costs against them. The time has come to institute a uniform quality control system in our company."

15.3 Implementation of Sampling Plans in Smaller Firms

The concept and process of sampling have been fully described in Chap. 9, where it was stated that sampling plans are the foundation of every SQC procedure. Table 15.1 summarizes the symbols and abbreviations with which the director of an SME and his SQC manager should become familiar.

What the general manager of a company introducing SQC, and his immediate assistants, should appreciate is that in the background of sampling plans lies the fact they are expected to reveal the level of quality assurance in the population. It needs no explaining that whether we talk of manufactured products or financial accounts, their inherent quality level is very important.

The first step in utilizing sampling plans is to realize that this is a reasonable compromise and not an absolute guarantee of outgoing quality—which cannot even be provided by 100% inspection. Chapter 14 familiarized the reader with the percentage of defective items and the probability of accepting a lot containing that percentage of defects at a given level of significance. The concept of level of

Table 15.1 Table of symbols and abbreviations used in SQC

Widely used	
AQL	Acceptable quality level
AOQ	Average outgoing quality
AOQL	Average outgoing quality limit
LTPD	Lot tolerance percent defective
OC	Operating characteristics
OCC	Operating characteristics curve
P_A	Probability of a lot being accepted by a sampling plan
SQC	Statistical quality control
in Sampling	
N	Number of items in a population
n	Number of items in a sample
in $\bar{x}$ *and R Charts*	
x	Measurement of one item in a sample
$\bar{x}$	Mean value of a sample
$\bar{\bar{x}}$	Mean of mean values
R	Spread, or range, of a sample
$\bar{R}$	Mean range
UCL	Upper control limit
LCL	Lower control limit
UTL	Upper tolerance limit
LTL	Lower tolerance limit
in p charts	
p	Percent defective
$\bar{p}$	Mean percent defective
in c charts	
c	Defects per production unit
$\bar{c}$	Mean defects per production unit

significance, or confidence, has been introduced in Chap. 10. Basic notions in a sampling inspection are:

- A representative sample is one drawn from a uniform population.
- Random sampling could make a "not so uniform population" act *as if* it were nearly uniform.
- The sample size should be large enough to adequately represent the population.
- The size of the population generally does not affect the representativeness of the sample; more important is the sample size.

Typically, sampling plans are classified by sample size, a measure of the amount of inspection required, and acceptable quality level (AQL) of the lot (or sample). A company starting with SQC must appreciate the importance of capturing the characteristics, effects, and interactions of items in a population. This is done by using the sample as proxy.

The bolts and nuts of sampling are simple. Typically, a random sample is taken from a lot, and a decision reached to accept or reject is based on the number of

defectives found in it. There exist different sampling methods and choice among them is usually influenced by intended use. Such choice should take place at the beginning of a quality control program, in full consideration of the dynamics of the statistical inference we are after. A post-mortem choice is like betting in a horserace after the horses run their course.

A standard or normalized sampling inspection procedure is a procedure for selecting and using sampling plans in accordance with statistical theory. With a standard procedure, the range of choices is narrowed to relatively few alternatives, with detailed prescriptions becoming available for choosing among them. A normalized approach leads to quality control decisions through properly established evaluation steps.

Because the mass production of manufactured goods and of services like the handling of transactions and accounts, is the order of the day, it is no longer practical to sort item-by-item and look up each one's quality right after they have been made. I do insist on these matters because statistical inference is so vital to the success of an enterprise—of practically every enterprise.

- A sampling plan works in accordance with statistical laws and its results are always subject to probabilities.
- But over a period of time, a sampling plan will give desired protection, even if there are risks associated to the behavior of "this" or "that" variable.

An interesting similitude between SQC, indeed quality control at large, and business decisions is the importance of identifying and handling the controlling variables. Decisions are not made in the abstract. This identification provides the necessary focus which concentrates the decision maker's mind on what is really important.

Let us consider a case in which it is desired to control the variability of a production process. Statistical relationships connected to random variations add by the sum of squares, rather than by straight addition. *If* one source of variation contributes seven units and another two units, the total variation is not too different from the more important of the two[4]:

$$\sqrt{7^2 + 2^2} = \sqrt{53} = 7.28$$

In effect, this is saying that the vital variable has such an overriding effect that even complete elimination of a secondary source would be insignificant. The lesson to be learned from this example is that the proper combination of vital few variables, identified by the approaches already described, is the best way to be in charge of a process—from decision-making to quality assurance. This is, as well, one of the simplest ways to explain the logic behind SQC.

What the preceding paragraph brought to the reader's attention is the so-called *zero center method*. Say that the manufacturing process has the capability to be

[4] This in managerial parlance may be behind the *salient problem* confronting the CEO.

within engineering tolerances, but *resetting* is required due to tool wear. If so, resetting is the key variable.

The way to be in charge of it uses quality control by attributes (Chap. 14). Companies employ a marked board, laid out in colored areas, in which holes are drilled to accommodate the workpieces which belong to a sample and have been gaged by the operator.

- Parts above the nominal dimension are placed on one side of the board and
- Parts below the nominal dimension are placed on the opposite side.

If one side of the board has been filled and a critical number has not been exceeded on the other side of the board, this simple SQC procedure conveys the message that the process has shifted and needs to be reset.

Just like the operator must be trained to apply this method the SME's CEO must be trained to appreciate it. The operator also needs to be provided with a gage set at the nominal dimension of the process, as well as with a board containing holes that have been equally divided on the left and right sides. The top hole(s) on both sides are painted, say, red to designate the critical number.

The operator's or inspector's work is by no means complex. What he does is to check the parts at random intervals depending upon how fast the process shifts. This resembles the normal, tightened, and reduced inspection of which we spoke in Chaps. 13 and 14. He places these parts on the correct sides of the board.

When either side of the board is filled, the operator looks at the opposite (remaining) side to determine whether or not he has gotten "out of the red". If not, then his machine must be reset.

The message this simple example brings to the reader's attention is that statistical inference does not always require sophisticated models. At operator level the setting may be very simple so that the statistical method is applicable without extensive training. The inspector should however have a deeper knowledge so that he can explain to the operator (and to management) not only how the method works but also *what* went wrong and *why* it did so.

15.4 Lot Templates for Quality Inspection

Lot templates, the theme of this section, is a fairly simple and popular sampling technique from quality inspection that could assure an accuracy comparable to that of conventional sampling plans, particularly where lot sizes are small. The example with the board in Sect. 15.3 is indeed a lot template.

Fundamental to a lot template quality control plan is a histogram which gives information about product quality. The essential activity is no different from that discussed in Chaps. 13 and 14. Samples are taken from ongoing production to be controlled by the template. Our assurance of the end result's dependability comes from the knowledge that:

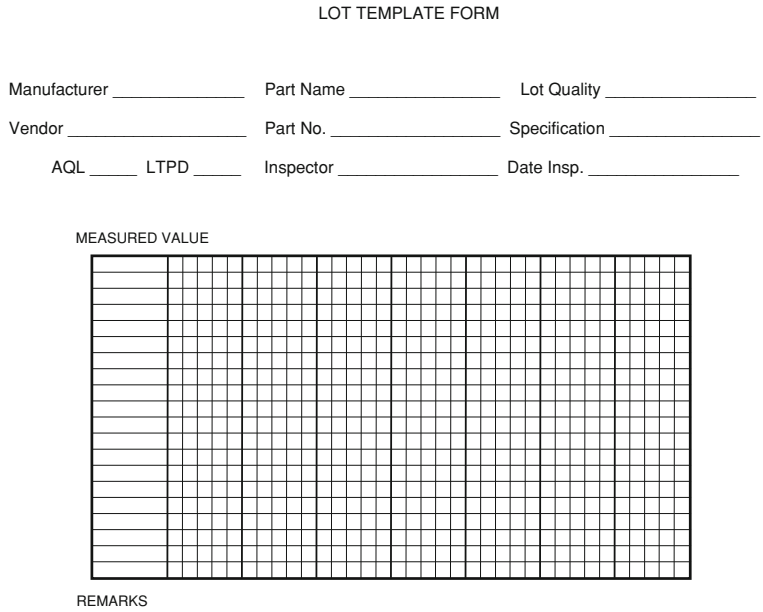

Fig. 15.1 Lot template form

- The variability of the sample is small and
- The histogram is well centered within specification limits.

Contrary to the example in Sect. 15.3 the lot template plans we will study in this section are for inspection by variables and not by attributes. Moreover, the basic procedure is for *acceptance inspection*. Templates are not a tool for control of a production process like the applications we have examined in Chaps. 13 and 14.

To start working in a lot template plan we must obtain a random sample of 50 pieces which will be measured for the specified quality characteristic we wish to control. This must be a random sample. As with every quality inspection plan, the next step is to record the measurements on a *lot template form* (LTF), on which we have set the appropriate specification limits and a suitable scale. An example is shown in Fig. 15.1).

After each measurement is made, a number from 1 to 50 in sequence is placed in the row or cell that corresponds to the value of the measurement. When all 50 readings have been plotted, we have a simple frequency tally or picture of the spread of the product's characteristic that was measured.

Whenever possible it is advisable that the measurement scale is adjusted so that the resulting frequency tally (or histogram) has between 9 and 15 cells. This permits to get a more accurate estimate of the population from which the sample of 50 pieces has been taken. Such an adjustment can be accomplished by estimating

Table 15.2 Determination of lot template scale

Range	Units per cell
3–6	1
7–13	2
14–26	3
20–32	4
27–32	5
33–40	6

the spread of the product from the range of the first seven pieces, driving the scale according to Table 15.2.

The *range R* is computed from the first seven measurements of the random sample of 50, used to construct the plot. *Units per cell* gives the number of units of measurement that must be assigned to each cell to result in plots of approximately 9–15 cells. For range values over 40, or for decimal values, the quality inspector or operator should move the decimal point to the left or right accordingly.

- *If* the *R* value is between 0 and 3 measurement units,
- *Then* the sensitivity of the measuring instrument must be increased.

Notice that while a range of one sample of seven observations may give the most efficient estimate of the scale to be used, the calculation of template values is based on the $\overline{R}/d_2$ relationship which provides a proxy of the standard deviation (see Chap. 2 for the values of d_2). Hence product history and specification limits should also be considered in determining the appropriate scale.

Figure 15.2 presents an example with three templates. The first is a normal template of those most frequently used (we will see how). It has nine cells and a standard deviation (s) of 1.5 cells. The second is also a normal template with 12 cells, with an s of two cells. It has been included to underline that the lot template method does not deal only with normal distributions and their approximations.[5]

When the product being inspected is well centered within the specification limits, this indicates that the process is in control. *If* the product is grouped against one of the specification limits, *then* there is a problem and it may be necessary to follow the procedure for screened lots.

Depending on the application, it may happen that during the definition of inspection by variables it becomes necessary that the measurable range be subdivided into small intervals. *If* the specification is such that we cannot divide its range into a suitable number of intervals, *then* either:

- The specification is unrealistic or
- The measuring instrument is not sufficiently sensitive.

[5] It might happen that because of low product variability, the use of an inadequate measuring device, we cannot divide the range of measurements into sufficiently small intervals. When this happens, we may have a plot only 3 or 4 cells wide.

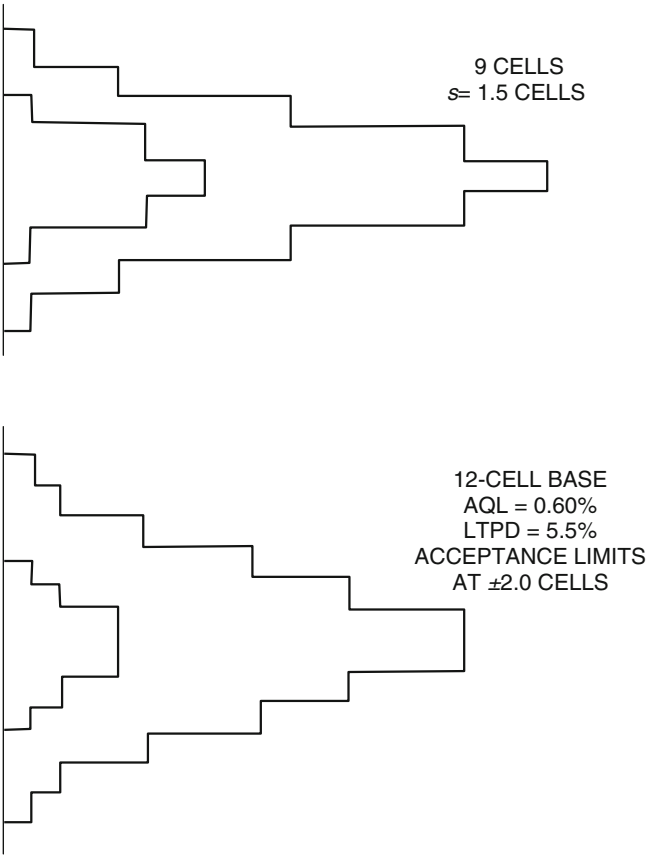

Fig. 15.2 Example with two lot templates for normal distribution

Provided that this setup phase of lot inspection by templates has been successfully completed, we can proceed with the second phase of the plan which consists of testing the plot through the use of transparent guidance templates on which are marked the upper and lower cell limits. An example is given in Fig. 15.3 with skewed templates, designed to be fitted over the sample plot. When this is done, an estimate of the variability is determined in terms of cell units.

As the foregoing discussion suggests, template design is a crucial aspect of the whole process. A company will be well-advised to develop a series of templates having different numbers of cells and able to accommodate plots of varied spread or base width is available.

For an example on how to proceed with implementation, say that we have plotted a random sample of 50 observations from a lot. If this lot is approximately normal, the number of observations in each cell of the sample lot can be expected to fall within the upper and lower cell limits of the template. The determination of *cell limits* is accomplished by binomial expansion using the expected frequency

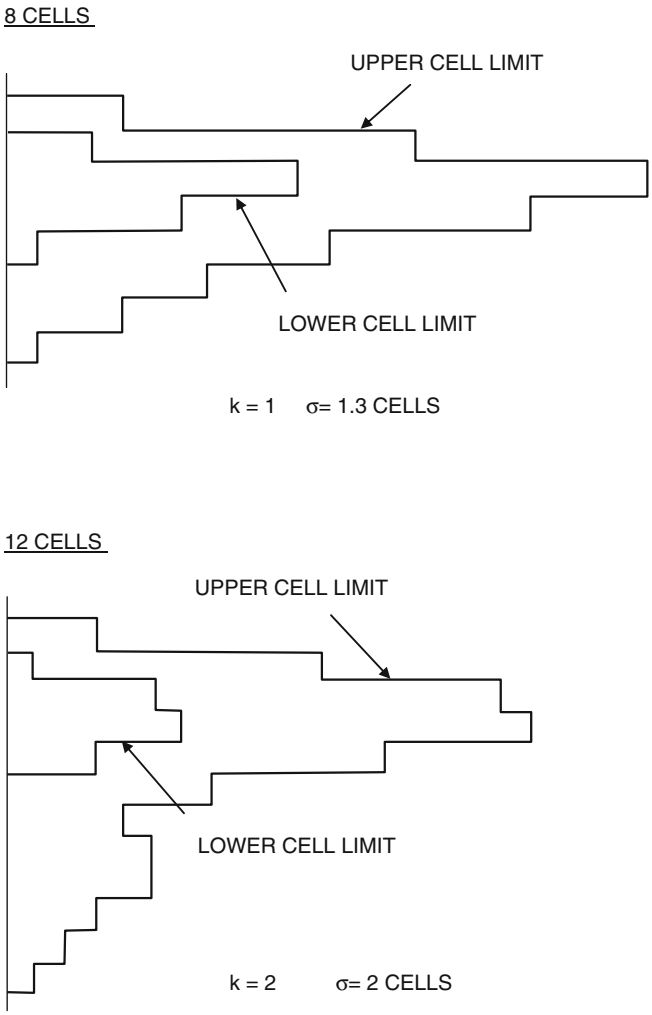

Fig. 15.3 Example with skewed templates

limits for each cell. This should be calculated so that the overall results will fall within 95% acceptance of plots from essentially normal lots, when tested with normal templates.

It is not difficult to appreciate that the implementation of the template method is quite forward. Although it requires training it is not necessary for this to be done at a sophisticated level. On the contrary, the developers have to be versatile in mathematics because behind the foregoing example was the performance of a test similar to the Chi-square (χ^2) for goodness fit.

When the smallest template which fits the plot is found, this becomes the best template estimate of the shape or spread of the parent lot from which the plot was

made. If the normal templates do not fit the plot, the developer(s) should try skewed templates of $k = 1$ or $k = 2$. The developer(s) should also be keen to estimate the mean and variability of a lot. For this they can compare the template estimates with other standard estimates of mean and standard deviation. For instance,

- For instance the template estimate of the mean can be compared with the arithmetic mean of the samples and
- The template estimate of the standard deviation compared with the root-mean-square method.

The distribution of the template means and standard deviations can show whether there is less or greater variability than the distribution of the true averages. If neither is the case at the chosen level of significance, it can be concluded that the template estimates are quite satisfactory.

If the quality inspector does not know whether the lot is or is not normally distributed, it is better to start testing with normal templates and then change according to the obtained results. It is a recommended policy always to try to find the smallest template that fits. As an example, a 9-cell lot is better than a 12-cell lot. The quality engineer should start by trying nine-cell templates rather than jumping higher.

All said, the use of a lot template plan makes possible quality control through meaningful patterns. The producer's and consumer's risk can be reduced by the increased discrimination of the plan. By this is meant that for a given AQL one can reduce both:

- The chance of rejecting acceptable material Type I error, α and
- The chance of accepting products that contain too many defectives (Type II error, β).

Specific solutions for nonnormal distributions can also be provided, with the variables plot often giving a clue to the reasons for defective items. Such conditions as skewness, widespread variability, or off-centeredness will frequently be indicated by the histogram—providing a good basis for bringing the manufacturing process in control.

For procurement activities, too, the lot template method can find many useful applications in acceptance inspection. Indeed, it is particularly well adapted to receiving or final inspection where large quantities of completed material must be handled. Its limitation is that while it is widely applicable with manufacturing goods it cannot help in process control, at least to my knowledge.

In conclusion, as the examples which we have seen demonstrate for the manufacturing industry, and most particularly for the SMEs which do not have an army of quality engineers, a lot template plan offers a relatively simple SQC approach which reduces training and administrative problems while it is adaptable to different inspection situations. The constant sample size and elimination of calculations and/or use of formulas frees the inspector for more hands-on work.

15.5 Acceptance Limits for Lot Templates

An important step in the development of a lot template plan is that of testing the plot for acceptance with the appropriate acceptance limits. These are derived for any degree of protection or AQL desired, by varying the distance of the limits from the center or mean of the template. This must be accomplished with attention because established acceptance limits will be responsible for acceptance or rejection for quality reasons.

The reader should notice that such limits must not be confused with lot limits of the lot plot plan, which are fixed a ±3 sigma. The engineering specifications limits help in establishing the positions at which the lot template's acceptance limits should fall.

Acceptance limits of ±3 sigma will provide a tight plan of AQL 0.05% which can be employed in place of 100% inspection. If the measurements fall by a large majority inside the acceptance limits, and therefore the tolerance limits, the lot should be accepted even if a couple of measurements exceed the acceptance limits but are within specifications.

Figure 15.4 shows a typical a typical plot tested with an acceptance template to determine lot acceptability. The lot is acceptable because the plot falls within upper and lower cell limits, with only two exceptions out of 40 which however fall within upper and lower tolerance limits. These individual units in the sample falling outside of control limits can be rejected, but this does not affect the decision made with regard to the whole lot.

This example demonstrates the simplicity of the lot template plan; it also shows how easy it is to apply it. There are almost no calculations required. The limits are automatically determined by proper choice of a template with the appropriate quality level. The operating instructions can be stated simply as follows:

- Select a random sample of 40 pieces from the lot to be inspected.
- Decide on a suitable scale and plot the observations and the specification limit(s).
- Select the smallest template that will contain the observations within its cell limits from the series of templates of desired quality level.
- Accept the lot if the acceptance limits are inside the specification limits.

Attention should be paid to the fact that many manufacturing processes are subject to slight shifts in central value and/or an extension of one side of the distribution. Because the probability of finding these pieces near the end of a distribution becomes pretty small in a sample of 40 or 50, from time to time tests should be made with larger samples.

Empirical results give an approximate operating characteristics curve for the probability of calling various skewed distributions normal. The operating characteristic (OC) curves in Fig. 15.5 show that this probability of calling a skewed lot normal when tested with normal template is significantly reduced if instead of a single lot three successive lots are inspected.

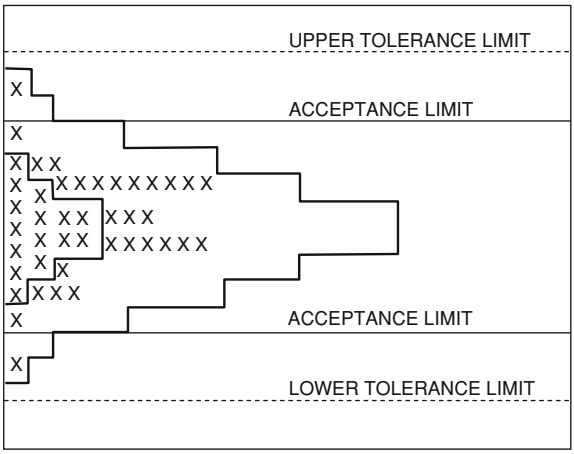

Fig. 15.4 12-cell plot with $\sigma = 2$ cells, acceptance limits at ± 2 s, LTPD = 5.5% and AQL = 0.60%

We have also spoken of the case of using skewed templates. These are typically designed for a skewness of $k = 1$ and $k = 2$ and employed to approximately establish the nature of various non-normal lots when the normal template does not fit.

Acceptance limits for such templates must be determined through careful study. The method is similar to that for normal distribution except that the limits are not equidistant from the center value. Hence, they must be calculated separately for each side of the distribution. In principle, the greater the skewness,

- The lower the probability of fit with the normal acceptance templates and
- The greater the width of the normal templates which do fit the plot.

This is a consequence of the fact that acceptance limits are extended to cover the longer distribution tails. At the same time, the use of wider normal templates is limited by the fact that for significant skewness center cell limits will be exceeded.

Sometimes we may fit a template which is too small and at other times one which is too large. Two different errors which may arise are in the estimate of the variability of standard deviation of the lot and in the estimate of the true mean. A sample of 40–50 observations will not give us these key data with high accuracy.

Another error may arise in rounding off values to the nearest cell interval. This problem is minimized through the use of templates differing from each other by the least amount that is physically possible. Every lot condition will have its own operating characteristics curve, and all of these OC curves will differ slightly from each other.

Among the challenges confronting the quality engineer is that of a production process which has shifted, as well as that of lots that have been mixed. This results in two levels around which the values are clustered. If these two levels are close together, we may find that the distributions overlap or alternatively an increased product spread requires the use of wider templates.

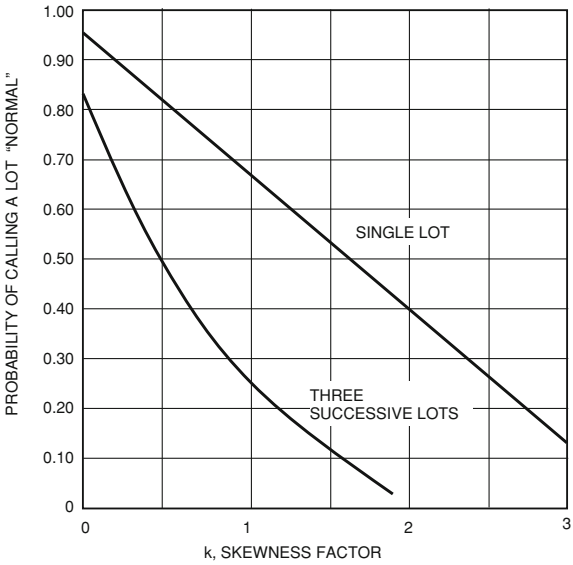

Fig. 15.5 Operating characteristic curve for skewed distributions

When two or more distributions are clearly recognized, it is wise to plot additional observations and test for product acceptance by shifting the template to fit each plot independently. These remarks impact upon the implementation of the lot template method because in industrial production skewness of $k = 2$ or less is not uncommon.

One of the cases that come to mind is electrical characteristics like insulation resistance. It is important however to appreciate that many distributions which are not normal can be adequately treated, for purpose of lot template acceptance, by considering them to be skewed in various amounts.

One of the interesting cases of non-normal conditions is when the manufacturer has screened his product before the lot template method is used. This also happens with procurement. A special condition also arises when the product has overrun one or both of the specification limits, requiring performance of attribute inspection at or near the specification limit to segregate the bad from the good.

Greater protection can also be achieved by attribute inspection of an additional sample, combining these data with the original sample. As the reader is aware from the preceding examples (see also Fig. 15.5) we get greater dependability under double or multiple sampling. Alternatively, we can obtain equivalent protection with smaller additional samples using an acceptance number of zero.

In conclusion, the lot template method will fulfill in an able manner quality control objectives and it is particularly attractive to the smaller firm as well as for bigger companies wanting to acquire the culture of causal inference prior to investing in more complex and more expensive SQC tools and methods. It is however very important that the lot templates plan is not seen as a side issue but is carefully applied and administered under a well planned SQC policy.

15.6 Overcoming Communications Barriers

The reference has been frequently enough made that a common problem confronting companies of all sizes is that quality control information does not circulate freely within the enterprise. Speaking about mistakes in the production process is taboo, and the fact that available manufacturing machinery is not able to meet engineering tolerances is not even allowed to be discussed.

- Management looks the other way and
- Hopes that the problem will disappear by itself.

To a significant degree the background reason is secrecy about a negative evaluation of a production process. But such secrecy is counterproductive because once the problem(s) confronting something important is known, everything follows as an alert management takes measures to upgrade the equipment or the system.

One of the domains where lot templates can contribute to the evaluation of products and processes is that of substantiating the policy of technical auditing brought to the reader's attention in Chap. 3. Rather than being characterized by secrecy, the results of an evaluation should become known to all authorized persons whose work is affected by this technical audit.

A policy of open information channels is rewarding in more than one ways. Operations become so much more efficient *if* the organization takes the initiative to break down the *communications barriers* which exist because of tradition, or of a clash of personalities. Companies do not always appreciate the high cost they are paying by allowing the existence of silos within their borders and even within some of their departments.

Communications barriers are in reality *discipline barriers* as interdepartmental and interpersonal exchange of information breaks down even between teams working within the same engineering office or laboratory. I have seen in my practice more communications barriers being raised when design cycles are longer and/or engineers, within each discipline, are prodded to pursue their own portion of the design independently of work done by their colleagues—leaving integration for later on. By contrast, when design teams are requested to cross disciplinary barriers at the beginning of their design process, they:

- Discover opportunities to optimize their work taking advantage of a wider realm of know-how and
- Eliminate expensive and time-consuming integration errors which have the nasty habit to pop-up only at the last minute.

Such an exchange of inter-disciplinary information will be the more effective if a policy is established (and maintained) that targets the adequacy, completeness and currentness of interfaces between design and manufacturing engineering. Process instructions and industrial instructions relating to a particular design must not only be developed but as well be up to date.

- *If* the lot template method is chosen for SQC.
- *Then* design engineers should not only become familiar with its feedback, but also with the method itself.

This requirement is in direct application of the principle that a sound quality assurance program must provide complete coverage of all information elements necessary to design and produce an article. The double feedback I am suggesting is as well key to complete compliance with contract requirements for proposing, approving, and effecting of engineering changes.

Further still, *if* the company uses contractors *then* what has been stated about the free flow of information inside the organization—in product quality, specs, drawings, costs, and other elements—should include also the contractor's own departments and laboratories. The contractor must be responsible for assuring that this is also true for all supplies and services procured from his suppliers (subcontractors).

Controlled conditions include documented work instructions, adequate skills, first class production equipment, and any special working environment that might be needed. Information about all these issues, on the supplier's behalf, should be an integral part of deciding on acceptable or unacceptable partnership in the sense of a supply chain.

The supplier(s) methods of measuring, monitoring and inspecting should be examined and their suitability demonstrated with a reasonable degree of evidence. The same is true of the supplier(s) statistical methods employed in production and purchasing, including statistical tests, analysis, and quality control procedures.

This underlines the need to break down the communications barriers both in-house and with suppliers. The latter has been done since the late 1990s with enterprise resource planning (ERP) as far as factory scheduling is concerned. The focus of this discussion, however, is not scheduling but wide ranging information from R&D to manufacturing and testing,

- Leading to an information grid and
- Helping management decide on quality versus cost for each produced item.

Evidently, such a system has to be tuned as it requires the development of both qualitative and quantitative criteria of quality assurance, effectively applied in the company's home country, its foreign subsidiaries, and all of the suppliers which it uses in the global market. Wider dissemination of information keeps other projects and departments informed about actual developments and how ongoing programs are progressing toward meeting their goals. I have seen many cases where this policy steered subsequent engineering efforts by revealing the areas needing the most attention, and thereby avoiding that each department had to rediscover the wheel.

If information cannot flow freely within the organization because of mountains of resistance, the only alternative left is the creation of a strong central authority invested with the power to crack the nut of secrecy. Prior to suggesting to the board of companies where I was a consultant in the creation of such a central

authority I tried to open the way by conviction, because I considered that flat orders are a regrettable approach inasmuch as they risk to generate a permanent animosity between departments and projects. When things take this turn, it is not technology and product quality but company politics which take the high ground.

Philosophically speaking, when the politicking which can be found in all enterprises and in nearly all families is discounted, it is not quality in the large and quality in the small that is most interesting. It is what you can accomplish with their results.

Reference

1. Wooley J, Peters G, Gerald R. Ford; Remarks at the U.S.S. Nimitz commissioning ceremony in Norfolk, Virginia. http://www.nimitz-museum.org/nimitzbio.htm