CHAPTER I

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1.1. Standard Techniques of Quality Control

The problem of quality control is that of detection and elimination of assignable variation arising in a production process. It has therefore two aspects: (i) detection of assignable variation, and (ii) determination of suitable corrective action. Statistical techniques in this field have been mostly concerned with the first aspect of the problem. The control chart for example, is basically a diagnostic device for detecting the presence of assignable variation in the quality of articles. The standard practice is to plot observations (usually means of samples of articles produced at times $t_1, t_2, \ldots,$) on a chart marked with lines corresponding to an upper and a lower control limit for the observations. So long as the plotted points remain within the control limits, the process is regarded as in a 'state of statistical control' and the variations are supposed to be random. If however at any time t_i ($i = 1, 2, \ldots,$), a point goes beyond these limits, presence of assignable variation is suspected. In such a situation, it is for the maintenance personnel to locate the sources of assignable variation and take suitable corrective action.

It may however be noted that the standard control chart described above may not be so effective even for detecting assignable variation. For it only takes into account the value of only one observation at a time, and does not consider the earlier observations, the use of which may lead to a quicker detection of assignable variation. Duncan (1956), Bartlett (1953) and Cowden (1957) have shown how a run of several successive observations above or below the target value can indicate the presence of assignable variation, even when all of them are within the control limits. Page (1954, 1957) and Barnard (1959) have investigated a new type of control chart, called the cusum chart, in which the cumulative sum of all observations upto a point of time is plotted instead of a single observation. The cusum chart, which makes a direct use of all available observations, appears to detect assignable variation much more quickly than a standard control chart.

All statistical devices for detection of assignable variation however, presuppose human intervention for taking corrective action, which is usually time consuming. This drawback seriously restricts the usefulness of such devices for quality control in industrial processes with a high rate of production. To avoid excessive maintenance costs and loss due to substandard articles in a high speed industrial process, 'the measurement, calculation and adjustment phases of the quality control function must take place at a speed comparable with the process being controlled' (Bishop, 1965). This implies that there should not be any considerable time-lag between the appearance and the elimination of assignable variation, and hence, a quality control device, to be of any use in high speed production, should not only detect assignable causes of variation, but also provide for prompt corrective action.

1.2. Quality Control Viewed as Feedback Problem

In some recent investigations (e.g. Barnard, 1959, Box and Jenkins, 1962, Bishop, 1965) concerned with quality control methods and devices which perform the twofold function of diagnosis and correction, the problem of quality control has been considered as a problem of feedback. It has been noted in the first two investigations* that even the control chart involves the principle of feedback. Barnard (1959) states that there is a long standing practice in some industries 'of using the control chart as itself an element of a feedback loop, which not only signals the departure of a process from its target value, but also indicates the magnitude of its departure, and the amount of correction needed to bring it back'. Box and Jenkins (1962) have defined two types of feedback, namely, technical feedback and empirical feedback. Technical feedback occurs when 'the information coming from an experiment interacts with the technical information contained in the experimenter's mind to lead to some form of action'. The control chart used solely for detection of assignable variation is an example of this type of feedback. Empirical feedback, on the other hand, takes place when some simple rules determine unequivocally what action is to be taken on the basis of information coming from an experiment. Thus the control chart practice referred to by Barnard is an example of empirical feedback.

Quality control methods involving empirical feedback should, therefore, do both the diagnostic and corrective functions. Thus, in this case, observations made on the process will have to be used not only to detect presence of assignable variation but also to determine the necessary corrective action. We are concerned here with methods of feedback control, the basic idea of which is 'to use the very deviation of the system from its desired performance as a restoring force to guide the system back into its proper functioning' (Bellman, 1961). Box and Jenkins (1962) have referred to such methods as methods of 'adaptive' quality control. The term 'adaptive' however seems to be open to some objection, as all methods of empirical feedback control are not 'adaptive' in the strict sense (c.f. Florentin, 1962). In the present thesis, quality control methods involving empirical feedback are called methods of empirical quality control.

1.3. Empirical Quality Control in High Speed Processes

For routine quality control in many modern high speed processes, it may not be necessary to hunt out and eliminate the source of assignable variation after such variation is detected. It may be enough to make a comparatively simple readjustment of the machinery, like changing the process operating level, to bring the process back under control. In the above circumstances, it will be quite feasible to use methods of empirical quality control, or mechanisms based on such methods.

Some aspects of the problem of empirical quality control of the process mean or process operating level have already been studied by Barnard (1959), Box and Jenkins (1962, 1964), Volosoff (1958, 1961) and Bishop (1960, 1965), among others (see 'References'). Barnard (1959), and Box and Jenkins (1962, 1964) have investigated the general problem of obtaining optimum methods of control. Their studies are mainly of theoretical interest. The control procedures suggested by them seem to be too complicated and costly to be of much practical use. Volosoff (1958, 1961) and Bishop (1960, 1965) have made studies of some particular control mechanisms which are actually used for empirical quality control in some high speed processes. But the scope of their studies is somewhat limited, and Volosoff's investigations contain some obvious flaws.

The present thesis is devoted to a study of some empirical quality control devices which are of practical interest in high speed production processes. Although the mechanisms investigated are simple (and can be automatised at an economic cost), they seem to control the assignable variation adequately in many situations.

The control mechanisms studied here are the fixed and variable one-sided controllers, the fixed two sided controller and the proportional controller. The one-sided controllers can control the movement of a process parameter in one direction only. For example, they may only reduce the value of a process parameter by a fixed or variable amount whenever observations from the process indicate its necessity. Hence, these mechanisms are suitable for use in situations where a process parameter undergoes a systematic upward movement (or a systematic downward movement) due to the operation of a "constant assignable cause" (c.f., Bishop, 1965), that is, a constant disturbing influence like tool wear at a constant rate. The two sided controller and the proportional controller can control the variations of a process parameter in both the upward and the downward directions, by some times increasing its value and sometimes reducing it, depending on the values of observations made on the process.

Among the mechanisms studied here, the variable one sided controller and the two sided controller do not appear to have been investigated earlier. Volosoff (1953, 1961) has made an investigation of the use of a fixed one sided controller (under the name of 'resetter') for controlling the variations in the dimension of items finish-machined by an automatic grinder. Bishop (1960, 1965) has made an investigation of the use of a proportional controller for controlling variations due to "constant", "infrequent" and "random" assignable causes. In the present thesis, however, the study has been made from a different view point, which makes possible a more complete analysis of the long term performance of the various control mechanisms.

In Part 1 (Chapters I - III) of the thesis, the problem of empirical quality control is formulated (Chapter I); the work done so far in the field is reviewed (Chapter II) and the approach followed in the present thesis is outlined (Chapter III). We introduce suitable stochastic models to represent the overall movement of an industrial process when a specific type of control mechanism is used for its control. The circumstances under which stability is attained are then investigated. We then discuss methods for numerically evaluating the steady state probability distribution of the process mean and that of individual observations from the process.

In Part 2 (Chapters IV-VII) the control of variations due to a constant assignable cause, with the help of one sided controllers, is considered. We first investigate the use of a one-sided fixed controller, which sets back the level of the process mean by a fixed amount when one observation from the process exceeds a critical value k (Chapters IV and V). In Chapter IV, we introduce an appropriate stochastic model and investigate its characteristics; while in Chapter V, we consider an application of the model to the problem of empirical quality control in a specific type of industrial process. The use of a variable one sided controller, which sets back the level of the process mean by a variable amount when one observation from the process exceeds the critical value k, is discussed is Chapter VI. In Chapter VII, we consider two modified uses of the fixed one sided controller. In the first modification, the controller operates when the sample mean of several successive observations exceeds the critical value k, and in the second it operates when the median of three successive observations exceeds k.

In part 3 (Chapters VIII and IX) the control of variations due to a random assignable cause system is considered. We discuss the use of a two sided fixed controller in Chapter VIII. This controller sets back the level of the process mean by an amount A_2 when one observation from the process exceeds a critical value k_2, and it sets forward the level of the process mean by an amount A_1 when one observation from the process falls below another critical value k_1 ($k_1 \le k_2$). In Chapter IX, we discuss the use of a proportional controller for the control of the same type of variations. Following an observation x, the proportional controller adjusts the value of the process mean by an amount $k(x - M)$, where k is a constant of proportionality and M is another constant. We consider a method for obtaining 'optimum' values of k and M, that is, values of k and M such that the steady state distribution is unbiased and has minimum variance. We also investigate, as usual the conditions under which the controller induces stability, and also discuss a method for the determination of the steady state distributions.