QUALITY PERFORMANCE RATING

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THESIS SUBMITTED

AS PART OF THE REQUIREMENTS FOR

THE DEGREE OF

DOCTOR OF PHILOSOPHY OF THE UNIVERSITY OF ASTON

IN BIRMINGHAM

DEPARTMENT OF PRODUCTION ENGINEERING

October, 1974.

SUMMARY.

This Thesis reports on the principles and usefulness of Performance Rating as developed by the writer over a number of years.

In Part one a brief analysis is made of the Quality scene and its development up to the present. The need is exposed for Performance Rating as a tool for all areas of management* At the same time a system of Quality Control is described which the writer has further developed under the title of 'Operator Control'. This system is based on the integration of all Quality control functions with the creative functions required for Quality achievement.

The discussions are mainly focussed on the general philosophy of Quality, its creation and control, and that part of Operator Control which affects Performance Rating. Whereas it is shown that the combination of Operator Control and Performance Rating is both economically and technically advantageous, Performance Rating can also usefully be applied under inspection control conditions.

Part two describes the principles of Area Performance Rating. This is expressed as $P_A = \frac{\Sigma x_i}{\Sigma n_i}$, which is derived from the fraction effective $q = \frac{x}{n}$, where x is the number of effective parameters in a sample and where n is the sample size.

*The need for, and the advantages of, Performance Rating are particularly demonstrated in Case Study No. 1.

From this a summation expression is derived.

$$P_A n_A = P_{a_1} n_{a_1} + P_{a_2} n_{a_2} \;..\;..\;.. + P_{a_i} n_{a_i}$$

which gives the key for grouping of areas (a_1, a_2 etc) with similar Performance Rating (P).

A model is devised on which the theory is demonstrated. Relevant case studies, carried out in practice in factories are quoted in Part two, Chapter 4, one written by the Quality manager of that particular factory.

Particular stress is laid in the final conclusions on management's function in the Quality field and how greatly this function is eased and improved through the introduction of Area Performance Rating.

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ACKNOWLEDGEMENTS

The writer wishes to express his sincere appreciation for the assistence and encouragement received in general from Professor R.H.Thornley and in particular from Dr. J.D.Morrison, his Supervisor.

The writer also wishes to express his gratitude to Mr. W. Green, Quality Manager of Mirrlees Blackstone for providing the material for Case study 3 .The sincere appreciation of the writer must be also expressed to his secretaries Mrs. M.Beath and Mrs. G.Turner for their unending patience whilst typing this Thesis.

DECLARATION

No part of the work described in this thesis has been submitted in support of an application for another degree or qualification of this or any other University or Institute of learning, with the exception of Appendix 2 as stated in the thesis.

R. K. GRUNAU.

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PART ONE

QUALITY MANAGEMENT

A CASE FOR

PERFORMANCE RATING.

INTRODUCTION TO PART ONE

The problem of controlling Quality in industry has induced much thought, particularly since the continuous pressures for higher productivity put an increasing load on all concerned with production. In the course of time the pre-occupation with quantity tended to develop means for higher output at a faster rate than those required for producing consistently within the terms of a given specification. Yet, once Quality failure has produced rejects or customer dissatisfaction, the corrective effort involved is costly and often out of proportion to the effort and care required in the pre-production and production stages to ensure 'Quality' (or conformance to specification).

Often the specification itself is insufficiently developed to satisfy the market. This lack of development can lead to a diminishing demand for the product, resulting in losses far greater than those incurred in the form of scrap and rejects.

Hence a substantial amount of the nation's resources was and still is being lost, mainly due to industry's failure to create and ensure Quality of both design and manufacture.

Even to date a great deal of confusion exists regarding the functions and responsibilities to be carried by each department of a production unit in relation to Quality. This applies often to the Quality department itself. So,

even where conditions and product are similar, organisation varies considerably from factory to factory.

A short historical review, followed by some critical remarks, is given in order to establish some of the background and evaluation which led to the work in hand:-

When Quality had its origin in the desire for adequate creation in the hands of individual craftsmen - in an era when often individual survival depended on customer satisfaction - there seemed to be little need for its control. So individual motivation - often with minimal technical facilities - produced results some of which long outlasted the age in which they were produced. The development of precise demands and specifications came only with the increased sophistication of methods of manufacture, but is is well to bear in mind that the craftsman who had the desire or motivation for good performance would generally give satisfaction, even with minimum instructions. But then came the pressures for quantity and managements' need to maintain output.

In response to these pressures came the introduction of incentives in all their many forms. Incentives encouraged the drive for volume even at the price of Quality. When it became apparent that Quality was getting out of hand, inspection was taken away from direct supervision and increasingly put under a separate department. The role of this department was clearly one of verification or checking

to - only too often not clearly defined - standards.

In many companies inspection grew to a giant octupus whose tentacles were reaching into every area of manufacture: although this development is too complex to describe here in detail, the main steps taken in its course are of interest and relevant to this discussion.

Inspection often started at the end of processes or assemblies. It was then understood that rejects were found much too late and inspection forces entered the manufacturing areas, firstly in 'key points' (stage inspection) and finally as patrol inspection. In company after company emphasis moved from one system to another with inspection to direct labour ratios reaching very high proportions, from 20 to even 50 or more per cent. This was the direct result of management holding inspection increasingly responsible for Quality.

It is simple enough to understand why this was done:- Managements had less time to deal with the many aspects of their Quality problems and looked to someone - such as the Chief Inspector and his department - who would take this responsibility off their shoulders. But in doing so they created only someone to shoulder the blame, a punch ball, who was however powerless to deal effectively with the causes of Quality problems. Although it was mostly acknowledged that production personnel (from foremen to operators) shared the responsibility for Quality, the "centre of gravity" was moved increasingly in the direction of inspectors, who, in order to maintain their

position, accepted it. In a continuous effort to catch up with an ever escaping target, the inspection forces grew, without substantially reducing Quality failures.

Statistical methods were introduced to the techniques of inspection* in an effort to reduce the large work load and for years they were thought to be the answer to the whole problem :- Yet, in fact, they were only a device for speedier assessment of Quality without effectively creating it. In an attempt to forecast Quality failure, Shewhart* Charts were introduced, but the limited range of applications made them unacceptable, save in a relatively small number of factories.

The need for the introduction of statistical methods is not debated here. They are an essential tool of Quality assessment. But statistics alone could never be looked on as a solution to the problem of maintaining Quality, let alone of creating it, mainly because they did not deal with the correct apportioning of responsibility.

From the United States came the concept of total Quality control*,* which pointed the finger in a new direction. Every unit of the organisation had its Quality responsibility. At the centre of the Quality organisation was a new Quality department, with the task of Quality communication to all other departments; but this Quality department, although correctly conceived, in practice was mostly superimposed on the inspection department, doing little more than giving the old octupus a few more tentacles. Furthermore the Quality and Inspection

*Chapter 10.
Ref: 14

** Chapter 10
Ref: 7

departments, in addition to fighting everyone else, now did a fair amount of infighting.

To prevent this chain of events inspection should never have been made responsible for Quality achievement. A brief analysis will indicate clearly the misconception of inspection responsibility for Quality :-

The four main functions which affect Quality are :-

1. The design department should specify clearly and precisely all its requirements, which in their entirety must - if adhered to - lead to a satisfactory product. the term 'satisfactory' embraces functional performance, reliability and attractive appearance. In addition design must do its share to make the product competitive in its market.

2. The production engineering department should provide facilities for manufacture and assembly which are thoroughly capable inside the specification.

3. Works management should provide the skill for manufacture and assembly which must be thoroughly capable to maintain the specification.

4. The purchase department should supply material and B.O. components in line with the specification.

From this list of functions it is clear that the inspection department has no influence whatever on initial performance. It can only judge the product at various stages. Management should hence not have burdened the inspection

organisation with responsibility for the achievement of Quality. Instead the role of inspection should have been clearly defined as one of monitoring performance. Design, production management and works management should have been clearly told to accept the burden of responsibility for Quality - solely and entirely. No doubt under these conditions more thought would have been given to pre-production functions, resulting generally in better Quality performance and hence much waste could have been avoided.

The recognition of this prompted the writer to introduce the concept of "Operator Control" * , the beginnings of which were found on the Continent of Europe; but its origins can be traced to the beginning of industrial activity, to the creating craftsman, whose motivation for Quality and pride of workmanship were generally not in question. Most functions and techniques in this thesis are described with the assumption that Operator Control methods are used and accepted. This is, however, not a condition for most techniques as will be pointed out in Part two.

Operator Control has now grown to a sophisticated yet economical system of Quality assurance and will be later described in as much detail as is relevant to this thesis. Basically it is a system which clearly defines all Quality

* See Appendix I.
Excerpts from Report to Industry, 'Quality its Creation and Control', produced under the writer's chairmanship by the Quality Committee of the Institution of Production Engineers. (Ref.19)

functions and integrates these functions and responsibilities with the normal work content of each individual.

Having accepted this principle, each management is faced with the question of how well departments are coping with their Quality tasks. It was mainly in an effort to find a solution to this problem that the writer developed "Area Performance Rating" which is the main subject of this thesis and will be fully discussed in Part two.

However, it was felt that only by expounding the philosophy behind these 'new' Quality assurance procedures that the significance of Performance Rating as applied to Quality can be judged. Hence a brief outline of this philosophy, which may well prove to be the major trend of future Quality procedures, is given in Part one of this thesis.

It is therefore not intended to present a description of all facets of Quality management, but generally only of those which have a direct bearing on the need for Performance Rating.

The measurement of product Quality in relation to its specification is well understood in industry. Scrap rate, rectification rate and service complaints are generally accepted as yardsticks for this measurement. Yet the real Quality Performance is often far worse, as the above measures do not take into consideration acceptable rejects and those which find their way into the end product. All these may cause bottlenecks and dissatisfaction without appearing on scrap data. The writer has had occasion (based

on experience) to liken a poor Quality Performance of a factory to an iceberg, the peaks of which represent the actual final scrap, whereas the extent of the real Quality failure is represented by the large mass beneath.

This thesis therefore intends to demonstrate the need for Performance Rating of human and technical resources in the first part and in the second part will describe methods developed by the writer which provide a practical solution to the problem.

But let us begin at the beginning :-

CHAPTER 1

THE CONCEPTS OF CREATION AND CONTROL

So the inspection department should not carry the responsibility for the achievement of Quality. This must be shared by all departments and the allocation of responsibility becomes a foremost Quality function of management. Before discussing this in detail it is important to define Quality itself, as the term "Quality" embraces many different concepts to different people.

From the consumer's point of view Quality is measured by a product's appearance and sustained functioning. Price enters into his buying intentions, but after purchase his opinions are based on the former attributes.

To the manufacturer these requirements, when analysed, are extremely complex. They affect the functioning of different groups of people who, in turn, have to be given clear objectives. To this end the overall Quality objective has to be broken down into departmental objectives, of which the two major ones are the development and creation of a suitable and competitive specification on the one hand, and the creation and development of manufacturing and production facilities on the other.

From the manufacturers point of view therefore, Quality can be defined as the achievement of a specification which in turn has been developed to satisfy market requirements within a given price range.

The market requirements, influenced by a series of environmental, financial and technical considerations, change constantly. Hence the targets for design and development of suitable specifications are constantly moving.

Likewise and partly because of this, the targets of the production organisation are under constant consideration. A continuous battle rages in boardrooms between the economic need for rationalisation - and with it the stabilisation of production - and the competitive pressure for change to improve both design of product and the method of its production.

The Quality of the specification determines a product's position relative to market and functional requirements. Its development is therefore vitally important and managements will, or should, always remember that a well developed specification is the best salesman in every organisation.

In the context of this paper, however, we must accept the specification at one of its least mobile moments (it can never be totally static) and consider the problem with respect to the Quality of manufacture and hence as it affects the production organisation.

Modern production conditions are inducive to error and omissions and moreover the complexity of systems and products have developed to such a degree that even when given maximum goodwill and care, failures can be

experienced. Under these circumstances reliance on individual skills and forethought is insufficient. Organisation must be brought to bear to achieve Quality of conformance.

To ensure such conformance a Quality system should be in operation with two distinct aims :-

Creation of Quality on the one hand, and

Control of Quality on the other.

1. Creation

After the acceptance of the competitive and capable design Quality must be created through the provision of capable production units.

This is a pre-production activity, involving all departments concerned with production. To create Quality effectively, the capability of all systems must be developed to be well within the demands of the specification. (Capability will be defined later.)

2. Control

Quality must be controlled through verification and measurement of parameters at the point of production. At worst this will prevent rejects to proceed further, and at best it will stop rejects being made altogether. 'The verification of any Quality (attribute) should take place as near as possible to the time and place of its production.' *

* Statement made by the writer in the magazine "Production" in January 1958. (Ref.16)

This should be so, because the more time elapses between production and the discovery of a reject, the greater the cost. The overall aim is to eliminate rejects. The only effective way to do this is to prevent rejects being made at all.

The system should further control (monitor) the performance of all facilities (human and technical), and determine through planned and continuous checking the capability in relation to the existing specification.

Finally the system should open efficient lines of communication to all areas involved in the creation of Quality with the aim of generating action. Each area must be motivated towards reaching total capability and react sharply if the control system indicates otherwise.

It can clearly be seen that the above functions involve different parts of the manufacturing organisation. Managements tend to avoid the problem of apportioning responsibility and enforcing action and rather look for an overall cover, for an "all in" insurance. At best they turn to inspection and Quality control to facilitate lines of communication to the various departments. At worst, they hold inspection responsible for Quality failure. Even the former procedure is rarely effective because Quality or inspection departments are lacking in authority to enforce action. They can, of course, stop production, but for effective Quality achievement it is necessary to create Quality capability, which involves functions over which they have no real control. The only body which has the authority

to enforce change is management. The appreciation of responsibility for Quality must hence guide managements actions when dealing with Quality failure and it is their first and foremost task to clearly allocate responsibilities:

The Allocation of Responsibilities for Quality.

1. Creation of Quality.

1.1. Design to be responsible for the provision of capable specifications. The production drawings to be toleranced as far as possible within available capabilities.

1.2. Production Engineering to be responsible for the provision of capable facilities, including all instructions for methods of production and verification.

1.3. Works Management to be responsible for the provision of capable skills.

1.4. The Buying department to be responsible for the provision of correct proprietary articles, components and raw materials.

1.5. Training department to be continuously devising training programmes to meet all training needs of the company.

2. Control of Quality.

2.1. Works Management to be responsible for the verification of Quality at the point of production (Foreman - Setter - Operator - Testing Department).

2.2. The Quality department to be responsible for testing and auditing the performance and capability of all facilities and communicate findings to all concerned including top management.

2.3. The Quality department to be responsible for auditing the performance of outside suppliers.

2.4. The Quality department to instruct screening of product where considered necessary.

2.5. All departments to re-act sharply to information received from the Quality department and to programme action for the speediest possible solution of Quality problems.

The allocation of responsibility must be based on the appreciation that the creation of Quality is the primary function. If carried out adequately there will be a minimum number of Quality failures. Obvious as this statement may be it is nevertheless an area in which even the most sophisticated organisations are producing poor results.

Quality and Factory Economics.

Much has been written on the subject of Quality costs and in line with the terms of reference of this thesis no attempt will be made to deal with this subject in depth. It should, however, be stated that economics must be the ultimate yardstick by which Quality management is measured. It is difficult to make a case for Quality outside the framework of economics in modern industry. The sale of an article can be increased because of its better Quality of performance and/or appearance. Production costs can be lowered through the reduction of Quality failures. Both these cases present a sound economical reason for a Quality improvement programme. There is no doubt that any attempt to introduce Quality improvements outside these considerations will be doomed to failure.

There is one exception to this, namely, where safety critical parameters are involved. But it can even here be argued that this safety factor is part of the product's performance and hence is a part of the sale value of the product. To avoid any errors in this area it is important that the specification must indicate each safety critical parameter and Quality programmes and organisation must be geared to ensure conformance to such requirements. The objective of the production organisation does not change due to safety implications. It is simply stated as conformance to specification, no better and no worse. But the intensity of verification must necessarily be greater.

The economics of each individual situation has to be borne in mind when organising manufacturing details. To this end formulation of a principle may be helpful :-

If one were to assess the capability of available technical facilities relative to a specification or attribute, and likewise the capability of available skill, it is fair to expect that the sum total capability must be equal to the specification, and hence skill and plant must be complementary :- The greater the capability of the plant alone to cope with the specification the fewer will be the demands on the ability of the operator. On the other hand, where insufficient funds are available for sophisticated, automatic machinery, more skill may be required. And again, in cases where specialised jigging and tooling is not obtainable for economical reasons, for instance when batches are too small, both skill and machine tools may have to be

of a high order to produce the required product.

Quality costs are generally made up of costs of inspection and Quality personnel, plus costs of rework and scrap, plus costs of guarantee claims. It is vitally important for companies to maintain a correct specification and at the same time keep these Quality costs at a minimum level. Performance Rating if used in conjunction with Operator Control will achieve this efficiently even under difficult conditions as described later, and in particular on page 46 'Final Audit.'

The Need for Measurement.

Management, having given all Quality objectives to all departments will now have to appraise their performance. Hence each area needs to be analysed relative to its objective. This analysis must be inexpensive and accurate and issued to all areas of management (including, of course, the section under review). Performance Rating as described in Part two offers a solution to this problem.

Summary of Chapter I

Quality functions can be broadly grouped under creation of Quality on the one hand and control on the other. They must be organised to be counter-effective and self-generating; so that the creative functions are improved as a result of the information from the control areas. This information is considered the key to success, because without it even a willing team cannot effect improvements. Let us now consider the two aspects - creation and control - in greater detail :-

CHAPTER 2.

THE CREATION OF QUALITY.

Design should be the only specifying authority in an organisation. This point is made as often inspection and even production personnel take it on themselves to give concessions. In some cases (always clearly stated) this authority can be delegated. But generally design must clearly specify all its requirements (including such items as material specifications, surface finish, squareness, concentricity) and be invariably consulted when concessions for deviation from specification are wanted. The design and development departments, together with sales, are, in their endeavour to meet the market requirements, constantly changing their targets.

The basic objective of design is, in line with customer's needs, to specify an ideal product. But such a product may be entirely different from the existing specification. To discuss a case in point, the following may be a suitable example :

A manufacturer of an agricultural implement found himself to be in serious transmission trouble, due to a gear train not being adequate for the shock loads which were transmitted when a digger hit hard soil, stones or similar obstructions. A great deal of time and money was spent in developing a better load carrying transmission by hardening gears and strengthening of materials and other components. In the meantime a new and very similar product came on the market which had the identical task to perform, namely the digging of rough ground. This particular design managed without a gear box altogether and

transmitted its power through a series of belt drives straight from the engine into the work unit. The result was a much more flexible, powerful, and most of all, cheaper product with a greater market potential. It is obvious that the former company producing the gear box version would either have to change its design or go out of business.

This may be an extreme case, but it does indicate clearly that in between this and the change, for instance, of a locking device, or similar minor feature, there are a hundred and one possibilities for design to show its ability and ingenuity in its quest for a maximum part of the market.

Although this search for the perfect product does not fall within the terms of this thesis, the importance of the design function in its attitude towards the production unit, in effect does.

An effort was made by the writer to indicate some of these design functions as they affect Quality in a paper issued to the Institution of Mechanical Engineers under the title "Quality Functions of Design". * The information contained therein on realistic tolerances is relative to the arguments developed here.

The discussions concern the fact that on small batches even capable distributions can, as a result of incorrect setting, produce scrap and rectification. To overcome

* Extracts from this paper are enclosed in Appendix 2. (Ref.17)

this problem it was suggested to create an extended tolerance band outside the existing one and allow a small percentage of components to be manufactured outside the original specification. The extended tolerance will vary from company to company according to the demands of their respective specifications. Where technical requirements do not allow an extension a closer working tolerance is recommended (see Appendix 2).

It is important that in addition the design department continuously reviews tolerances in the light of experience as seen from information received from the Quality department. Managements who would like to see their Quality performance improved at the least possible cost will insist on making time available in the design department to receive and act on capability information from production areas. On occasions design will insist on production facilities being improved to cope with important tolerances. But often the cheapest solution to a complex Quality problem may well come from the design department.

To summarise, design should clearly state all its requirements. Each attribute must be toleranced as far as possible and in line with capabilities of production. To perform these Quality functions effectively, the design department must have information on capabilities and performance from all areas of the production organisation.

Production Engineering.

The Production Engineering Department's functions are carried out in factories under many different names and disguises. In the context of this discussion the departments referred to are those which are to be responsible for the provision of the total package, comprising all the facilities necessary for the production of an assembly, component or attribute. They have, therefore, to provide space, transport, materials, plant, tooling, including equipment for verification (measuring). They have to allow adequate time for manufacture, which must include the time for checking. They have to be responsible for systems of payment and hence have control over the cost of production. In the context of this thesis the only element outside their responsibility is the provision of the necessary skill, which is the task of works management and will be discussed later.

It is not proposed to list methods and techniques used by the production engineer to fulfil his tasks. The discussion here must concentrate on those additional functions which create Quality. A great deal of detailed attention is required for the production of each attribute. After the creation of the correct environment the production engineer will have to go into the minutest detail of each process, jig and tool design. He must not only know how to produce a given attribute, but also how to produce consistently within the specified tolerance. In other words, how to create capable conditions.

The term capability has been mentioned in various parts of this Thesis and attention will be drawn increasingly

to it, because the whole Quality structure must be built on the foundation of fully capable processes and operations.

For the sake of completeness a definition of capability should be given. Assuming that a tolerance is produced to a normal distribution with a "range" of $\overline{W}$. If T is the tolerance required by the specification then capability exists when $\overline{W}$ is smaller than T. It must be smaller in order to allow for some setting error and the writer has suggested in factories to declare a process capable if the range $\overline{W}$ is equal or smaller than 75% of the tolerance T. This allows for a setting variation of 25% of the tolerance, and if this is so, we refer to a capability of 75%. Hence all processes with a capability of under 75% are capable, and all those over 75% are incapable. Capability of any one process can vary due to a number of causes, such as wear or breakage of tools and fatigue of operators. One should hence determine capability relative to a given period of time and therefore capability studies should normally be done on consecutive pieces coming off a process.

The information regarding capability of facilities in many factories is not normally made available to the production engineer. Although he has generally a fairly good idea what his methods can be expected to produce, he should have direct confirmation of this from the Quality department. This information should be organised on a routine basis and should not only reach him after the failure has already taken place. In many factories scrap figures are published and hence available to the production engineer.

But apart from the limitations already mentioned, scrap figures will often only be acted upon if they frighten management. This is a situation which could be pre-conditioned by past performance. Many a factory has been working to a scrap rate, such as say 3%, and because management get used to seeing such figures on the monthly or annual statements, they may not feel that much needs to be done to change this situation. Another firm, producing a very similar product, having been used to a reject rate of say 1% may well be petrified if the figures from the first factory appeared on their returns.

Another point to consider is that percentages can mean a great deal or very little- even 1% of £10,000,000. is a substantial sum of money and well worth reducing by some 10% or 15%, if possible. The argument developed here is that historic information is only of value when it promotes remedial action. General scrap rate may make conscientious people wring their hands in despair, but they do not point the finger in the direction of specific areas in which something needs to be done to improve a given problem. Action frequently only happens as the result of an additional 'post mortem'. Such investigations are costly, time-taking and often resisted by an already harrassed inspection department.

With Performance Rating, such information will be issued automatically as will be shown in Part two. Hence, general reject information is no substitute for comprehensive and continuous Performance Rating and capability studies.

Planning for Quality.

Production processes must be issued with clear statements of Quality instructions, which should be displayed at each point where a production operator functions. These Quality instructions should go beyond the listing of available equipment for checking. They must include the frequency of checks to be made by the operator and list Quality information concerning every aspect of the particular operation. The information so displayed must be easily readable and should not, normally, contain long passages of small print. Where possible, sketches and operational drawings must accompany these instructions, which should hence be a summary of all specifications and verification requirements.

Quality instructions are an excellent vehicle for imparting new Quality information to all concerned with production. As new facets come to light they must be added to the instructions so that experience build-up will occur and the number of problems of any one operation can be reduced in time.

The frequency of checks to be made must depend on the capability of the process. It is therefore important that capability studies should be carried out on a continuous basis and secondly that the performance rating of the 'process - setter - operator' entity should be considered. If planning departments are to instruct operators and production personnel in general on the frequency of checks, they have to be in possession of information on which the determination of this frequency can be based :- A clear case for Performance Rating.

There are, however, some difficulties which have been experienced. For instance, capability or Performance Rating is not available on processes which have not been carried out before. Also, it is difficult to tie production down to using certain machines and operators, particularly in a machine shop where a variety of different medium to small size batches are being produced.

There are a number of ways in which these difficulties can be overcome, such as, for instance, basing the relative measurement on the performance of existing similar operations. On the whole it is invariably better to have some information than to work completely in the dark. Also, with the build-up of data goes often a reduction of problem areas.

All control systems are easier where running lines give the production engineer sufficient time to perfect the process, and even the most complex problem can be solved given sufficient pressure, finance and time. The most difficult problem is, therefore, the production of small to very small non-repeatable batches. Thought has to be given here to a group-technological approach and even performance rating and capability should be based on operations with a common factor.

Works Management.

The task of works management is to control the labour forces under their supervision and to obtain maximum output from the facilities provided by production engineering. Basically this boils down to controlling the human element

in a manufacturing organisation. It entails the creation and application of adequate and capable skills.

It is essential therefore, that works management be in possession of information regarding the performance of the skilled employee. In the past this has been carried out through observation and personal contact and is hence often inaccurate and unfair. Politically it is even more difficult on today's shop floor to discuss the failure of skills as unions do not (officially) accept that any variation in the degree of skill exists.

Training for Production and Quality

Industrial training in recent years has come to the fore and many new methods have been developed, such as training through analytical programming and the creation of modules. The application of this thinking has concentrated on semi-skilled operators and on young people, who wish to enter industry.

With careful preparation training programmes can be devised for groups of employees. This can be done through discussion groups ('circle' techniques), incentive schemes and other such methods. S.Rubinstein, in particular, has done a great deal of work in this field and is lecturing at present in the United States and Japan on this subject.

Quality instructions, measurement facilities, and, of course, production facilities must all produce an environment conducive to the required Quality level. But the existence of this environment alone is insufficient. The additional organisation of an effective training programme for operators is essential. Such a programme should include the correct interpretation of Quality instructions and

requirements. It should entail the practice of production, which should not only teach what to do but also what not to do and why. It should include likewise, the practice of checking, including the limits of accuracy and repeatability.

The more each operator knows about his particular job, the better. In addition the more he understands about capability and distribution the more effectively will he create (and control) the Quality of his own production. And only then can an operator-controlled factory claim that each of its producers is also an inspector.*

Motivation.

The views and systems described here can be of considerable assistance when discussing the motivation of employees in general, and shop floor workers in particular. It is generally accepted that the setting of objectives for individuals greatly improves their performance and if applied to a team it encourages also their co-operative function. The same effect is achieved when setting individual Quality targets to operators, provided they are given the means to measure and monitor their own performance. This approach can, if properly applied, favourably influence the economical and social environment inside the factory in general, as it encourages shop floor personnel to become part of the company's "think tank".*

Through checking his own work an operator will find greater interest in his job. Through the application of skill, operators can narrow the range of any one distribution and

* Evidence in Paper on Job-Enrichment, Ref. 19 Chapter 10

they will often show an investigator with pride the progress they have made. The writer has found again and again that encouragement towards active participation in the creation of Quality, even in semi-skilled personnel, will reduce failures and rejects. (See case study 1 p.84).

Much discussion has taken place on the appearance of psychological side effects on operators doing repetitive work. The simpler the operation the more likely this can happen. Such - sometimes serious - mental disturbance may well be averted by adding a critical function to the process. M. Tibon of Israel has done work in support of this.*

But it should be clearly recognised that the right environment must be created if operators are to react positively. Performance Rating can assist here considerably by the creation of 'A' areas (targets), as will be shown later.

Checking Equipment.

Situations in which inadequate equipment is available for checking will produce poor results. Checking equipment must be easy and quick to apply and interpret. On operations which create more than one attribute, multi-dimensional checking equipment should be provided. Clocks should be used where possible, in preference to limit gauges, so that variation and drift can be measured. Limits should be clearly marked on clock faces to eliminate errors of interpretation as far as possible. Design of gauging equipment incorporated in the machine tool has made great strides and is much in line with the idea of self-checking.

* Ref. 19 Chapter 10.

Difficult cases for gauging again are those where small quantities make the purchase of special equipment uneconomical. Nevertheless, it is possible to design adjustable equipment which can quickly be set, such as adjustable caliper gauges with clock attachments, similar depth gauges and many more. In this area alone there is room for much research and it is not intended here to go into greater detail than the case for performance measurement demands.

Although the checking function of operators is really part of the control function, it is mentioned at this stage because it has considerable influence on the Creation of Quality whereever a skill-element is needed for its' achievement.

Payment for Quality.

In general, the checking function of operators should add very little to the production time.

There are three reasons for this :-

1. In many factories a checking time allowance is included in the production time. This is often used by operators to boost bonus earnings and hence has lost its significance as far as Quality is concerned.

2. Many operations and processes are semi automatic and allow ample time for the operator to check the one but last piece produced.

3. A number of operations are carried out on machines with built in checking equipment which registers size during the actual operation.

In general, planning has to be experienced to judge where and how frequent checking should take place, so that the overall effect is one of increased rate of productivity.

Incentive schemes are supported or condemned nowadays, according to the experience of the critic. Operator control can work under most incentive conditions, providing two golden rules are observed :

Firstly, an operator must not be penalised for declaring his own rejects - or in other words, bonuses must be paid on a limited amount of scrap. This is under most circumstances the correct action, because in conventional systems, scrap is often only discovered after payment has been made and retrospective action is not possible. It is therefore much cheaper to discover rejects as early as possible in the process and pay for them.

Secondly, where extra checking time is really necessary, it must be added to the production time.

As for the alternative, on the whole Quality should prosper under day-rate systems. But this is not necessarily so and still needs organisation and deliberate planning. And similar effort and organisation can produce good results under incentive conditions :

In all circumstances it is necessary for all levels of management to be informed how well the system is functioning and where the black and grey areas are - only some form of performance rating can do this. It is often argued that the bonus earnings plus scraprate will indicate this efficiency of an area. Providing the information (particularly on scrap) is accurate, this may well be so, but

additional major investigations and exercises are required to obtain a picture. Whereas performance rating is produced automatically and can indicate more accurately and in greater detail the Quality performance in all areas.

Material Movement and Progress.

These functions have much influence on Quality performance and are therefore briefly mentioned. Material movement facilities and practices must be in line with Quality needs. Often a carefully planned process is ruined by use of poor handling and transport facilities, resulting in damage of one sort or another. It is not only a case for planning to provide facilities. Often facilities are incorrectly used, such as pallets which are not returned to the shop floor, or even used for incorrect components.

Many Quality problems arise from excessive emphasis being given to quantity rather than to Quality. The movement of work from one operation to the next before completion is but one example. Splitting of batches because of urgent requirements is another. All such practices may be unavoidable due to priorities, but they must be properly organised with sufficient emphasis being given to Quality.

Environment and Supervision.

An environment should be created by Works Management, which generally encourages Quality. Supervision at all levels must be trained and instructed in line with this thought. It is often found that supervision is - because perhaps of management's emphasis - quantity orientated and Quality is

considered the job and concern of the inspection department. It is by no means easy to correct such malpractices, where they exist. The introduction of area-ratings resulting from auditing, as will be shown in detail later, will pin point weak areas, and the fact alone that such measurements are in the hands of management will make supervision conscious of their shortcomings and need to do something about it.

Maintenance of All Equipment.

The maintenance of all equipment in the factory must be so organised that its capability is kept in line with specification requirements. There are many well tried schemes in existence, and yet too often is maintenance left until breakdown conditions occur.

One such scheme is to organise tool replacement (re-grinding) based on the average number of components a particular tool will cut before needing attention. Another scheme triggers off maintenance inspection at given intervals.

But all these schemes should be based on capability testing and performance rating and should deal with situations not as panic measure, but in an orderly manner.

Summary of Works Management Functions.

Works management should therefore create the skill through training at all levels, create the correct environment on the shopfloor through organisation and communication and encourage work-interest and enthusiasm. In our strike

ridden factories this sounds almost naive. And yet not all factories are strike ridden and there are many where in fact - at least in part - such conditions prevail. But, whichever the situation it will be greatly assisted by Performance Rating.

Incoming Materials.

The buying function - carried out by the buying department - has a direct influence on the Quality of a product and hence is part of the creative function.

The question is often raised who should accept responsibility for the Quality of incoming materials, the Quality (or inspection) department or the chief buyer.

This responsibility lies clearly with the Buying Department, because they alone have the choice of suppliers and hence maximum influence on his performance.
In practice they are far too inclined to accept the cheapest quotation and then only change a supplier if his deliveries are not to schedule.

The buying department relies on the Quality department for information on the performance of its vendors, and hence should introduce - with the assistance of the Quality department - a vendor rating system.

There are many such systems in operation, all based on statistical sampling of one sort or another, allowing a certain A.Q.L. (Acceptable Quality Level) into the factory. The dilemma of incoming inspectorates is manyfold. They can firstly rarely cope with the volume of incoming materials so that in many companies they have to be selective which

supplies to sample and which to allow into stock without checking. Secondly, many incoming items are assemblies and they cannot criticise much more than the application of paint without taking the thing to pieces, which they mostly cannot do. Most materials are wanted by production, even before they arrive. Progress people often live in the incoming goods area - and hence much friction and many bottlenecks can be found at this end of the factory.

A system of vendor rating used frequently is one which is based on the number of batches rejected. The frequency of checks in this system is directly proportional to the number of batches rejected. This system is not fully effective or fair mainly because batches are often accepted or rejected according to the pressures from the assembly lines: When work is desperately needed even an off standard batch is accepted either in part or wholly - and vice versa. The writer has developed a system of performance rating of vendors which is relatively foolproof and which will be described in detail in the second part of this thesis.

The principle of vendor ratings involves the division of suppliers into A, B, and C Groups :- The "A" suppliers are considered reliable and their produce goes straight into stock - with an occasional confirmation sample being taken. "B" and "C" suppliers are being checked and screened and should be warned that company's policy is to change as soon as possible to group "A" suppliers. This approach can - if effectively applied - overcome many of the incoming inspection difficulties and at the same time assist the supply problem of the company. Performance rating in this

area has shown itself to be an accurate tool of assessment and will be discussed in detail in Part two of this thesis. Vendor rating as such does not produce acceptable supplies. It can only act as a sorting device of good and bad suppliers.

Occasional visits by an inspector will rarely turn a poor Quality area into a good one. Buyers and inspectors must keep in mind that only if all points which are discussed in this thesis are applied in the vendor company, and only if their Quality organisation is efficient, will they become a reliable supplier.

Summary of Chapter 2.

The Creation of Quality involves many preproduction and production functions in a company from management through design, marketing, production engineering, works management and buying to the shop floor operator and fitter. The principles have been discussed with the metal working engineering factory as a background, but are equally applicable in all manufacturing organisations.

In all functions it is shown that a suitable system of Performance Rating would be helpful if available and attention is drawn to such a system which will be outlined in Part two of this thesis.

CHAPTER 3.

THE CONTROL OF QUALITY.

The Need to Verify.

If all functions described earlier were carried out correctly and if this could be taken as a certainty, there would be no need at all to verify, crosscheck, screen. There would be no need for sampling after production.

In our imperfect world it is obvious that such an assumption would be unrealistic. But it is still important to remember that a capable area (or machine, operator) will produce Quality at any one point in time. The reference to time is essential, because Quality is the result of the integration of previous actions, and will only result in the correct article or component, if all that has gone before is equally correct. It is well to remember that the checking function as such adds nothing to the component being checked. Only the distribution of the resulting information can influence the future and hence it is important that information resulting from Quality checks is accurate and speedily distributed. Speedily, because action where necessary must be taken quickly to prevent recurrance of an undesirable event.

The attention of auditors should therefore in the first place be focussed on facilities (machines, processes, tools) and on the skill element involved in manufacture. In the second place it must deal with the piece in question - in order to prevent its further progress along the production line.

In the above order the first priority is hence to stop and adjust the process if necessary, and secondly to screen the work produced to find all rejectable components. But the auditor, against the background of Operator Control, should only have to act as the second 'line of defence'. It is important therefore, at this stage, to state the principles of Operator Control.

The Principles of Operator Control.

The first principle of Operator Control requires the complete integration of all checking and verification processes with the production process. There are, of course, limitations and areas where the full application of this principle is difficult. But in general this is less often the case than one might assume. It is clear that all the pre-conditions and preparations for this, as described earlier, should have been carried out before the first principle can be applied at the point of production.

The second principle assumes that during the pre-production activity failures and ommissions occurred which must be found and corrected as soon as possible. The checking operator is mostly the nearest person to the process he controls. The information on the Quality of his performance is available to him immediately and no time whatever is lost in communication.

From here onwards the story becomes more complicated because the operator cannot often find remedies for errors himself and must involve setters, foremen, production engineers and finally management. So, the operator should be seen as one arm of a multi-armed production entity and the information of a difficulty or hold up should quickly reach the

point where remedial action can be taken in the shortest possible time.

So far the whole system has been designed without the use of an inspection or Quality team. It is in the writer's opinion essential that a small and competent team of sampling inspectors is employed whom the writer prefers to call auditors. It is their task to assist firstly with the communication of failures, and secondly to audit the functioning of the 'operator - setter - foreman - production engineer' entity, or in short of the production unit.

The whole scheme therefore involves an integrated Quality system where everyone in the 'production unit' has a precise task to perform. As a result the whole unit should function in principle without inspection or Quality Control. An audit team of skilled inspectors should, with aid of sampling, check on the performance of the production team.

Operator Control therefore implies both the control by and of the operator (or the production unit).

Other Systems of Control.

Situations are possible - particularly in the near automated factory - where the number of attributes is out of proportion to the number of operators. The first thought which occurs in such circumstances is that the amount of capital invested in capital plant may well be increased profitably to create inter-operational automatic inspection and checking stations. However, where this is not possible, inspectors may have to be introduced. The system then changes from Operator Cotrol to 'Inspection Control'.

It is obvious that inspection control immediately changes the areas of responsibility for Quality and different tech-niques have to be applied where this is necessary. Performance Rating can be superimposed, but this may become expensive, as the Performance Rating cost may have to be added to an already heavy inspection expense.

Another situation arises where some operations in a production process are found to be incapable and no immediate remedy is in sight. Production has to proceed and an answer in this case could be the introduction of production controlled checkers who are charged with screening faulty work. It is clear that the checking, screening, rejection and replacement of rejects imposes a burden on production which must not be perpetuated. But this scheme does in fact highlight the excessive cost of incapable operations which under conventional inspection controlled systems would be hidden under the cloak of inspection overheads.

Where inspection control has to function statistical control charts must not be overlooked. Although their range of application is limited, a number of process industries would be the poorer without them.

In all these cases the inspection function only replaces the operator checking function (or vice versa) and the need for accepting the various responsibilities by the 'production unit', as defined earlier, should remain unchanged.

Capability Testing.

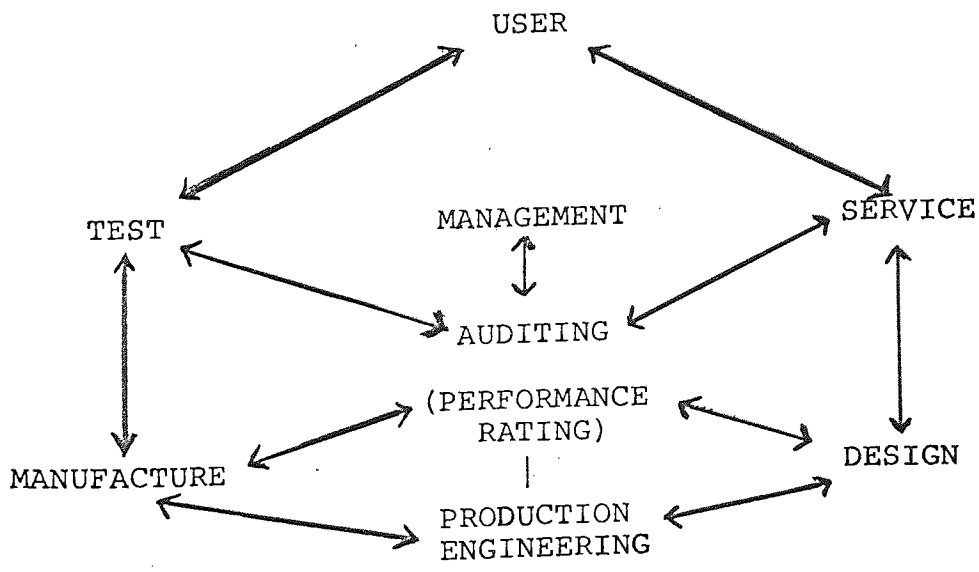
The task of the auditing team - in addition to sampling for

Performance Rating, is to test the capability of new processes - prior to their commencing the production run. Only under special circumstances should incapable processes be allowed to commence production. And, moreover, capability testing of running processes must continue on a routine basis. This testing of capabilities should become the foundation of all Quality thinking and the whole Quality structure should be built on it.

The Cycle of Communication

There is no doubt that a sound Quality programme will enhance the overall productive efficiency of the company because Quality is the result of an efficient and effective organisation.

To achieve this efficiency, communication in general and Quality communication in particular must be organised on effective lines. The lines of communication should not only run from customer-user to design, but also in the opposite direction, with the audit team in the centre linking management to the whole cycle.



Final Audit and Safety Critical Areas

There are conditions and circumstances when the checking-audit function needs yet another line of defence.

One such case in point is a company manufacturing components for assembly where a final audit (rather than a final inspection) is called for based on A.Q.L. requirements. Here again the writer has developed a system which is linked to Performance Rating activity and this will be described in detail in Part two.

A similar situation applies to safety critical areas, where again the whole team must play its part to prevent failure:

1st line of Control:	Preproduction Capability Test (intensified)
2nd line of Control:	Operator Checking (intensified)
3rd line of Control:	Audit (Performance Rating)
4th line of Control:	Routine Capability Testing (intensified)
5th line of Control:	Final Audit, using information from 1st, 3rd and 4th line of control.

Under Operator Control conditions such control can now be exercised with a relatively small increase in overheads and it further gives an exceptionally high confidence level of Quality achievement.

The Role of the Quality Department

From the foregoing the auditing role of the Quality department should have become evident.

The Quality manager employs a relatively small team of auditors whose functions can be listed as :-

1. Capability Testing (initial and routine)
2. Performance Rating
3. Auditing of Incoming Materials (vendor rating)
4. Final Auditing (where necessary)

The advantages of the scheme lie in the fact that with about half the numbers needed for conventional inspection control, not only is a high Quality attained, but a flood of pertinent information is reaching all areas, and thus closing the 'loop' for a selfgenerating process.

The flexibility of the scheme only becomes apparent when one studies the data which can be extracted from the mass of information collected.

The Quality department becomes an arm of management and carries obviously only responsibility over the area of its functions. It places, on the other hand, management in a much stronger position as the information it receives is rarely based on panic-inspired investigations but on facts collected over a period of time from all parts of the organisation.

The Role of Management

Firstly management must apportion Quality responsibilities as indicated earlier and react to Performance Rating information which should indicate clearly how well these responsibilities are being carried. The information

should be condensed on one sheet of paper of an easily read chart, covering if necessary several production units. Everyone in the organisation must be aware that top management receives (and understands) the information distributed and that alone will mostly encourage action.

Without this information management is left to rely on opinions and historical and incomplete data.

And this is the case for Performance Rating.

PART TWO

THE PRINCIPLES

OF

AREA PERFORMANCE RATING

AND ITS

APPLICATION TO QUALITY OF MANUFACTURE

INTRODUCTION TO PART TWO

Part one established the need for performance measurement with particular emphasis on its application to the creation and control of Quality*. Part two is therefore concerned with the development and description of systems, based on performance measurement, which have been introduced by the writer in factories at home and abroad. Such systems should have the following characteristics:

1. They should produce a numerical measure of performance which will be meaningful to both the group (or section) whose performance is being assessed and the control point which has to acknowledge and react to the rating.

The measure (in future referred to as Rating) should therefore be related directly to activities under review and be as free as possible from obscuring formulas, weightings and points allocation.

2. The Rating should be applicable to the smallest unit of an activity or industry, and should lend itself to a progressive integration of units, from a singular unit to a group (or sub-area) and further to the total area under review.

3. The Rating should be presentable in the simplest possible form so that all concerned do not need to spend any time at all on interpretation of results.

4. The Rating itself, together with brief comments, should give clear indications of necessary action to improve an unsatisfactory situation.

*This statement is also supported by case studies and many industrial examples at home and abroad.

5. As the Rating refers to certain areas under review, the name Area Performance Rating (APR) seems appropriate.

Based on the above characteristics, the first chapter will discuss the principles of APR. The second and third chapters will describe methods of application and these will be followed by descriptions of actual case studies in factories in which APR has been introduced by the writer.

Management and its function in industry is, as always, under attack and suffers the ultimate criticism of inaptness to deal with situations. It is therefore reasonable to discuss the effect of APR on management and on the great problem of direct communication with all units of even the largest system.

It is considered that any new management tool, and APR is ultimately just that, must be economically justifiable. Hence it will be shown that when using Operator Control techniques, as described in Part one and again later in Chapter 2, APR becomes simply a by-product, obtainable not only without incurring additional expense, but when compared with conventional systems, applicable at considerably lower costs. It thus supplies important additional information and may, on introduction, produce a saving at the same time.

Even if, on the other hand, APR is used together with conventional systems (as an additional audit on inspection and Quality Performance) its cost may well be justified.

Finally, as pointed out in Part one, the discussions are

using the metal working industry as a background. The principles and techniques are, however applicable to all manufacturing industries.

CHAPTER 1

PRINCIPLES OF AREA PERFORMANCE RATING (APR).

Following the concept outlined in the introduction, APR will refer to an area A and, taking a sample from parameters produced in A, express the performance p by a fraction

$$p = \frac{x}{n} \tag{1}$$

where n = the number in the sample and x = the number of effective parameters. The compensating non-performance or failure rate is the fraction q, and

$$p + q = 1 \tag{2}$$

If 1 is expressed in form of a percentage, then

$$p = \frac{x}{n} \times 100\% \tag{3}$$

As the latter is likely to be more easily understood by people with a limited mathematical education (who are in fact frequently at the receiving end of the rating information) it will be this expression which will be used and developed here.

Let us assume we have an area A consisting of, say, 100 sub-areas as shown in Figure 1.

If performance is measured in each sub-area and the sample from area A_1 indicates a performance P_1 where $P_1 = \frac{x_1}{n_1}$, and the performance from a sample out of A_2 is P_2 where $P_2 = \frac{X_2}{n_2}$ and so on, then the APR of the whole area is

$$P_A = \frac{\sum_{i=1}^{100} x_i}{\sum_{i=1}^{100} n_i} \tag{4}$$

Using numbers, if for instance the total number of parameters measured were, say 3,000; that is

$$\sum_{i=1}^{100} n_i = 3,000$$

and the sum total of all measured parameters showing satisfactory results were, say 2,500 or

$$\sum_{i=1}^{100} x_i = 2,500$$

then the APR

$$P_A = \frac{\sum_{i=1}^{100} x_i}{\sum_{i=1}^{100} n_i} \times 100 = \frac{2,500}{3,000} \times 100 = \frac{5}{6} \times 100 \text{ or } 83\%$$

From the foregoing it appears obvious that the only criteria to be considered is whether or not the measured parameter meets the specification. The pre-requisite for the ability to apply APR is therefore a clear cut specification, against which each sample taken from sub-areas can be measured.

This black and white technique may not always lead to practical results and the introduction of a 'grey' area will, therefore, be considered later. But at first, for the sake of clarity the simplest form of APR will be discussed.

Definition of Areas

An area can be any summation of parameters, each of which cannot be further broken down, and each of which does not appear again elsewhere. Hence if one were to accept a machine shop as an area and each machine in that machine shop as a sub-area, the parameters of a component would have to be allocated to sub-areas, so that the parameters produced at sub-area a_1 are not counted again at a_2, a_3, and so on.

A component could, for instance, be produced in three sub-areas, (such as Turn, Mill and Drill) and could be part of a batch which is simultaneously machined on all three machines. It would cause confusion if one were to count the correct (or incorrect) components at a_1, a_2, a_3, as these same components might reappear in all other sub-areas. It is, therefore, correct to count the parameters only produced at a_1 in relation to sub-area a_1, at a_2 in relation to a_2 and so on. By using this method one treats each parameter as a unit and any Area is hence made up of sub-areas which in turn produce units to be measured.

This method will also work when the same parameter is produced in several sub-areas, providing samples are taken from each sub-area and the result referred to this area only.

The term area can be applied to any entity consisting of clearly specified units.

1. It can for instance be a geographical area (say a factory or office, or part of either) in which the sub-areas are machines (and/or operators) with clearly specified and toleranced tasks to perform.

2. It can also be an assembly of units, a number of components or an assembly of a number of parameters into one component.

3. It can be a group of people with specified tasks to perform.

The geographical area need not be continuous so that each sub-area borders on another, but can be a selected number of sub-areas.

Therefore, if -

P_A = APR of area A

P_{ai} = APR of sub-area a_i

n_A = the number of units in sample taken from A

n_{ai} = the number of units in sample taken from a_i

X_A = the number of units correct to specification in sample n_A

X_{ai} = the number of units correct to specification in sample n_{ai}

Then $P_A = \frac{X_A}{n_A} \cdot 100$

and $n_A = n_{a1} + n_{a2} + n_{a3} \quad \cdots \quad + n_{ai} = \sum_{i=1}^{i} n_{ai}$

and $X_A = X_{a1} + X_{a2} + X_{a3} \quad \cdots \quad + x_{ai} = \sum_{i=1}^{i} X_{ai}$

Therefore:

$$P_A = \frac{\sum_{i=1}^{i} x_{ai}}{\sum_{i=1}^{i} n_{ai}} = \frac{X_{a1} + X_{a2} + \ldots X_{ai}}{n_{a1} + n_{a2} + n_{a3} + \ldots n_{ai}} \qquad (5)$$

also $x_{ai} = P_{ai} \cdot n_{ai}$

and $n_A = n_{a1} + n_{a2} + \ldots n_{ai}$

Substituting in (5) gives therefore:

$$P_A = \frac{P_{a1}\, n_{a1} + P_{a2}\, n_{a2} + P_{a3}\, n_{a3} + \ldots P_{ai}\, n_{ai}}{n_A}$$

and $P_A\, n_A = P_{a1}\, n_{a1} + P_{a2}\, n_{a2} + P_{a3}\, n_{a3} + \ldots P_{ai}\, n_{ai}$ (6)

It can be seen from (6) that if $P_{a1} = P_{a2} = P_{a3} \ldots$ then

$$P_A = P_{ai}$$

Therefore only if the APR of the sub-areas are identical to each other will the APR of the total area be equal to each of them. This is important when discussing the analysis of APR, as it will be seen that grouping of areas with similar APRs has great advantages.

Sample Sizes

The only condition for the application of APR, as has been pointed out before, is the ability to measure a number of units against a given specification and tolerance. In order to ensure that a sample taken from a sub-area is in fact representative of that area, a sampling scheme should be applied which will give an approximate assurance of this condition. From a statistical point of view this is not over critical as a smaller sample will simply widen

the confidence limit (see below). It would, however, obviously be misleading to take an unbalanced proportion of samples out of sub-areas and subsequently assume the APR of the total area to be correct.

The writer has suggested to determine the size of samples out of sub-areas according to an AQL-Plan* for a chosen confidence limit using selected OC curves*.

The Use of Different AQLs

Assuming that we have chosen an AQL-Plan of, say, AQL = .01 and have come against a situation where either a higher AQL has to be applied (say of .001), or a batch has to be 100% screened; the aim at this stage is to arrive at an APR of the sub-area, which can also be used when calculating the APR of the total area. It is not to pronounce the output of an area acceptable or otherwise (although this will be an additional requirement to be discussed later).

To deal with this problem one has to simply translate the higher AQL results into the lower ones. So, for instance, if the result of a 100% screening operation in a sub-area gives 810 units in tolerance (IT) and 90 units outside tolerance (OT) (∴ APR = 90%) and the number to be sampled at that station according to the AQL-Plan (applicable in the remaining area) were 80, it would mean one has to assume for APR that a sample of 80 had been taken (n = 80) and that 72 of these (or 90%) were found to

* For definitions see p.115 and Ref.1 on p.114.

be IT (in tolerance). Using this sample size and defective number, this would in no way adversely affect the confidence of the APR of the total area, although the confidence level would vary inside the area.

Therefore, if one has to summarise areas of different AQLs, the rule is to bring the higher intensity of sampling to the lowest level with possibly indications of varying confidence levels. In practice it is sometimes more convenient to separate the areas and quote different APRs for each area representing a different AQL. This point will be illustrated below when discussing Performance Rating of suppliers.

Very Small Batches

Decisions on and assessments of very small batches are presenting a problem to any approach to assessment. However, when using APR the difficulty is alleviated by the fact that parameters are (or can be) counted instead of components. Hence a single component manufactured in factory A may have 30 parameters and a batch of only 3 becomes a batch of 90, which is easier to deal with when assessing the performance of factory A.

Generally when dealing with very small batch quantities N it is important to keep the ratio $\frac{N}{n}$ (where n is the sample size) as constant and as large as possible.

Confidence Limits

It is of importance to appreciate that each sample taken will give a measurable degree of confidence. Using the confidence intervals from Quality Control and Statistics by Acheson J. Duncan (page 436)*, but giving it APR nomenclature, for a sample of 10, 100, and 1,000 we can see the application shown on Fig. 2.

Assuming a confidence limit of 95%, if a sub-area has a sample of 10 taken which shows one defect (90 APR on horizontal scale) the actual batch can vary between 55% and 99%. If, however, a sample of 100 were taken the limits for APR are between 94% and 83%. If, however, similar readings were taken out of say 10 sub-areas, giving a sample size for the total area of, say 1,000 with an overall APR of 90%, the confidence interval would be from 92% to 88%, which of course is much closer and hence more meaningful. A similar closer result can be obtained by taking further samples out of the same area.

The writer has had the experience that out of a number of factories sample after sample is showing great consistency and little variation when spread over a larger area, which only proves the point made here. Providing the samples taken from sub-areas give a reasonably narrow width of intervals, the total area reading is considerably nearer the factual situation than those of the sub-areas. The addition of sub-areas produces accurate results for the whole area, but this process must not be reversed. More about this under Assembly of Units.

* See Ref.1.

Time and APR

The APR must be considered a moving measure and hence samples, even from a large area, should be taken in the shortest possible time. This is, however, not always practical and it is therefore desirable to state the time interval in which samples were taken.

Another important consideration is the build up of information. Assuming only a small sample can be taken in a sub-area for good reasons, and the interval chart shows too large a possible variation, it is reasonable to wait for the next possible sample and add the new to the original readings. The more readings are taken the closer will be the result to reality. The result refers to the time span in which the readings were taken. If individual readings show a large variation, the deterioration is also shown in the larger sample. Time in this case is not of the essence, but the time span in which readings were taken should be stated.

The Assembly of Units

If one assumes that a certain component with, say, four dimensions was to be considered as an area, and if two of these dimensions are produced in sub-areas a_1, a_2 and the other two in sub-area a_3, and if one further assumes the APR from a_1, a_2, and a_3 to be 90, 80 and 100 respectively, one could take a sample size in each case of, say, 30 and using formula (6) establish the APR of the whole area:

$P_A \times 120 = 90 \times 30 + 80 \times 30 + 200 \times 30$

and $P_A = 92.5\%$.

It would hence be logical to state that the APR for this component is equal to 92.5%. But this statement would only be correct for the sum of all dimensions. Or, in other words, of ALL dimensions produced in area A 92.5% are likely to be correct (within certain confidence limits). It does not follow that any one dimension out of this area has such an APR. This is only the case when sub-areas within a limited APR are grouped together. In this latter case it can be stated that tolerances out of such an area are within the group limit.

Further, the APR does not mean that any one of the components out of area A will be correct within this bracket. In order to translate APR to an assembly of sub-areas (or an assembly of dimensions into one component, or an assembly of components into an assembly of a functional commodity) we have to find the probability of a totally correct assembly. Going back to the above component with four dimensions we know that $P_{1,2,3\ \&\ 4} = 90, 80, 100, 100$ respectively. The number of ways in which good and reject parameters can be assembled must be:

$$\frac{(90 + 10)}{100} \times \frac{(80 + 20)}{100} \times \frac{(100)}{100} \times \frac{(100)}{100}$$ or in general terms:

$$\frac{\{P_{A1} + (100 - P_{A1})\} \times \{(P_{A2} + (100 - P_{A2})\} \times \{P_{Ai} + (100 - P_{Ai})\}}{100^{i}}$$

This expression represents all possible combinations of

ITs (in tolerance) and OTs (out of tolerance). But because the first factor $\left(\frac{90 \times 80 \times 100 \times 100}{100 \times 100 \times 100 \times 100}\right)$ is the only one which carries no OTs, it must be the probability of obtaining an assembly out of this area having all correct parameters. In this case this probability is $\frac{9 \times 8}{100} = 72\%$, being the APR of the component. (Or equal to the chances of obtaining a good assembly of parameters out of this area).

The Grouping of Areas

It is therefore in practice useful and necessary to group areas within a common APR range. Most will be, in any case (in most manufacturing organisations) in the 98-100 bracket. These should be called A areas and an APR_A allocated. It is then reasonable to group the remaining areas into groups of an approximate variation of, say, 5%. This will enable one to assess approximately the quality of components coming out of such areas. For instance for a component having 10 dimensions of which

8 come out of area A with an APR of 99.2

2 come out of area B with an APR of 95.0

The quality of the component is likely to be $99.2^8 \times 95.0^2$ which is equal to 84.6% approximately.

It is obvious that the assessment of component quality based on APR can only be an approximation, unless the Rating is established accurately for each tolerance. This is particularly so when a multi-dimensional component is considered, because even 99.2 raised only to the power 8 (and there are more components with more than 8 dimensions

than with less) is 93.8 which gives a difference of 6.2 (from 100) for 0.8 difference of Rating. Furthermore the lower down the scale one goes the larger the difference becomes. The assembly of tolerances should rather be used as a demonstration for need of accuracy and how very important it is to maintain the highest possible APR.

Despite the above and for practical reasons, depending largely on product and circumstances, the clearance of batches may take place out of a high performance area, and (as will be shown) from a high performance supplier. This must be based on the realisation that, if risks have to be taken - and any practitioner of Quality Control knows how often he has to do this - they are far smaller out of a 99% plus area than from an unknown supplier.

Final Audit and Acceptance of Batches.

It is quite clear that in order to assure a quality level for components of, say one per cent, the APR must be well over 99% throughout. The release of batches should hence take place from sub-areas with a sufficiently high APR. Units which come from 'B' areas however have to have further checks carried out before components can be released for use.

Finally the sample size used for APR must be considered at the final audit stage. Sample sizes sufficient for the confirmation of an APR may not be sufficiently large to give a clear AQL. But using the quantities checked for APR purposes gives a considerable saving, as only

additional quantities to satisfy the respective Quality plan have to be checked.

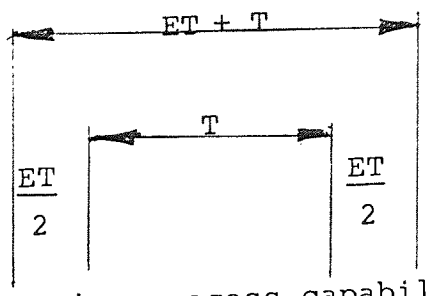
All the above will be considered in greater detail when discussing the organisational aspects of APR systems.

The Use of Extended Tolerances

A specification is fixed by the designer for management. A continuous problem arises when performance hovers around the ends of the tolerance band and the decision machinery that has to be applied firstly to determine the fact of a borderline problem, and secondly to make decisions on their acceptability is costly and often grossly inefficient.

In recognition of this the writer has - in a paper to the Institution of Mechanical Engineers (see appendix no. 2) suggested an 'Extended Tolerance' scheme, which is also briefly mentioned in Part one of this thesis. The advantages of this scheme will therefore not be repeated here, but the techniques only referred to as they affect APR.

The additional tolerance band is referred to as ET (extended tolerance) and can, as has been pointed out, be pre-determined by design or the specifying authority.



If T is the drawing tolerance ET (extended tolerance) could be, depending on product, from plus/minus 20% to 40% of T. Assuming process capability of 75%, even in a process with its mean at the extreme of tolerance, tolerance T will be contained within ET. In practice, due to immediate action

once parameters appear in ET, it is found that the number of ET rarely exceed 2-3%, and, as pointed out elsewhere, do not as a rule involve the company in an assembly problem.

As far as APR is concerned this becomes a most important tool of assessment in as much as three ratings are given:

$P_{A(IT)}$ = in tolerance

$P_{A(ET)}$ = in extended tolerance (ET)

$P_{A(OT)}$ = out of tolerance (defective)

When assessing the performance of an area it is of great interest to know if some of the cases are borderline cases. An example will demonstrate the point made.

In a bay out of 1,000 units (dimensions checked)

950 are found to be IT

40 are found to be ET

10 are found to be OT

From the audits taken it is found clearly that the majority of ETs are due to faulty setting (on investigation mainly due to short and very short batches). The resulting APR reads IT = 95%, ET = 4%, OT = 1%.

The effective APR is IT + ET, or 99%, which is a different story from 95% which, particularly on a multi-dimensional product can be an apparently disastrous rating.

Using this nomenclature the previously developed formulas are:

$$P_{aIT} = \frac{IT}{IT + ET + OT} \times 100 \qquad (10)$$

$$P_{aET} = \frac{ET}{IT + ET + OT} \times 100 \qquad (7)$$

$$P_{aOT} = \frac{OT}{IT + ET + OT} \times 100 \qquad (8)$$

$$P_{aIT} + P_{aET} + P_{aOT} = 100 \qquad (9)$$

The Final Assessment of 'Assemblies'.

It will be useful at this point to answer some questions on the use of APR. Part one, set out to stress the need for knowing the performance of detail facilities in a manufacturing organisation. It is now necessary to indicate what sort of information APR can provide.

APR clearly gives an indication of the level of Performance in a given Area. It is very flexible in as much as the same information can be used in different ways (Performance of sub-areas, summaries, assemblies, as previously described). Although there are limitations when trying to deduct information "in reverse" that is from APR of an area to the APR of its sub-area, once understood the indications are still important and relevant to all concerned.

The Rating, however, can have a wider meaning than so far indicated. Take for instance two areas which have the following APRs.

	IT	ET	OT
Area one:	95	4	1
Area two:	80	12	8

Firstly, the meaning of these readings is that the total facilities (men plus machines) are 99% or 92% effective. But they also indicate that 1% or 8% respectively of facilities have to be replaced or reorganised. If the cost of these facilities in the two areas are known it will

not be difficult to work out the estimated maximum cost of correcting an unsatisfactory situation. This becomes a useful and important management tool because it is important for management to know the magnitude of the task to correct a situation.

APR readings can be organised to give specific information in the engineering industry to design. If all tolerances between .0005 and .001 are taken as a sub-area and an APR taken, it will clearly indicate to design (from continuously supplied information sheets) the ability of their production units to meet their demands. And when the truth is brought home, they may not be quite so liberal - unless of course it is essential - to quote costly tolerances. In this connection a scheme applied was to allocate cost to area facilities, for the use of production and design personnel.

Perhaps the most important aspect of APR is that it can be applied to people. A sub-area may consist of one machine plus one certain operator. The lower the level of automation the higher will be the influence the operator has on the process. Although operators have less influence on Quality than is normally thought, the comparison of performance of one set of equipment as handled by the night shift and subsequently by the day shift gives often startling information.

Further investigation can lead to APR given to setters, when assessing for instance the position of means of distribution relative to the mid limit.

The use of APR in the buying function is so important that it will be discussed in a special chapter.

From the Quality Consultants point of view the APR has enabled us to tell companies, after a few weeks of samplings, situations they were wholly unaware of in their own factories. To illustrate this point two case studies are added in Chapter 4.

APR has hence been found to be an easily applicable and interpretable tool and in the next chapter its application and the organisation for this will be described.

CHAPTER TWO

THE APPLICATION OF PERFORMANCE RATING

The General Assessment of Quality Performance.

In Part one the question of assessment of Quality has been raised and it has been suggested that the conventional indications, such as scrap and reject rate are inadequate. Reasons for this have been stated, in particular that scrapping of production is likened to the act of knocking the peaks off the iceberg, without touching its hidden mass beneath the surface*. To supplement the information on rejects, a factual statement of Quality Performance is of interest to general management, to Quality management and to the consultant, who are all charged with the assessment of Quality of manufacture.

To illustrate the practical application of APR to this problem, it may be best to describe the procedure a consultant would follow, who has to ascertain the Quality performance in a factory consisting of say 40 machines. Let us assume that at the time of checking, 20 machines were producing batches of 500 components, 10 machines, batches of 1000 and 10 machines, batches of 3000. In each sub-area two significant dimensions were to be measured.

The consultant would request the company to make available one to two inspectors who would take samples from each machine (sub-area). The records of findings were to be kept and subsequently analysed.

*A good example is case study No.1 p.85, where scraprate was o.84% and APR was found to be 86%. And that on a multi-dimensional product.

It was thought to be of interest to devise a working model, from which, after having invented a factual situation, samples can be taken and analysed. The results of this analysis can then be readily compared. The model was supplied by Dr. J.D. Morrison of Aston University and consists of a box with 3000 plastic balls. 8%, 4%. 2%, 1% and ½% of balls are black, blue, green, yellow and red respectively.* A ladle with fifty suitable blind holes scoops out samples of 50 balls, the coloured balls giving the number of defectives in each sample.

The assumed 'factual' situation is given in table 1, p.101, showing the sub-areas divided into two (2 parameters per sub-area) and giving the assumed (factual) respective APRs.

A sampling plan was devised, according to which

samples of 50 were taken out of batches of 500,

samples of 50 were taken out of batches of 1000

and samples of 100 were taken out of batches of 3000.

Using the model in accordance with the sampling plan, table 2 gives the result of the sampling in number of defectives and table 3 gives the respective sampling APRs.

On analysis, taking all 100 to 99 APRs as area A, all 98.9 to 96 APRs as area B and all 95.9 and below as area C, and computing the APRs for the assumed (actual) situation and the situation from the sample as per table 3, the following comparison can be made:

*The remainder are white.

Area	Actual APR	Sample APR	Lower Confidence (95%)
A	99.64	99.81	-0.5
B	97.57	98.10	-1
C	90.5	93.65	-5
Total	98.88	98.95	-0.4

It was obvious that area C would be the least accurate, because it is based on the smallest area and sample. Also due to sample error 5 'B' sub-areas are in group 'A', but as explained elsewhere, further sampling will adjust this. One way of overcoming this problem is to reduce sample readings to their lower confidence limit.

The confidence interval for area A, based on a sample size of 3550, must be very close to the reading. This is also borne out by the comparision. Nevertheless a lower confidence limit of -0.5 is attached as a safety factor.

The interval for area B (sample size 1050) is also small and hence a lower confidence limit of -1 was allowed.

Area C with a sample size of 450 may fluctuate (according to the confidence interval tables) by some -5% and again this is found to be so by comparision.

Let us now assume that areas 2a, 7a, 8a, 11a, 14a, 16b, 26a, 34a, 37a and 38a all manufacture tolerances from 000 "to .001". This could be taken as an area, and the APR of that area would be 95.71 (as per formula (6)).

This clearly points to an area of inadequate facilities, either of tooling or skill and further investigations are called for. In practice this investigation gives normally much more dramatic results as will be shown in the respective case study later.

Such groupings can be done for the Production Engineering department on request (Question: In sub-areas x to n, we are using jig A and in sub-area y to z we are using jig B; which is more capable?)

The same question and answer game can of course be played by the Quality department who should furnish Production Engineering with the relevant information.

To return to the problem set at the beginning of this Chapter, the consultant would extract all such above information from the audit carried out by the company's inspectors. He would use paper work for this which would give much additional information, such as capabilities of men and machines and setters. Such paperwork has been developed by the writer. To illustrate this, and such an exercise in general case study 1 has been added in Chapter 4.

The Control of Quality on the Shop Floor Using Operator Control Techniques.

Much can be written about Operator Control (in future referred to as O.C.) techniques in various situations. There are areas where O.C. is very useful, areas where its advantages are marginal, and some where its introduction

may not be advisable. To describe these situations would depart from the terms of reference of this thesis, and hence the writer will concentrate only on those aspects of O.C. which concern APR.

The principles of O.C. have already been discussed in Part one. They are only briefly summarised here by stating that - in addition to all pre-production functions - the checking or verification functions should be as fully integrated with the production process as possible, so that if all inspection staff were to disappear, the works would still carry on efficiently. This may not be a fully attainable target, although the writer has seen a number of very efficient organisations pretty near to it.

However, assuming such a situation has been achieved as far as is practical, the inspection forces (referred to also as auditors) carry out analytical work designed to determine the degree to which the efforts of all concerned with production have been successful. They should act as a thermometer in a self generating Quality atmosphere and APR is the suggested method to use for measuring performance.

The Four Bin System

One of the techniques developed by the writer in aid of this measurement (or auditing) is to place four bins at the disposal of each operator.

In some cases the word 'bin' is only used to describe a location - as for instance where components are too large to be placed in a bin. There are, in fact, a number of

exceptional circumstances where this system has to be replaced, but generally in the metal working industry there are many applications for it.

To return to the bins, bin number 1 holds a given quantity which is fed straight from the machine or sub-area. Out of bin number 1 the operator takes a prescribed number of components and checks them with gauges specially designed for his use. When satisfied, the checked components are placed in bin number 2 (referred to as the 'green bin').

The placing of all checked (correct) components in the green bin releases bin number 1 which is then emptied into the bulk bin, i.e. bin number 3. Any rejects found by the operator (or auditor) are placed in bin number 4 (referred to as the 'red bin'). As soon as rejects appear (and rejects include ET (extended tolerance)) in bin number 1, the operator must stop the process and get the setter to adjust it. Rejects are placed in the red bin. Instructions are given by the auditor as to the intensity of re-inspection to be carried out in the bulk bin. For this and other reasons auditors must go through a period of intensive training.

The auditor alone is responsible for clearing the 'green bin'. Where possible the quantities in the green bin should satisfy the required sample size for a given AQL. The auditor will take a sample out of the green bin large enough to satisfy himself that the green bin itself is free from defects. In addition he may under certain conditions

also take a sample out of the bulk bin. Auditor's sample sizes have to be specially determined according to product and quantities produced.

There are many variants to this procedure. Just to mention one - it is often possible, particularly on automated processes, to arrange a 100% check on critical dimensions. Obviously in such a case the 'green bin' disappears and all production goes into the bulk bin.

In all cases the auditor is charged to record all information, i.e. the number checked by the operator (green bin), the number checked by himself (additional checks from other bins are also recorded), the number rejected, the number scrapped and the number of accepted rejects.

The developed paperwork (see Figures 4&5) is of interest, because it is very flexible in its use and forms the basis of APR on running production. The information is recorded separately for each batch, each operator, each component, each operation, each setter and each shift. In other words, every time one of the above facets change, a new record sheet is started. Hence the sheets can be sorted into any of the above categories and an APR can be produced. The information on these sheets, as far as APR is concerned, is really concerned mostly with the contents of the green bins, or in other words with the work passed by the operator. Therefore the Rating measures the performance of the operator (his ability to control Quality) as much as anything else. And for this reason the sheets also carry

information on the reject rate of each machine, as it is possible that an incapable operation with a good operator can produce a high reject and scrap rate and a 100% green bin record at the same time.

As suggested above, the variations of the scheme are as numerous as there are variations in conditions; but the basic embracing idea is a continuous auditing service producing thousands of readings from all sub-areas and providing a continuous stream of APRs to all concerned with Quality.

Final Release of Components and Batches

Components and batches do not necessarily have to be collected in a "final inspection area", as this extra handling may not always be necessary. The audit sheets however should be collected when batches or part batches are to be released to assembly operations, or into stores or to despatch. At this point a Quality engineer (or other senior Quality control officer) should analyse the sheets and record his findings:-

1. He should ensure that all operations have been carried out and have been audited. On occasions operations may be released from 'A' areas without auditing, where skill and facilities are well known and have in the past produced good APRs. An important point here is that judgement is not made on irrelevant personality considerations and opinions, but on actual APRs taken over a period of time. But even in such cases some evidence is required that all

operations have actually been carried out. Such evidence should be given by other production personnel, such as foremen or progress people.

2. All operations from 'B' areas or those with important tolerances, where a higher AQL is required, have to have additional checks carried out and direction is given in such cases for this to be done. Where possible, additional checking should take place nearest to the location of the last operation to avoid increased material movement. More often than not this work verifies that adequate controls have been exercised in the course of production, but on occasion of course, particularly when work comes from 'B' areas, further sorting may have to be done.

'B' Areas

A further point about analysis has to be borne in mind. Under O.C. conditions such as described above, the APR refers to the Quality of materials after inspection by operators. Hence the information on capability of facilities - such as is presented from a pure investigation exercise described earlier - will not appear in general. (In practice it is found that even after O.C., where serious capability deficiencies appear, rejects can still be found in the 'green bin'). So other additional routines have to be introduced, such as regular capability tests. These tests are ultimately almost identical with the investigation procedure described earlier, only carried out by auditors on a planned regular basis. Therefore, 'B' areas will be classified as such not only from information

collected from the audit sheets, but also as a result of capability tests.

It is again emphasised - and the writer does not even apologise for perhaps labouring the point - that such large volume of factual information is only possible under O.C. conditions, unless the company is prepared to pay for audit personnel in addition to the conventional inspection forces.

APR and other Quality Control Systems

There is, of course, no reason at all why APR should not be applied in addition to other Quality control systems under 'inspection control' conditions. If applied to the final product it need not even be carried out in the area where production takes place, and can be organised for instance in the finished part stores on finished components. The Rating can be applied exactly as under O.C. conditions. In fact the writer has assisted a large company in this country to do exactly that.

The Communication of APR

From the audit sheets information should be collected and distributed by the Quality department to all from management downwards. The writer has developed two different types of audit sheets and they are shown in Chapter 4 under case studies, filled in by a company who has used them over a period of years. The relevant points of this paperwork will be discussed therefore in Chapter 4.

CHAPTER 3

APR AND VENDOR RATING

In Part one, Chapter 2, a brief survey was made of the problems affecting the buying and Quality departments in relation to incoming (bought out) materials.

The job of the buying department is to find capable and economical sources and it must do this guided by a 'vendor Rating' scheme, the Rating being carried out by the Quality department, based on information supplied by the incoming inspection section.

From previous discussions it is not difficult to see how APR can easily be applied to this function. Each supplier is firstly considered as an area and APRs can be allocated according to samples taken from deliveries similar to shopfloor techniques. In some companies the Rating is based on the number of components IT, (ET) and OT; in others APR is based on parameters as described in Chapter 1.

Suppliers are grouped into A, B and C suppliers, where - after certain safeguards - supplies from 'A' suppliers can be accepted without going through the prescribed inspection routine, 'B' suppliers are warned of being in danger of having their orders cut, whereas supplies from 'C' suppliers are -where possible - discontinued at the earliest opportunity.

Most vendor Rating systems follow the above routine. APR, however, can do more. By grouping suppliers into such groups as steel suppliers (and their categories), rough machining, finish machining, grinding, fabrications and many others, and by building individual APRs into group APRs one is able to determine the position of each supplier in his group.

So, for instance, if a supplier has only a 95% Rating and yet all other suppliers are worse in that particular area, (such as for instance in fabrication), a 'B' Rating may be unjust. Ratings have to be considered against the 'trade' Rating and this is a consideration of obvious importance to the buyer, the inspector and the designer.

Inside one company investigation will show varying capabilities in different areas of operation. So, for instance, a company may produce an 'A' Rating in their welding department and a 'B' Rating in their machining sections, with the obvious conclusion being drawn by the procurement organisation.

Finally, the APR of the total supplies of a company gives the Performance Rating of the procurement organisation whose task it is to maintain the highest overall APR (at reasonable cost!).

To illustrate the whole scheme a case study has been added in Chapter 4.

APR as Delivery Index

The writer has suggested to companies a delivery index based on APR.

The point at issue is, that Quality alone is not the only criteria on which a supplier's performance should be measured. He should be competitive, approachable, not too distant from the procurment organisation and, above all, his deliveries must be on time.

It is possible to consider all these points in one Rating. To begin with delivery, the supplier must be given an earliest delivery date with a, say, 2 weeks tolerance. By simply counting the number of deliveries IT and OT (and perhaps allowing one week for ET) one can give a Rating based purely on delivery performance.

The next step is simply to treat the two Ratings as an assembly and by multiplying the Quality APR by the delivery APR one could get an overall Rating for Quality and delivery.

So, for instance, a supplier whose Quality is 90%, but whose delivery is 100% stays a 90% supplier, whereas one who produces 90% Quality and whose APR on delivery is also 90% is Rated as a 81% supplier. This can be justified by reasoning that the procurment organisation only has an 81% chance of receiving acceptable supplies on time.

Finally, one could either invent a tolerance for other attributes (such as price and distance) or apply some sort

of points system to arrive at a third APR which then might become the third factor of an APR assembly. And, hence, a supplier who would get for price and distance, say, only a 50% Rating, would not really be considered seriously even if his Quality and delivery were near to 100%.

Practically, there is no reason why delivery APR should not be used with Quality APR. The third factor may need further practical considerations.

CHAPTER 4

THREE CASE STUDIES

Study No:1. Investigation of Quality in Factories A and B Both Belonging to One Company.

The company has two works employing together some 3,000 people. They are manufacturers of internal combustion engines and had continuous Quality problems, mainly in the form of hold-ups of production. Their scrap rate was relatively low (approximately 1%) but their inspection strength high (17.5% ratio of inspection to direct labour) and the department was under pressure to employ more inspectors. The factory obviously worked to 'inspection control' principles.

The first task was to establish the true Quality performance in order to understand the real need for the large inspection force.

This assessment was based on an audit of functional dimensions from current production in the two factories, which was carried out under the author's guidance by two of the company's inspectors over a period of three months. Figure No. 3 gives an illustration of the type of form used for the collection of data. The headings under which records are taken are self-explanatory. From this information Performance Ratings could be computed. In addition, information on capabilities, setter function, drawing-office capability and others were evaluated. The following is an extract of the writer's report to the company.

QUALITY PERFORMANCE RATING.

1. This assessment is based on an audit of the Quality of functional dimensions in batches of components from current production in the two factories. In total, over 29,000 Quality readings were made covering 967 dimensions in 163 components. These readings have been subject to considerable analysis.

2. The results of the Quality Audit are summarised in the following table :

Factory.	A	B	Group.
No.of readings.	18,312.	10,740.	29,052.
No.in tolerance.	16,087.	8,988.	25,075.
Percentage in Tolerance (IT) (APR).	87·9%	83·7%	86·0%

These results indicate that only 83.7% to 87·9% of the components checked are within the specified limits, with a Group average of 86·0%. It is accepted that these figures include components accepted through the application of inspection discretion, or official concessions.

3. A proportion of the Quality readings were obtained using measuring equipment, as distinct from fixed gauges. This enables the effect of extended tolerances to be assessed, although no system of extended tolerance is in use in these factories. In this analysis an extended tolerance of ±30% of the specified tolerance was adopted.

The summarised results of the quality readings by measurement were as follows :-

Factory.	A	B
In Tolerance. (IT)	78·3%	80·0%
In Extended Tolerance (ET)	8·9%	11·1%
Out of Tolerance (OT)	12·8%	8·9%

On the basis of this extended tolerance, 87% to 91% of the functional dimensions are within the extended tolerance.

The "In Tolerance" figures obtained by measurement are less than the totals indicated in paragraph 2 above, particularly at 'A' Factory. This is due to the measurement checks being more precise than fixed gauging methods.

4. The readings obtained by measurement have also been analysed in relation to various tolerance ranges.

The Quality performance relative to tolerance levels for the Group is given below.

Tolerance Range.	% of dimensions measured.	IT.	ET.	OT.
Up to ·001"	23·7%	79·8%	12·0%	8·3%
·0011" to ·005"	49·1%	81·9%	8·1%	10·0%
·006" to ·010"	16·3%	84·2%	7·6%	8·2%
Above ·010"	10·9%	76·5%	7·9%	14·6%

5. Process Incapability - Examination of the spread of readings where the audit was by measurement reveals an appreciable proportion of operations which appear to be

incapable of providing consistent conformance to specification. The percentage of such operations relative to the total number measured in each factory is given below.

Factory.	A	B
% of Operations Incapable.	11·9%	13·0%

6. Faulty Setting - Further examination also underlined in significant degree the results of faulty setting up of operations. The corresponding percentage for the two factories is tabulated below.

Factory.	A	B
% of Operations Affected.	9·5%	12·1%

7. As indicated in paragraph 1, the audit was carried out relative to individual functional dimensions rather than to components. This was done in order to give a clear indication of the extent of non-adherence to specification.

It does not, however, indicate the number of components which are correct or otherwise, since a component may have two or more functional dimensions.

In this audit the average number of functional dimensions checked was 5 and the Group Quality Index 86% (see para.2). It is, therefore, unlikely that more than 50% of the manufactured components are entirely correct to specification.

8. From the foregoing it is obvious that a large number of components are going forward to assembly which are out of drawing tolerance. Our contacts with the company's specifications (drawings) to date do not give us an impression of a liberal call for close tolerances, but the survey does suggest that satisfactory engine units can be built at least to some extent, from components outside specification. In our view this would support the adoption of a formal system of extended tolerance.

9. General Comments.

9.1. The statistics which have been brought together reveal a combination of a low scrap rate and a poor Quality Index. The low scrap rate in a poor quality performance context must result from either ineffective or inadequate (missed) inspection or both, or from permissive inspection. If it is the former, this is all the more surprising, combined as it is with an excessive inspection force, but it has already been noted that an appreciable proportion of the inspectors are limited in capacity and ability.

9.2. In our opinion the low Quality index reflects all three conditions, with some emphasis on inadequate inspection.

9.3. The analysis of the audit relative to tolerance ranges (see paragraph 4) indicated that the inability to conform to specification is substantially spread over the whole range of manufacture. Examination of the Quality index relating to the tolerance ranges and in the two factories suggests a varying degree of concentration between the close and wider ranges.

9.4. As indicated in paragraphs 5 and 6, it is likely that more than 10% of operations are incapable of producing to the requirements of the specification, while additionally, a slightly smaller proportion result from faulty setting up. In such circumstances adequate control of Quality is not possible under any system of inspection other than sorting. A few capability studies have been carried out by the inspection department, but it has not been possible in the available time to pursue this line to determine whether the indicated incapability is due to shortcomings of plant, equipment, or methods, or inadequate skill, or both.

9.5. The Quality found from this audit is low by any standards, and we suggest that unless the company takes steps to secure a higher Quality conformance, considerable difficulties may be encountered in securing the expansion which is planned, and controlling the cost of dealing with large scale deviations from specification.

As the poor performance in this factory was relatively evenly spread the definition of 'A', 'B' and 'C' areas, as explained in Part Two, Chapter 2, was not considered important. It could, of course, have been done without difficulty.

It is of interest to note the following brief extract from a report to the company 3½ years later:

..... An assessment of the rise in level of conformance to specification can be seen by comparing the Quality Performance Rating obtained during the writer's initial survey with the current figures.

At factory A where five major areas are under operator control and Performance Rating procedures, the Quality Performance is now between 99.5% / 99.7%. The comparative figures from my initial report were 88%.

At factory B where six areas are operating under the new conditions, the Quality Performance has risen from 73% to 98.5%.

In my opinion the results are very satisfying and their effect should increasingly be felt as more areas are introduced.

The cost savings made during this commission are running at the rate of £60,000. per annum. This is based on the fact that the Quality cost ratio has fallen from 4.43% to 3.75% in factory A and from 3.94% to 3.57% in factory B.

Study No:2. APR on the Shop Floor.

This case study is presented to show the report of APR in a factory on running production over a period of one month.

This particular factory employs about 1000 people and makes components for the motor trade. There are four major machining departments :-

A semi automated 'line' section with special purpose machines;

An automatic section mainly equipped with Wickman 6 Spindle Autos;

A general machine shop, capstans and second operation machines;

A grinding department.

The main point of this case study is to demonstrate the developed paper work and to show the type of information all areas of management receive from APR.

Fig.No.4 gives a blank audit sheet used by the auditing inspector. The headings are self explanatory.

The auditors are trained to take a suitable sample per machine out of the green bin. This particular factory is fully equipped with green, red and blue bins* as explained in Chapter 2 of Part Two. The auditor is instructed to commence a new audit sheet when operators, parts, shift, or batches change. Hence the audit sheets can be sorted in any of the required categories when analysing the data.

The whole works are organised on an immediate action basis when Quality problems arise. The period in question was

* Blue bin = bin no. 1 (see p.75)

very soon after introduction of Operator Control and Performance Rating, and the ratings are still relatively low. When studying the 'Audit Report' (Fig.No.5.) giving the Performance Ratings under 'Area Index', the following points are significant :-

1. The performance of the total machining area in the factory can be evaluated at a glance, even by an outsider who has never been to this factory.
2. The trouble spots (B & C areas) are stated and all concerned, who have local knowledge, will immediately understand the implications.
3. Much additional information is put on these reports (such as operation number and parts concerned and detail of failures). This was left out as it does not add to the points made here.
4. The right hand side of the report refers to the number of components scrapped in the various sections (in %). No detail is given if the percentage is within acceptable tolerances, which was the case. The important point is that a potentially dangerous and unsatisfactory situation would have escaped management attention if only the scrap figures had been published.

Finally the individual shop audit sheets are collected on a job number basis, and this information is used when releasing batches according to an AQL to customers. However, the techniques involved do not fall within the terms of reference of this Thesis.

Study No:3.

The Company in question did not object to their name being published and the writer is grateful to Mr.W.Green, Quality Manager of Messrs Mirrlees Blackstone Ltd., who offered to write the case study himself. This was felt to be perhaps further evidence of the acceptance of Performance Rating in Industry and the case study is hence included in Appendix No.3.

An outline of the information is given below :

The problem at the Company was that a considerable bottle-neck existed in their goods inwards inspection department. In addition the inspection force engaged on incoming supplies was considered too large, and yet there was considerable pressure, due to work load, to increase it even further.

The writer was asked by the Company to analyse the causes, and this analysis clearly indicated the need for a Vendor Rating System. The Buying department of the Company was asked to carry the full responsibility for Quality, which previously had been accepted by the Inspection department.

A Vendor Rating System was introduced, based on Area Performance Rating, and subsequently enabled the buying department to deal with suppliers according to the Quality of their produce. The documentations associated with the scheme consists of :-

1. A supplier record card located in the goods receiving department (Fig.6)

2. A monthly statement showing the overall picture and nominating the worst supplier in that particular area. (The Company names have been removed from the report for obvious reasons) (Fig.7).

3. Supplier record cards located in the purchase department. Samples of these documents are attached (Figs. 8 and 9).

In the monthly statement (Fig.7) a clear indication is given of how overall area rating assists the buyer in evaluation of the performance of individual suppliers. The net result of the introduction of this system indicates that an improvement in the supply position has been effected of 14%. The flow of material through the goods receiving department was vastly improved, eliminating all bottlenecks in that area, whereas the number of inspection staff has been reduced by 30%. Further evidence of the function of the scheme can be found in Appendix 3.

CHAPTER 5

CONCLUSIONS OF THESIS.

1. Area Performance Rating is a management tool. It lends itself particularly well to the area of Quality because it enables all levels of management to comprehend the Quality performance of the company in detail and in totum.

2. It is particularly useful in conjunction with Operator Control techniques, as it replaces the existing shopfloor activity of inspection to a large degree.

3. It can also, where required, be superimposed on existing inspection systems.

4. It gives accurate results to management over any desired area of Quality Performance. The breakdown into detail areas becomes (dependent on sample sizes) less accurate, but is still sufficiently informative to bring even top management into closer contact with shopfloor performance. This is considered particularly important as at present top management does not get sufficient information about detail Quality failures. Their appreciation of the Quality scene is based on financial scrap returns and it has been demonstrated that this information can be incomplete and misleading.

5. The application of APR enables shop management to apportion ratings to the performance of people and this brings the need for training into the Quality orbit, which was, up to now, only vaguely recognised.

6. The greatest advantage of APR lies in the fact that its existence alone is self-generating as far as Quality is concerned. This has been demonstrated in Case Study No.3 and similar results appear where ever it is introduced.

CHAPTER 6.

FUTURE WORK.

From the foregoing it appears reasonable that APR can be used for functions in industry which lie outside the Quality of manufacture area.

For instance design, planning, pricing, sales, training and service are but a few. The writer is at present engaged in persuading a number of companies to engage in pilot exercises in this direction and over the next five or six years some practical results should be achieved.

The difficulty in at least some areas, such as for instance, design, lies in the fact that it is not easy to clearly specify and tolerance (the basic requirement of APR) all functions. But the writer is convinced that these will be overcome and that APR may well become a universal tool for management.

CHAPTER 7.

LITERATURE SURVEY.

A literature survey was conducted with a view to finding any similar work which was done in connection with Area Performance Rating. This survey included 15 major works written on the subject of Quality Control and Statistics. None of the authors made any reference to the concept of Area Performance Rating and it was therefore decided to deal with the literary survey in a separate Chapter as there seemed no background in existence into which this Thesis could be placed.

Some authors discuss the problem of auditing the Quality control system for management. J.M. Juran (ref. 12 & 13) describes required management information and suggests written reports and also a point system for various functions. All authors refer to the need for evaluating Quality Cost. No reference is made to the concept of Area Performance Rating.

On the whole it was found that the statistical aspects of Quality Control were covered in great depth, whereas insufficient emphasis was put on the area of creation (rather than control) of Quality. Particularly the point made in this Thesis of placing responsibility for Quality in the hands of the producer has not been considered in detail. Feigenbaum in his "Total Quality Control" (ref. 7) introduces the idea of wider Quality responsibility and the involvement of the whole organisation to this end; but he seems to put more emphasis on the introduction of a Quality department in addition to the existing inspection department which involves companies in additional expense which can only be justified

by large Quality costs incurred at the time.

R.H. Caplen (ref. 4) discusses Operator Control in line with some of the ideas outlined in Quality, its Creation and Control, (which was first published in 1959, the revised edition is attached in appendix no. 1.), but no reference is made to Performance Rating. Also Operator Control is confined to operator checking, which is only a small part of the concept of an integrated system of creation and control as seen by the writer.

The following books were included in the survey:

J. Duncan: Quality Control (ref.1), A.H. Bowker: Sampling (ref.2), I. Burr: Engineering Statistics (ref.3), R.H. Caplen: Quality Control (ref.4), H.F. Dodge: Sampling Tables (ref.5), A.V. Feigenbaum: Quality Control (ref.6), A.V. Feigenbaum: Total Quality Control (ref.7), H.A. Freeman, etc: Sampling Inspection (ref.8), E. Freund: Statistics (ref.9), E.L. Grant: Statistical Quality Control (ref.10), A. Hagen: A Management Role for Quality (ref.11) J.M. Juran: Quality Control Handbook (ref.12), J.M. Juran: Quality Planning & Analysis (ref.13), W.A. Shewart: Economic Control of Quality (ref.14), C.P. Thomas: The Control of Quality (ref.15).

CHAPTER 8.

TABLES 1 - 3

TABLE 1

1 A B 500 99.4 96	2 A C 500 99 94	3 A A 500 99 100	4 A A 500 100 99	5 A B 500 100 98	6 A A 500 100 100	7 B A 500 96 100	8 C B 500 92 97	9 A A 500 100 100	10 A A 500 100 100
11 C B 1000 88 98	12 A A 1000 99 100	13 A A 1000 99 100	14 B A 1000 98 100	15 A B 1000 99 96	16 A B 1000 100 98	17 B A 1000 98 100	18 A A 1000 99 100	19 A A 1000 100 99	20 A A 1000 100 99
21 B B 3000 98 98	22 A A 3000 99 99	23 A A 3000 100 99	24 A B 3000 100 98	25 A A 3000 100 100	26 B A 3000 96 100	27 A A 3000 100 100	28 A A 3000 100 100	29 B B 3000 98 98	30 A A 3000 99 99
31 A A 500 100 99	32 A B 500 100 98	33 A B 500 100 96	34 A A 500 99 99	35 A A 500 100 100	36 A A 500 99 100	37 B A 500 98 100	38 B B 500 97 98	39 B A 500 98 100	40 A A 500 99 100

CODE

1 A B 500 99·4 96	SUB-AREA GROUP AREA GROUP AREA BATCH QUANTITY APR (1) APR (2)

TOTAL NO. PRODUCED = 100,000

TOTAL NO. EFFECTIVES = 98,877 ∴ 98.88 = APR OF TOTAL AREA.

∴ NO. IN 'A' AREA = 70,000

NO. EFFECTIVE IN 'A' AREA = 69,747 ∴ APR_A = 99.64

NO. IN 'B' AREA = 28,000

NO. EFFECTIVE IN 'B' AREA = 27,320 ∴ APR_B = 97.57

NO. IN 'C' AREA = 2,000

NO. EFFECTIVE IN 'C' AREA = 1,810 ∴ APR_C = 90.50

TABLE 2

1	2	3	4	5	6	7	8	9	10
50	50	50	50	50	50	50	50	50	50
0	$\frac{7}{6}$	0	0	0	0	$\frac{14}{6}$	$\frac{24}{6}$	0	0
$\frac{8}{6}$	$\frac{15}{6}$	0	0	$\frac{2}{6}$	0	0	$\frac{9}{6}$	0	0
11	12	13	14	15	16	17	18	19	20
50	50	50	50	50	50	50	50	50	50
$\frac{20}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{2}{3}$	$\frac{3}{3}$	0	$\frac{2}{3}$	$\frac{1}{3}$	0	0
$\frac{3}{3}$	0	0	0	$\frac{7}{3}$	$\frac{8}{3}$	0	0	$\frac{1}{3}$	$\frac{1}{3}$
21	22	23	24	25	26	27	28	29	30
100	100	100	100	100	100	100	100	100	100
6	1	0	0	0	3	0	0	1	1
2	0	2	3	0	0	0	0	0	3
31	32	33	34	35	36	37	38	39	40
50	50	50	50	50	50	50	50	50	50
0	0	0	$\frac{4}{6}$	0	0	$\frac{6}{6}$	$\frac{9}{6}$	$\frac{3}{6}$	$\frac{2}{6}$
$\frac{1}{6}$	$\frac{9}{6}$	$\frac{13}{6}$	$\frac{2}{6}$	0	0	0	$\frac{3}{6}$	0	0

CODE

1	SUBAREA
50	SAMPLE SIZE
0	NUMBER DEFECTIVES (1)
$\frac{8}{6}$	NUMBER DEFECTIVES (2)

Note: To adapt the model with a population of 3000 and a sampling ladle of 50 to a population of 500, one ball represented $\frac{1}{6}$ balls. Hence for a sample of 50 six ladles had to be taken and the result divided by 6.

TABLE 3

1 A B 50 100 97.3	2 B C 50 97.7 95	3 A A 50 100 100	4 A A 50 100 100	5 A A 50 100 99.3	6 A A 50 100 100	7 C A 50 95.3 100	8 C B 50 92 97	9 A A 50 100 100	10 A A 50 100 100
11 C B 50 86.7 98	12 A A 50 99.3 100	13 A A 50 99.3 100	14 B A 50 98.7 100	15 B C 50 98 95.4	16 A C 50 100 94.7	17 B A 50 98.7 100	18 A A 50 99.3 100	19 A A 50 100 99.3	20 A A 50 100 99.3
21 C B 100 94 98	22 A A 100 99 100	23 A B 100 100 98	24 A B 100 100 97	25 A A 100 100 100	26 B A 100 97 100	27 A A 100 100 100	28 A A 100 100 100	29 A A 100 99 100	30 A B 100 99 97
31 A A 50 100 99.7	32 A B 50 100 97	33 A C 50 100 95.7	34 B A 50 98.7 99.3	35 A A 50 100 100	36 A A 50 100 100	37 B A 50 98 100	38 B A 50 97 99	39 A A 50 99 100	40 A A 50 99.3 100

CODE

1 A B 50 100 97.3	SUB-AREA GROUP AREA GROUP AREA SAMPLE SIZE APR(1) OF SAMPLE APR(2) OF SAMPLE

TOTAL NO. SAMPLED = 5000
TOTAL NO. EFFECTIVE IN SAMPLE = 4947 $\therefore$ APR_S = 98.95

TOTAL NO. SAMPLED IN AREA A = 3550
TOTAL NO. EFFECTIVE IN AREA A = 3543.4 $\therefore$ APR_{AS} = 99.81

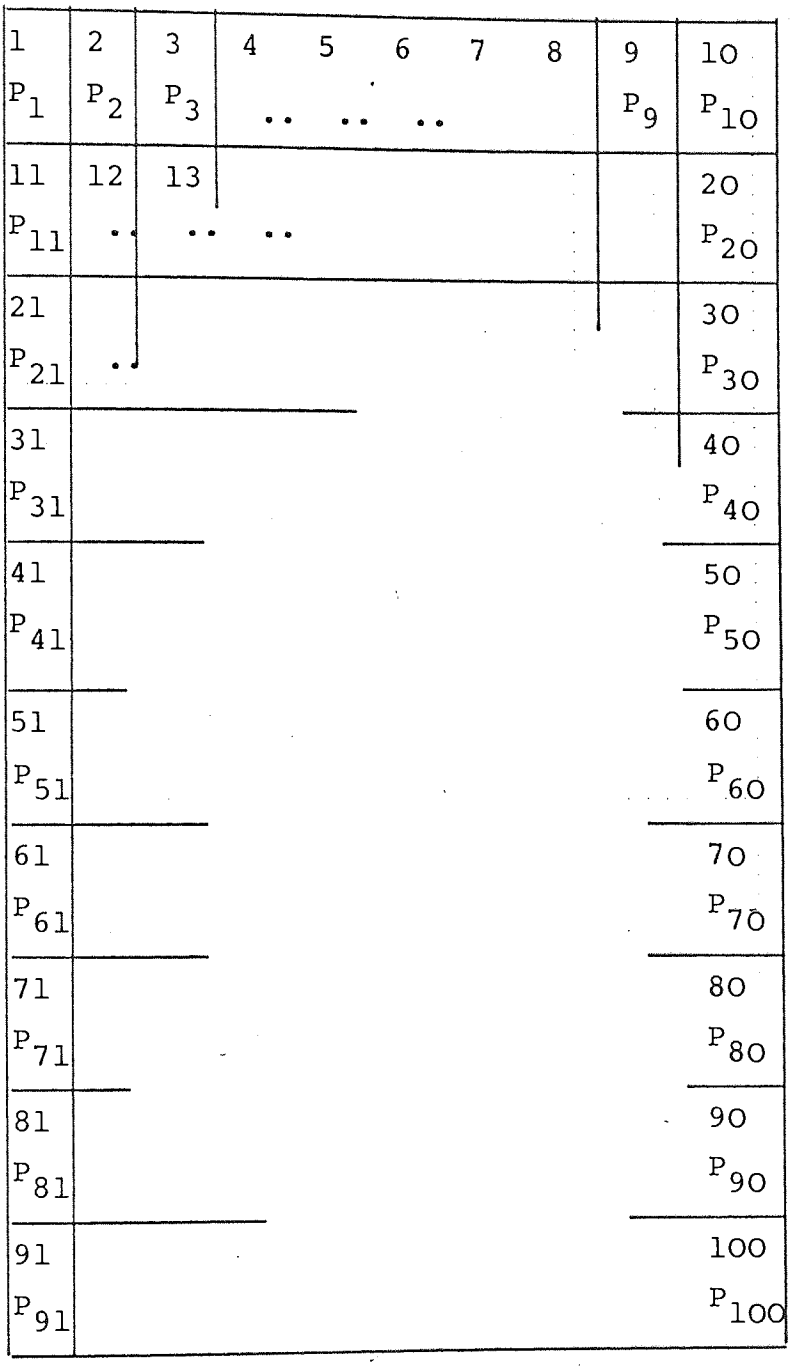
TOTAL NO. SAMPLED IN AREA B = 1050
TOTAL NO. EFFECTIVE IN AREA B = 1030 $\therefore$ APR_{BS} = 98.10

TOTAL NO. SAMPLED IN AREA C = 450
TOTAL NO. EFFECTIVE IN AREA C = 421.4 $\therefore$ APR_{CS} = 93.65

CHAPTER 9

FIGURES 1 - 9

FIGURE 1



Area A with P_A as APR of A

Consisting of sub-areas 1 - 100 with P_1 as APR of A_1

and so on .. ..

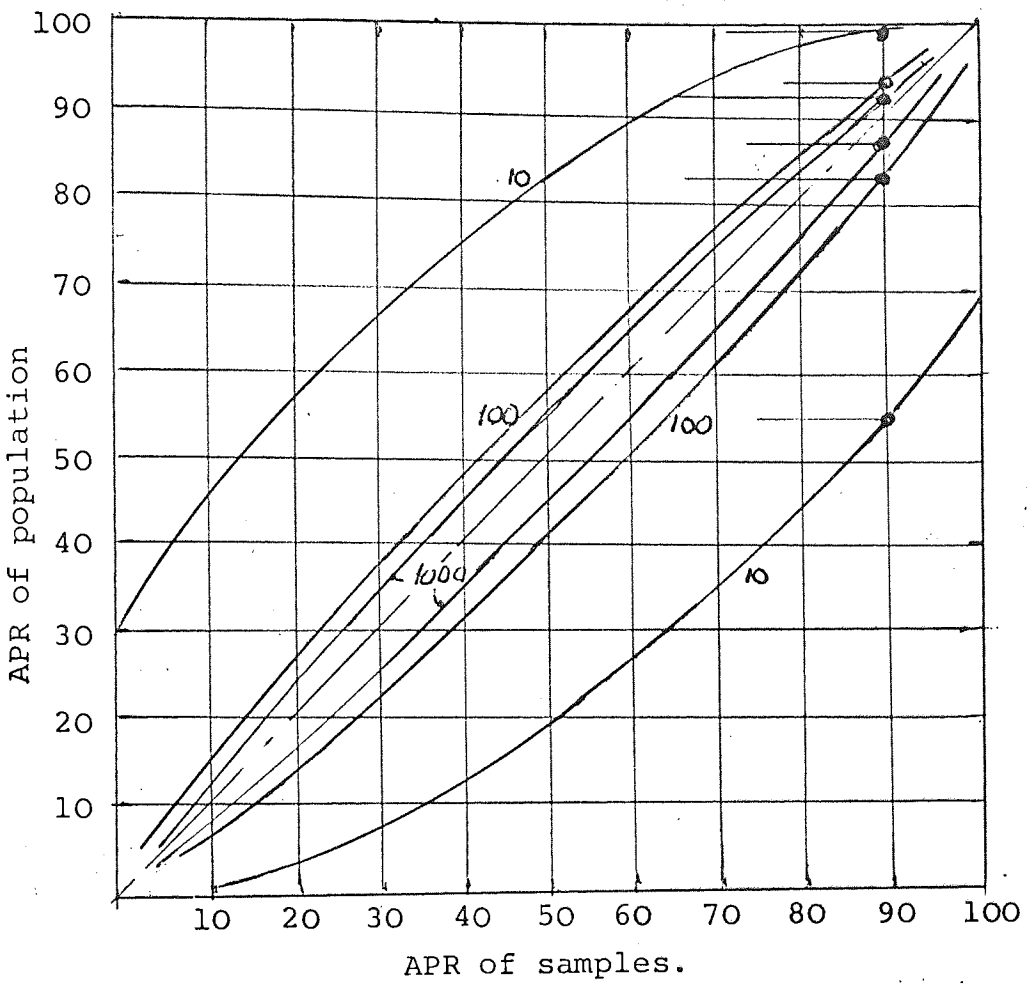
For relationship of P_A to P_1, P_2 ... see text, Part two, Chapter 1.

FIGURE 2

EXAMPLE OF CONFIDENCE INTERVALS

(Confidence coefficient 0·95)

Taken from tables - A.J.Duncan, Page 436.



Assuming a sample APR of 90 :

In a sample of 10 the population APR could be between 55 and 99.

In a sample of 100 the population APR could be between 83 and 94

In a sample of 1000 the population APR could be between 88 and 92.

FIGURE 3
QUALITY AUDIT

PART NUMBER		10669				
DESCRIPTION		KEYLOCK BACK JOINT -LONG HALF				
DIMENSION ID/OD/LENGTH		O. Dia. $\frac{15}{32}$ + 000 - 002	Length $1\frac{15}{16}$ + 005 - 000	Length $2\frac{3}{32}$ + 003 -	Length $2\frac{5}{16}$ + 001 - 004	O. Dia. $\frac{11}{32}$ - 001 - 002
TOLERANCE		.002	.005	.006	.005	.001
METHOD		MICROMETER	MICROMETER	GAUGE	COMPARATOR	COMPARATOR
OPERATION TYPE		TURN	TURN	TURN	TURN	GRIND
PLUS	10		/			
	9		///			
	8		////			
	7					
	6		////			
	5		//// ////			
	4		//// /			
	3	////	/			
	2	///				/
	1	///		//// //// ///		////
MINUS	1	//// //// //		//// //// ////		/
	2	////				//// //// //// //// ////
	3	//				
	4					
	5				//// ////	
	6				//// ////	
	7				////	
	8				///	
	9				///	
	10					
UNIT		.001	.001	GAUGE	.001	.001
OPERATOR		-	-	-	-	-
MACHINE		652	652	652	652	652
SETTER		-	-	-	-	-
NO. IN BATCH		-	-	-	-	-
NO. IN SAMPLE		30	30	30	30	30
NO. IN TOLERANCE		17	17	30	NIL	24
NO. IN EXT TOLERANCE		6	4	-	10	1
NO. OUTSIDE TOLERANCE		7	9	-	20	5

REMARKS

PART No.	QUALITY AUDIT													SECTION & M/C No.	SHIFT.
OP: No.	DIMENSION	O/C OR I/C		DATE & TIME	SAMPLE SIZE	M/R	O/R	AUD R	S	T	E/T	O/T		ACTION / REMARKS	
WEEK COM:															
SHEET No.															
ABBREVIATIONS															
T.- DIMENSION IN TOLERANCE															
ET.- DIMENSION IN EXT. TOLERANCE															
OT.- OUTSIDE TOLERANCE															
OP.- OPERATOR REJECT															
MR.- MATERIAL REJECT															
S.- TOTAL MACH. SCRAP															
O/C.- OPERATOR CONTROL															
I/C - INSP. CONTROL															
INSP. SIG.															

Fig. 4

M800

FIGURE 4

QUALITY AUDIT REPORT FOR DEPT. DATE 196 SHEET

OUT-GOING QUALITY INDEX % OF DIM'S

AREA	WORST	T	ET	OT
LINES				
AREA INDEX		97.1	1.5	1.4
AUTOS				
AREA INDEX		97.9	1.6	0.5
GENERAL M/CS				
AREA INDEX		98.4	1.0	0.6
GRINDING DEPT.				
AREA INDEX		99.6	0.2	0.2

M/c Nos.				GROUP	REASON FOR ACTION	DEPT.	ACTION REQUIRED	NO OF CC WORST	TR
116A	85.0	10.2	4.8	C	- OPERATOR	W	TRAINING SCHEDULE A		
2136	91.5	7.3	1.2	B	- CAPABILITY	P.E.	TOOLING INVESTIGATION		
6605	95.0	1.0	4.0	C	- CAPABILITY	P.E.	M/C CAPABILITY		
								AREA TOTAL	1.8
498	93.8	3.2	3.0	C	)				
125	90.6	8.5	0.9	B	) CAPABILITY	P.E.	MC/S NOT ABLE TO WORK		
425	94.4	3.5	2.1	B	)	P.E.	TO TOLERANCE ASK FOR		
						P.E.	CONCESSION.	AREA TOTAL	1%
191	92.4	76	0	B	) OPERATOR FAULT	W	-		
225	93.2	1.1	5.7	C	) TOOLING WEAR	W	MAINTENANCE		
384	90.0	2.9	7.1	C	) SETTING ERROR	W	DISCUSSION GROUP	AREA TOTAL	1.3
323	94.8	3.3	1.9	B	)				
233	97.5	1.8	0.7	B	) OPERATOR	W	DISCUSSION GROUP		
								AREA TOTAL	0.2

FIGURE 5.

SUPPLIER

SHEET NO.

DATE INSPECTED	GRN	PART No	QTY REC	DIMENSION	1st Sample			2nd Sample			No REJ	ACTION	INSP SIG
					T	ET	OT	T	ET	OT			

Fig 6.

FIGURE 6

T - Items in tolerance
ET - Items in extended tolerance
OT - Items out of tolerance
RR - Rejection rate

T, ET, and OT percentages are based on batch samples.

RR is percentage of items received.

PMC - Precision machined component
MC - Machined component
RMC - Rough machined component
F - Fabrications
P - Proprietary
RM - Raw material (Bar & Tube)

Amended rejection rate includes rejections found after acceptance.

X - Actioned by
B - Buying
SC - Subcontracts
D - Design
QP - Quality Planning

Circulation:
Quality Manag
Works Manager
Chief Inspect
Production En
Chief Buyer
Financial Dir
Works Directo

Worst Supplier in Each Area	Area	T	ET	OT	RR	Remarks	X
Supplier 'A'	PMC	99.2%	-	0.8%	0.2%	The 7/16" dia. oil holes in 10 camshaft bearings - R20176/1 were 1/8" out of position. Quality Department will write to this supplier to prevent a recurrence of this quality failure.	Q.P
Amended Rejection Rate							
Supplier 'B'	MC	90.2%	-	9.8%	3.4%	32 Piston Pins - R20022 were badly rusted and the surface finish was unsatisfactory Mr. O'Connell visited our works on Friday 23.8.74 when our quality requirements were explained in detail	Q.P
Amended Rejection Rate							
Supplier 'C'	RMC	96.6%	-	3.4%	2.5%	3010 various items had dimensional errors. Quality Department will write to this supplier to prevent a recurrence of these quality failures.	Q.P
Amended Rejection Rate							
Supplier 'D'	F	96%	-	4%	10.5%	24 Support Brackets - K38586 were incorrectly fabricated. Quality Department will write to this supplier to prevent a recurrence of this quality failure	Q.P
Amended Rejection Rate							
Supplier 'E'	P	0.0	-	100%	100%	25 Water Pump Seals ref. 46700390 were $\frac{1}{4}$" undersize in the 1" dia. bore. Quality Department will write to this new supplier to explain our quality requirements.	Q.P
Amended Rejection Rate							
No Low Grade Suppliers in this area.	RM	-	-	-	-		
Amended Rejection Rate							

Purchase Area Quality Index

Area	T	ET	OT	RR
PMC	99.4%	-	0.6%	0.2%
MC	98.2%	-	1.8%	0.2%
RMC	98.4%	-	1.6%	1.5%
F	99.1%	-	0.9%	1.1%
P	99.5%	-	0.5%	0.5%
RM	100%	-	-	-

MONTHLY QUALITY REPORT - INCOMING MATERIAL

Month Ending 31.8.74

Overall Quality Index

T	ET	OT	RR
98.8%		1.2%	0.8%

SUPPLIER					WORK TYPE	GRADE							
						D DATE							

Date	Quality 1			Rejection Rate %	Delivery Index	Date	Quality 1			Rejection Rate %	Delivery Index
	T	ET	OT				T	ET	OT		
JAN.						JAN.					
APRIL						APRIL					
JULY						JULY					
OCT.						OCT.					
Total						Total					

Date	Quality 1			Rejection Rate %	Delivery Index	Date	Quality 1			Rejection Rate %	Delivery Index
	T	ET	OT				T	ET	OT		
JAN.						JAN.					
APRIL						APRIL					
JULY						JULY					
OCT.						OCT.					
Total						Total					

Fig. 8

FIGURE 8

QUALITY RESPONSIBILITY	TITLE	ADDRESS
Mr.		

RECORD OF VISITS

Date Visited	By Whom	Reason for Visit	General Comments

FIGURE 9

CHAPTER 10

REFERENCES

No.	Author	Title and Publisher
1	Duncan A.J.	Quality Control & Industrial Statistics Richard D. Irwin (1958)
2	Bowker A.H.	Sampling Inspection by Variables McGraw Hill (1955)
3	Burr I.W.	Engineering Statistics & Quality Control McGraw Hill (1953)
4	Caplen R.H.	A practical approach to Quality Control Business Books Ltd.(1972)
5.	Dodge H.F.	Sampling Inspection Tables John Wiley & Sons Inc.(1959)
6.	Feigenbaum A.V.	Quality Control, Principles & Practice McGraw Hill (1951)
7.	Feigenbaum A.V.	Total Quality Control McGraw Hill (1961)
8.	Freeman H.A.	Sampling Inspection McGraw Hill (1948)
9.	Freund E.	Elementary Statistics Prentice Hall International (1966)
10.	Grant N.L.	Statistical Quality Control (1952) McGraw Hill
11.	Hagan F.	A Management Role for Quality McGraw Hill (1962)
12.	Juran J.M.	Quality Control Handbook McGraw Hill (1951)
13.	Juran J.M.	Quality Planning & Analysis McGraw Hill (1970)
14	Shewhart A.W.	Economic Control of Quality of Manufactured Product. van Nostrand (1931)
15	Thomas C.P.	The Control of Quality Thames & Hudson

The following are publications by the writer and have either been included in the appendices or referred to in the text:

16	R.K. Grunau	Inspection Methods Magazine Production (1958)
17	R.K. Grunau	Quality Functions of Design Inst. of Mechanical Engineers. (1962)
18	R.K. Grunau	Quality, its Creation & Control in the Seventies. Inst. of Production Engineers. (1970)
19	M.Tibon	Job Enrichment as Quality Motivator Introductory notes to a Pilot Project. Israel Institute of Productivity.(1974)

CHAPTER 11.

List of Symbols.

SYMBOL	DESCRIPTION
A	Area.
a	Sub-area.
APR	Area Performance Rating
APR_{AS}	APR of sample in area A.
AQL	Acceptable Quality Level.
B.O.	Bought Out.
n	Sample size.
OC	Operational Characteristic
O.C.	Operator Control.
P_A	Perfprmance Rating of Area A.
P_{AOT}	Percentage of OT in area A(also denoted just OT)
P_{AET}	Percentage of ET in area A (also denoted just ET)
P_{AIT}	Percentage of IT in area A (also denoted just IT)
$\sum_{i=1}^{100}$	Sum of all i-s from 1 to 100
IT	In Tolerance (see also P_{AIT})ref. parameters
ET	In extended Tolerance (see also P_{AET})
OT	Out of Tolerance (see also P_{AOT})
x	Number effectives in sample

PART THREE

APPENDICES

APPENDIX 1.

Excerpts from:

QUALITY

its creation and control

in the seventies.

An outline from this Report is given covering the following sections :

The Title Page;
The Constitution of the Committee;
Contents;
Foreword;
Introduction by the writer;
The Summary and
Recommendations.

The full Report can be obtained from the Institution of Production Engineers.

For the attention of Directors and Managers in British Industry.

..... a concept of

quality and its control

for the seventies .....

The Council of the Institution of Production Engineers attach great importance to the creation and control of quality. It has, therefore, decided that among the formation of its Specialist Divisions and in co-operation with the Institution of Engineering Inspection a Specialist Division on Quality Assurance will be created which will further the ideas propounded in this report.

THE INSTITUTION OF PRODUCTION ENGINEERS

This Report, "Quality, Its Creation and Control" supersedes the report under the same title published by the Institution in 1958. The present work has been commissioned by the Standing Committee on Quality and Reliability.

R.K. GRUNAU

Chairman, Quality and Reliability Committee

Members of the sub-committee reporting to the Standing Committee on Quality and Reliability

Chairman - R.K. Grunau, CEng, FIProdE, MIMechE
(R.K. Grunau & Associates)

M.A. Alexander, TD, CEng, MIProdE, MIMechE
(C.J. Hampton Limited)

R.L. Carling, CEng, MIMechE, MITE, AMBIM
(Engineering Industry Training Board)

Dr.B.W. Jenney, BA(Hons), CEng, MIProdE, MIMechE, FIEI
(University of Birmingham)

Vice-Chairman - S.W. Nixon, MSc, CEng, FIProdE, FIMechE
(R.K. Grunau & Associates)

I.R. Smith, CEng, MIProdE, MIEI
(British Aircraft Corporation Limited)

E. Summerscales, BSc, CEng, FIMechE
(Joseph Lucas Limited)

C. Watkins, BSc, AIS, FIEI
(Raleigh Industries Limited)

Aston University

Content has been removed for copyright reasons

APPENDIX 2.

QUALITY FUNCTIONS OF DESIGN

Extract from

THESIS

For The

INSTITUTION OF MECHANICAL ENGINEERS.

By R.K. Grunau.
F.I. Prod.E.

Originally written in 1962.

Aston University

Content has been removed for copyright reasons

APPENDIX 3.

VENDOR RATING at MIRRLEES BLACKSTONE LTD.

Aston University

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