# COSTS OF QUALITY ASSURANCE SYSTEMS

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I, Anthony Cole, submit this thesis for the degree of M.Sc Engineering. I claim that this is my original work and that it has not been submitted in this or in a similar form for a degree at any University.

# SUMMARY

Generally within industry, the activities of the Quality Assurance department in a company, are considered to be a necessary cost, rather than a means through which savings may be made. Although it has been widely accepted that savings can be made by improving the quality of the product, (quality is defined as "fitness for use as defined by the user"), not all the costs of achieving, or not achieving a specified level of quality, are obvious. Hence many of the savings and potential savings of the activities of a quality sssurance system are not recognised as such.

The costs which may be attributable to obtaining a specified level of quality (quality costs), are investigated in this thesis. Often many of these costs are difficult to isolate, and quantify. This is because many of the quality costs are monitored and collected as costs incurred by other departments, while others are not collected as individual costs, but added onto the costs of manufacture as overheads. This thesis also looks at the difficulties involved in isolating these costs, and presents simplified methods of cost isolation.

There are a number of theories currently used to set the level, of product quality, which should be produced. The most prominent of these theories postulates that there is a quality level, which, if produced will minimise the overall costs of manufacture. When a product quality below this level is produced, a high cost is incurred due to product failure, both in and out of the factory, and a high expenditure is necessary to raise the level of quality above this 'optimum level'. These theories are discussed, and a practical method, of using the quality costs and the trends in these costs, to find an 'optimum level of quality' is presented.

Some of the methods of drawing trends from the quality costs are illustrated, and the information which may be drawn from them is discussed. Finally, some of the cost benefits of installing a quality assurance system are discussed.

Two case studies have been used to illustrate some of the aspects discussed in the thesis.

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# 1.0 INTRODUCTION

Modern industry is a dynamic field, characterized by rapidly advancing technology and production methods, with increasing complexity and rising costs of production. In this environment, with inflation alone increasing costs by approximately 15% p.a., it is essential that the costs of manufacture are minimised. One of the recognised methods of reducing production costs is to improve the quality of the product, and hence reducing the amount of scrap produced in the plant. This concept has been developed further into what is currently known as Quality Assurance (see chapter 2 for the development of Quality Assurance). The principle of quality assurance is to ensure that whatever is designed/manufactured/sold, complies with what the customer requires, as cheaply as possible.

One of the principle objectives of a quality assurance (QA) system is to reduce the costs associated with achieving a specified product quality. Usually the expenditure associated with eliminating the failures is increased in an attempt to reduce the costs associated with the failure of the product, both in the factory and once the product has left the factory.

In order to reduce any costs, a measurement of these costs is needed. The costs and expenditures associated with the attainment of a specified quality level, and some of the methods of evaluating these costs and the trends in these costs, will be looked at in this thesis (see Chapter 3).

Often many of the costs associated with the attainment of a level of quality (quality costs) are difficult to isolate and evaluate. An attempt will be made to devise simplified methods to isolate and to analyse some of these costs for trends (See Chapter 4). An attempt will then be made to isolate the costs of quality, using simplified methods, with two case studies. (See Chapter 5)

Although the actual costs associated with the quality of a product might be low, and initial indications are that monitoring the costs is not warranted, there are other immeasurable costs which are caused by producing a low quality product. These include such costs as the loss of sales resulting from customers not re-ordering due to the poor performance of the product. The axiom, "price makes the first sale, quality the second", often holds. There are also risks involved in producing a poor quality product. In USA, product liability suits have become very expensive. In 1976 the value of claims was $50 billion (1)(9). Most of the claims, that lead to legislation, involve all parties responsible for the design, manufacture, distribution, sales and service of a product, and can reach people on an individual basis (2).

Although South African legislation is unlikely to impose such severe penalties, South African products sold in USA are required to meet their standards (10), and the manufacturer could be prosecuted under American law. Hence a defective product could prove to be expensive, both in damages and in goodwill (future sales lost).

Means, to protect against these dangers, are needed. Insurance is one method of protection, but this can also be expensive (12), and usually the insurance companies require some form of product assurance before they will provide cover. A better approach would be to remove the need for liability protection, by producing a product of an acceptably high standard.

As noted above, one of the principle aims of a Quality Assurance (QA) system is to ensure that whatever is designed/manufactured/sold, complies with the customer's requirements. Thus by using QA techniques, the product quality can be improved, and the risk of a faulty product leaving the factory can be evaluated. Also the possible consequences of a fault leaving the factory can be estimated using techniques such as fault tree analysis (1)(12). Records of such analyses are the best defence against liability suits, as they show that every effort was made to ensure the safety of the product(3).

The establishment of a QA system, using QA techniques to monitor and control the production system can be espensive. One of the aims of this thesis is to illustrate that the establishment of a QA system results in cost reductions. Some of the cost savings of QA techniques are discussed in Chapter 6.

Thus, the aims of this thesis are:-

- to investigate what kinds of costs constitute the 'costs of quality', how they are incurred, and the difficulties in quantifying them.

- to investigate current theories used to analyse the costs of quality.
- to investigate the methods of drawing trends from the quality costs, and some of the uses of these trends to control the system.
- to develop simplified methods
  a) of finding the costs associated with quality, and
  b) analysing the trends in these costs, illustrating their application using two case studies.
- to illustrate some of the cost advantages of establishing a QA system, but indicating some of the costs incurred by not implementing the techniques properly.

## 2.0 THE CONCEPT OF QUALITY AND QUALITY ASSURANCE

### 2.1 THE DEFINITION OF QUALITY

To begin with it is important that the meaning of the word quality be established. The Oxford dictionary defines it as "degree of excellence", which seems to be the layman's perception of the meaning. This is not much help to those dealing with quality in a factory, as it exchanges two intangible words for one. The quality of an article has meaning only when related to the article's function. Essentially it requires that both the needs of the customer and his belief of his needs are explored.

The generally accepted definition of the word quality , is "fitness for purpose/use"(4)(9)(12)(13). This term was used in the early sixties by the European Organization for Quality Control (E.O.Q.C) but rejected as it broke the rule of compatibility with common usage(13). The E.O.Q.C. redefined quality as:-

> "The quality of a commodity is the degree to which it meets the requirements of the customer. With manufactured products, quality is a combination of quality of design and quality of manufacture."

This definition cannot be valid, as it defines quality in terms of itself, which is clearly unacceptable.

British Standards (B.S.) define quality as:-

> "The totality of features and characteristics of a product or service that bear on its ability to satisfy a given need."

To put the B.S. and the E.O.Q.C. definitions under a common denominator (see underlined words above) for engineering, production and contract use, one could define quality as:-

"Quality is conformance to an agreed specification."

This is tantamount to the definition used by Juran;(16)

"Quality is fitness for use as defined by the user",

and this will be the meaning attached to quality for the purpose of this thesis.

## 2.2 DEVELOPMENT OF THE CONCEPT OF QUALITY ASSURANCE

### 2.2.1 INSPECTION TO QUALITY CONTROL

Records of inspection of a final product have been found dating back to early Egyptian times. The guilds in the thirteenth century seem to have been the first organizations to have had quality standards. Unfortunately these guilds fell away, or were legally removed, and master-craftsmen were the only people left with "inbuilt quality systems". Such people, motivated by artistic pride, were able to monitor the customer's requirements with a knowledge of their own capabilities, and the control of the quality was automatic, as the craftsman was his own inspector. This situation typically exists in small concerns today where a single man starts his own business with himself as the sole operator.

In 1778, with the Industrial Revolution, institutions such as the Inspectorates of Brass and Iron Ordinance came into being.(17) In 1798 a major step was made when a musket manufacturer started to make muskets with interchangeable parts, and along with this he developed a set of manufacturing standards.(17)

Mass production methods and the concept of division of labour created the opportunity to use cheaper but less skilled labour (20), and inspectors became necessary to ensure that faulty items did not leave the factory.

This was not a satisfactory state of affairs, as there was a conflict of interests over acceptance/rejection of the product, added to this 100% inspection is rarely better than 85% inspection (21). Further, the product was already made and the options on rejection were only to scrap or to rework where possible.

It soon became obvious that the inspection function would have to be expanded. Initially in-process inspection was introduced, but in many cases this still proved to be expensive and not effective enough, due to inefficient control of the now cumbersome inspection department.

The concept of Quality Control (Q.C) was then developed. Juran (16) defines Q.C. as:-

> "the regulatory process through which we measure actual quality performance, compare it with standards and act on the difference."

The essential difference between the Q.C. function and the inspection system is the feedback loop to the process control to correct the process before further faulty, products are made. The differences between final inspection, in-process inspection and Q.C. are shown in Fig 2.1.

Often a company believes that it is creating a Q.C. department by adding statistical methods such as sampling, to the activities of the existing inspection department (23). This is not Q.C. in the accepted sense, as the use of statistical methods does not constitute an in-process feedback loop, which is the essential feature of Q.C.

This is not to say that statistical methods have no part in Q.C. In fact statistical methods such as sampling and control charts are one of the fundamental parts of Q.C. One of the initial problems in the application of the Q.C. methods was an over-emphasis of the use of statistical tools and an under-emphasis of the use of managerial tools (24). This led to a situation where the statistical methods became a means in itself, rather than a means to solve the problem. As Henry Clay said about 150 years ago, "statistical tools are no substitute for good sound judgement." (25)

Initially the statistical methods were not generally accepted and great care had to be taken to install them, as they had to be as effective as 100% sampling to be accepted (14).

Around the early and mid 1960's it was realised that the Q.C. and inspection function did not go far enough. It seemed to concentrate on finding and curing production problems after they had occured, rather than preventing them occurring in the first place (26).

### 2.2.2 QUALITY CONTROL TO QUALITY ASSURANCE

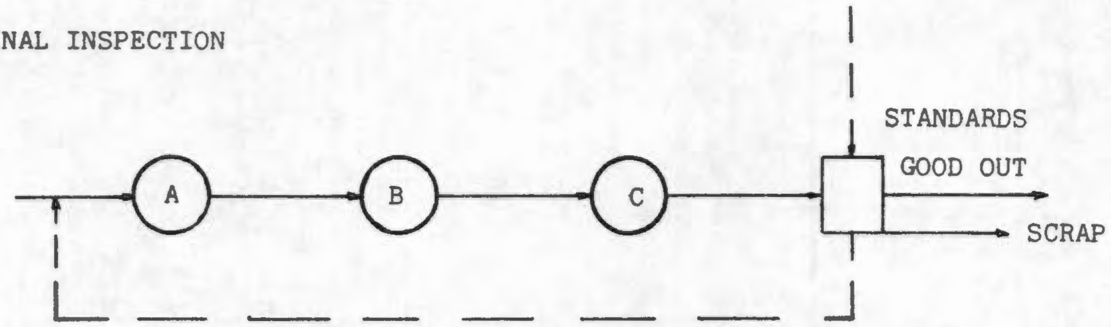
One of the basic assumptions made in the development of the Q.C. methods was that there were standards which could be used as a reference for comparison. Also that these standards were relevant and defined the required product to the satisfaction of the customer.

No matter how well the process is controlled, and how well the standards are met, it is of no use if the standards are not relevant, up to date, and do not define what the customer requires. This led Fiegenbaum (23) to develop Q.C. into a concept called Total Quality Control (T.Q.C.)

FIG. 2.1

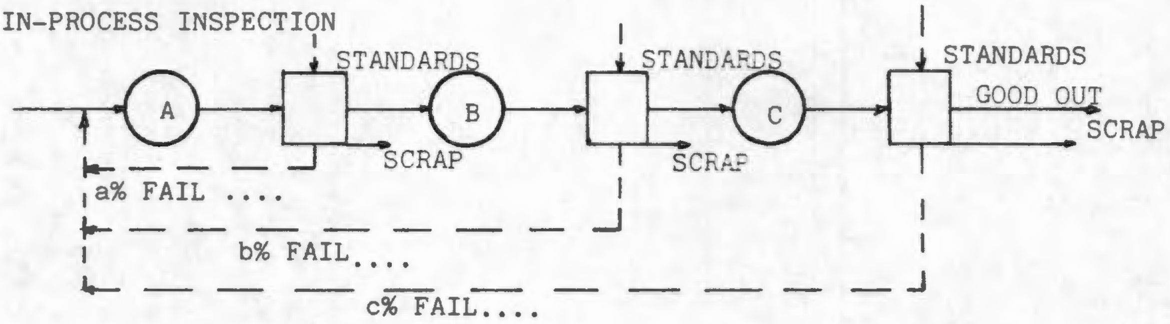
## THE DIFFERENCE BETWEEN FINAL INSPECTION, IN-PROCESS INSPECTION AND QUALITY CONTROL

1. FINAL INSPECTION



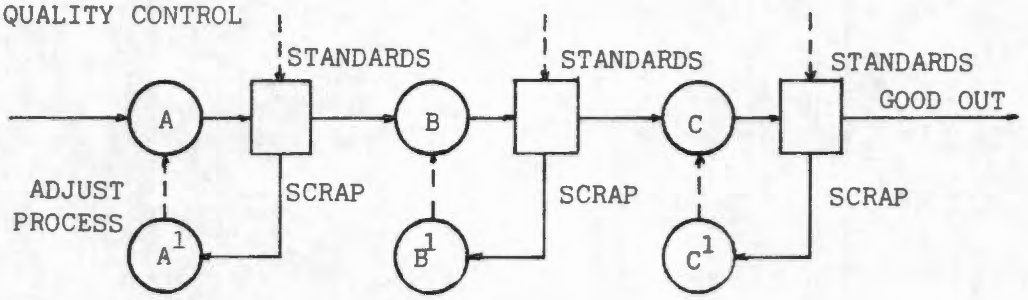
x% FAIL NEED $\frac{100x}{1-x}$ % MORE TO MAKE UP ORDER

2. IN-PROCESS INSPECTION



Same number fail as for 1, but less value lost, as failures at operation A do not have value added in operations B and C.

3. QUALITY CONTROL



Analyse scrap for reasons for failure and correct process before any more failures occur. Less failures occur than for 1 or 2 and the failures are filtered out at each process and do not have value added in subsequent operations.

| LEGEND: | | | |
|---|---|---|---|
| Ⓐ | Operation | ──→ | Product Flow |
| $A^1$ | Analysis of failures | – – → | Information Flow |
| □ | Inspection | | |

He defined T.Q.C. as:-

> "Total Quality Control is an effective system for integrating the quality development, the quality maintenance, and the quality improvement efforts of the various groups in an organization so as to enable and service at the most economic levels which allow for full customer satisfaction."

This is a further extension of the Q.C. theory and is the forerunner of the Quality Assurance (Q.A.) concept.

T.Q.C. represents a management tool with four main steps:-(23)

a) Setting quality standards.
b) Appraising the conformance to these standards.
c) Acting when the standards are not met.
d) Planning for improvements to the standards.

(Q.C. generally comprised steps b and c)

One must note that T.Q.C. methods are an aid to, not a substitute for good engineering designs, manufacturing methods and conscientious inspection

In the U.S.A. the requirements of the military, as set out in the MIL-Standards have been the main motivating force behind quality system improvement.(9) These standards started out as audit measures of the inspector system, but these, it was realized, were inadequate and a set of requirements were developed. These requirements have subsequently become the basis for a Quality Assurance (Q.A.) system.(28)

### 2.2.3 QUALITY ASSURANCE

The MIL-Standards and requirements developed from the need to evolve quality products from basic ideas, with product development, design, testing and evaluation being controlled in addition to controlling the manufacture.(30 ) A systems approach was needed, as invariably when one fault was corrected it caused another to occur,(30) and it was noted that in some cases three-quarters of all failures were due to design faults, and a weak interface between design and production (31).

Quality Assurance (Q.A) has been defined as:(16)(32)

> "the activity of providing to all concerned, the evidence needed to establish confidence that the quality function is being performed adequately."

This leaves much to be interpreted by the reader. ASME defines QA as two major activities (29 ), namely:-

a) quality control, which includes the examination of the physical characteristics of a material or product and its associated acceptance standards; and

b) quality administration, which is the management and documentation that assure that the specified quality control is carried out.

This definition is useful but it leaves an area which is not clearly laid out. A company could have a Q.C. system with a manager and delude itself that it had a Q.A. system.

A Q.A. system is one which goes beyond assuring that a product conforms to specifications. It ensures that these specifications are correct, correctly applied, and that the product will perform to its perceived useful life.

Q.A. can be divided up into three main sections:(35)(36)

a) quality of design

b) quality of conformance

c) administration of the above two sections.

Quality of design includes a number of functions. Among these are:(16)

i) Identification of what constitutes fitness of use to the user.

ii) The choice of a concept of a product or service to respond to the needs of the user.

iii) Translation of the chosen product concept into a detailed set of specifications which will meet the users needs.

The quality of design is often taken to refer only to functional requirements such as reliability and basic standards. It is much more.(12) It includes consideration of economy of manufacture, design of tooling, planning of the sequence of operations, process capability studies, "segmentation of characteristics into defect potentials and classifications."(21) It includes the design of sampling plans and the preparation of inspection procedures, which will define the conformance function (b. above). Thus a fourth function can be added to the three above:

iv) The design and planning of the production system which will be able to make the product to set specifications. This would also include the design of the procedures and methods and selection of the statistical methods and sampling plans used as references in the conformance function.

The quality of conformance would be the same as Q.C. (32) as discussed in section 2.2.1 above.

There is a very important tie-up between the quality of design and the quality of conformance. This is the tie-up to process capabilities (as mentioned in iv above). It has often been found that, left entirely to themselves, designers do not produce good specifications (37). Unnecessary and undesirable areas of ambiguity frequently occur; too many critical points, not easy to control during fabrication are left to emerge in production phases where their correction is costly; testing and measuring feasibility and their associated economics too often receive scant attention; thus there should be some monitoring and controlling of the design stage and the design production interface.

Q.A. also extends to departments which do not directly take part in design, manufacturing and testing of the product. These departments include sales, purchasing, personnel and others. To maintain an effective Q.A. system there has to be close liaison between the quality department and these departments, as, if the operations of these departments are not co-ordinated, the operation of the Q.A. function will not be effective. A direct and detailed control over these departments is normally limited to those cases where actual danger to the user and the public is present, for example in the construction of a nuclear power station (36).

Usually the liaison is laid down in the company's procedures, which define the interrelations between the departments. The quality function does not try to do the jobs of the other departments. Rather it can act as an evaluator of these departments and as an aid to improve their operating effectiveness, making their jobs easier by supplying a factual feedback to form a basis from which they can make better decisions.

## 2.3 EFFECTIVENESS OF QUALITY ASSURANCE SYSTEMS

The customer in his assessment of the quality of the product/service, makes no distinction between the quality of the design or the quality of conformance. His assessment will be on how well the product lives up to his expectations, thus all the segments of the Q.A. operations should be tied together to form an effective system.

The American Weapon System Effectiveness Advisory Committee defines effectiveness as a function of system availability, dependability and capability.(11) In other words a system must be ready to operate when called upon, it must operate for the time period for which the demand exists, and it must perform the function satisfactorily and achieve the required performance levels in a specified environment (9). In order to instal and maintain a system to control the manufacture of the product there must be some incentive to do so. Usually this incentive is financial.

### 2.3.1 FINANCIAL INCENTIVES

Often Q.A. programs are initiated as the result of an expensive product failure, and the management of the particular company decides on a drive to improve the quality of the product.(33) This sort of drive often does not work, as the quality of a product must start from the concept of the product (34). This does not mean that a Q.A. system should be installed only for new products, but the quality of conformance of an existing product can be improved. The quality of the design can also be improved with design modifications.

There are a great number of potential benefits which may be obtained by installing a Q.A. system in a company.

A few of these are:-

- reduced warranty claims as a higher percent of the outgoing product conforms to specification.
- the productivity of the plant increases as less product has to be reworked.
- less inspection needed to give the same guarantee of product quality.

These benefits may be obtained from an effective Q.A. system, but there is a cost of obtaining them. These costs and cost balances are discussed below in Chapter 3.

Once an effective Q.A. system has been installed it will not be perfect, and there will be a number of aspects overlooked, certain aspects will fall away, hence the system must be maintained. In order to maintain a system, there must be some form of measurement and monitoring of that system from period to period. One measurement by which quality systems can be measured is by the costs of that system.

### 2.3.2 MONITORING OF QUALITY COSTS

There can be a number of reasons why the costs of a quality system should be monitored, amongst these are:-

- to observe the variation in the overall costs as the quality costs vary. This gives an indication of the level of quality activity which will give the minimum overall costs.

- to enable the production and quality managers to know what quality the plant is capable of achieving, and quality it is achieving, and the cost of the variance.
- to indicate aspects of the system which are high cost causers and to form a factual basis from which to evaluate the potential benefits of a project to correct the error.
- to evaluate the actual benefits of a quality improvement project against the predicted cost savings.

The effort of evaluating the costs can only be warranted if the means of presenting them is clear, and definate trends can be picked up as they occur without too much effort on the part of the reader. Methods of evaluating and presenting these costs are discussed below in chapters 3 and 4.

There are a number of basic principles on which Q.A. systems rest. Many of these have been worked out to save costs, yet few of them are applied extensively and effectively (38).

### 2.3.3 BASIC COST SAVING TECHNIQUES OF Q.A. SYSTEMS

One of the principal aims of Q.A. systems, other than to improve the quality of the product, is to reduce the operating costs of the company. This resulted in the development of many techniques which improved the quality, but reduced the overall costs.

Amongst these techniques are:-

- Statistical methods. Although many of these methods were developed to monitor control of aspects of the system, they are cost saving, as faults are picked up earlier, and lower levels of inspection may be used giving the same assurance as 100% sampling (39).
- Worker involvement. One of the principal reasons why the Japanese quality drive has been so sucessful is that everyone in the company became quality conscious, (24) with the result that the operator became his own quality controller. The whole company is involved in improving the quality of the product using such methods as quality circles. (40) These are all methods of achieving better quality with little or no extra effort on behalf of the quality staff, and at a fraction of the cost of formal investigations, by involving everyone in the company.

By applying methods such as those mentioned above, the overall costs of the system can be reduced. Typical situations where such methods have been used, or could be used will be discussed in chapter 6, in connection with the case studies at A.E.C.I. Reasons why the use of these methods is not always sucessful will also be discussed, along with methods of assuring their sucessful use.

# CHAPTER 3 THE COSTS OF A QUALITY SYSTEM

## 3.1 CATEGORIES OF QUALITY COSTS

The measurement which most managers understand best is that of money, and for any project to be endorsed it must have a return greater than the policy minimum of the company. This return can be in the form of income generated, losses saved or both. This must equally apply to the activities of the quality department.

Much has been written on the costs and savings of a quality system, but there seem to be two conflicting points of view. These are the theory of an optimum level of quality, and the theory of zero defects. These theories will be developed and discussed below in Chapter 3.2

There are the three major categories into which the costs of quality are generally divided. These are:-

- the costs of Failure
- the costs of Appraisal
- the costs of Prevention

### 3.1.1. THE COSTS OF FAILURE

This category can be broadly divided into the Internal and External costs of failure and a break down of typical costs are shown in Appendix I.

Internal failure costs are those costs incurred when the product fails in the plant. These include not only the materials and production time lost, but such costs as additional handling and time and materials needed to rework the product.

External failure costs are those costs incurred by the failure of the product once it has left the factory. These costs would include claims made under warranty, the cost of investigating these claims, and the cost of replacement amongst others.

### 3.1.2 THE COSTS OF APPRAISAL

Costs which fall into this category are those associated with checking and maintaining the quality of the product. Such costs generally include those associated with checking and testing the product, the replacement and calibration of the testing equipment, and the cost of assuring that the results are to specification by retesting. Typical costs are shown in Appendix II.

### 3.1.3 THE COSTS OF PREVENTION

These costs are related to the elimination of the causes of the defects in the product and in the system evaluating the product. It has been said that in a great majority of cases the money spent on prevention of defects occurring is too low. (5) (16)(42). Usually costs in this category are difficult to obtain. They include such items as time spent in planning the Q.A. systems activities, design review expenses, supplier evaluation audits and time and money spent on training people. Typical costs allocated to the category are shown in Appendix III.

The cost of inspection and testing of incoming goods is often allocated to this category, as it is incurred in the prevention of faults entering the system (50); although it could be viewed as an appraisal cost in the sense of the word "appraisal".

## 3.2 COST THEORIES

### 3.2.1 OPTIMIZATION THEORY

The generally accepted theory for using costs to set an outgoing quality level of the product is that of cost optimization, which involves finding a minimum quality cost operating level.

A balance is drawn up between how much is spent on preventing failures against how much is lost due to failures. If the level of the outgoing product quality is varied there will be a variation in the expenses caused by failures, and the amount spent in assuring that the specified level of quality, or better, leaves the plant.

If the manufacturing cost of an item is plotted against the level of quality, a curve similar to fig 3.1 will be obtained. As the level of the quality is increased so the manufacturing costs will rise. The opposite trend is seen with the selling price. As the level of quality increases so the "price-possible-to-ask" will increase, but not as quickly as the cost of manufacturing (13). The contribution, the difference between the cost of manufacture and the selling price, increases to a maximum, and then decreases as the level of quality increases.(13)

This illustrates an aspect of increasing the quality of an established product. Quality can only be translated into a price increase if ;

- the difference can be explained to the user
- the user regards the difference as a superior fitness for use(16).

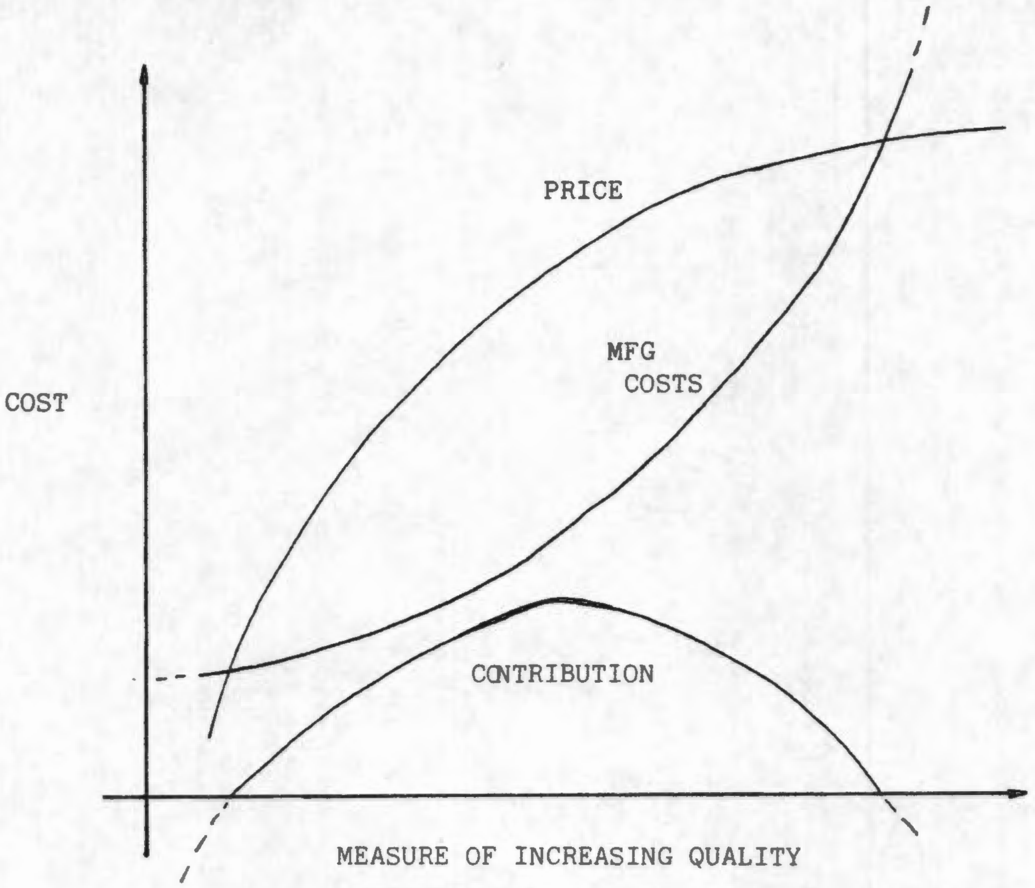


FIG 3.1 CONTRIBUTION VERSUS QUALITY (13)

For the manufacturer there is an optimum region of operation, that is in the vicinity of the greatest contribution. The purchaser wants the product to be as cheap as possible, but with the highest possible quality, thus some comprimise should be drawn. The manufacturer should optimise his overall costs when he decides on the region of outgoing quality that he is going to offer.

There are some basic flaws in the assumptions that have to be made to construct fig 3.1 These assumptions are that the manufacturing cost is representative of the overall cost, and, associated with this, that if the quality is very low no sale will be made.(13) This results in no external failure costs being included in the graph. Both these assumptions could be valid in certain circumstances, but not in all cases.

A way in which all of the quality costs could be illustrated is by plotting how these costs/expenditures vary against the level of outgoing quality. Typical plots of this nature for each of the three categories are shown in figures 3.2, 3.3 and 3.4. Figure 3.2 shows how the failure costs vary against the level of quality of the product. If the quality of production is very low compared with intentions there will be a high internal failure cost due to scrap and reworking. There will also be a high external failure cost due to warranty claims. As the level of quality made increases so the costs reduce.

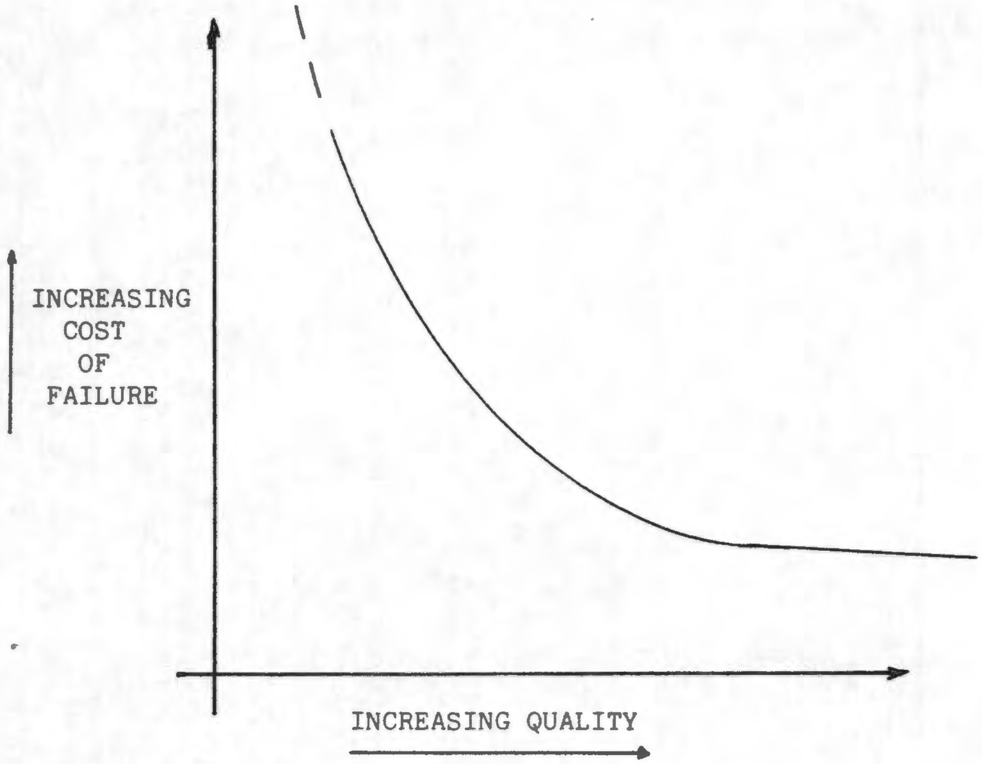


FIG 3.2 COST OF FAILURE VS. QUALITY

The cost of appraisal versus the level of quality is shown in fig. 3.3. As the required level of quality goes up so the cost of the inspection needed to obtain the necessary quality rises.

The cost of prevention versus the level of quality is shown in fig 3.4 In order to improve the level of quality, more time and money must be spent planning the system, and designing the product. Often too little money is spent on the prevention of failures, with the result that the total quality costs are very high $^{(6)(51)}$. The sum of these quality costs is shown in fig 3.5, where the curve exhibits an optimum region of operation. Such curves will vary with the product and with the process.

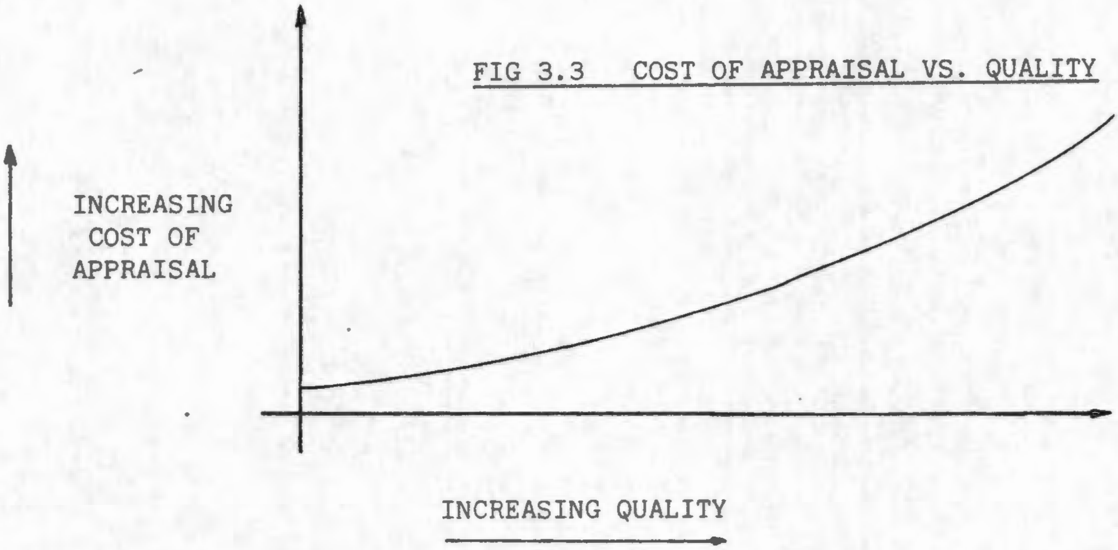


FIG 3.3 COST OF APPRAISAL VS. QUALITY

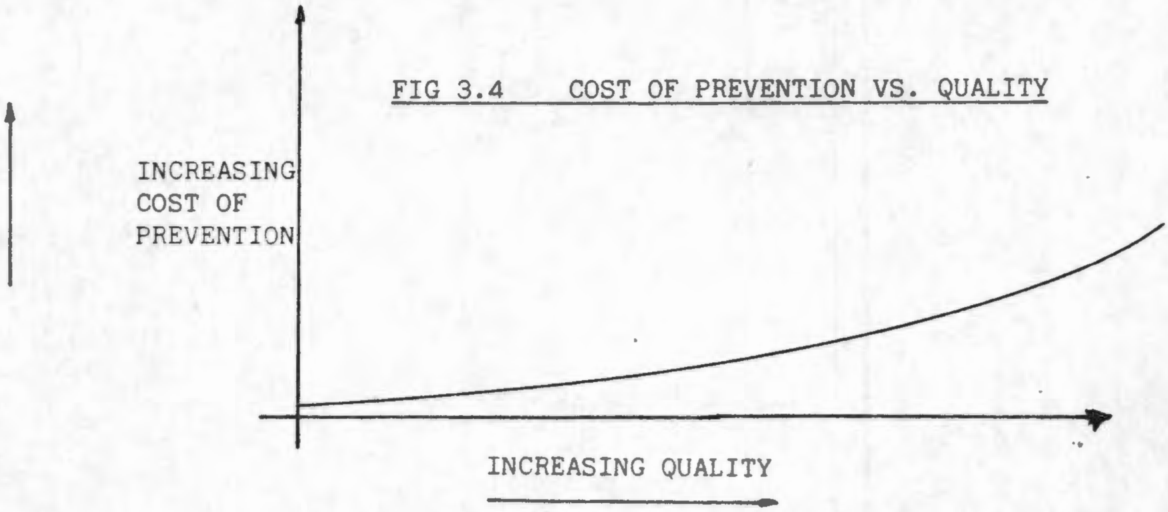


FIG 3.4 COST OF PREVENTION VS. QUALITY

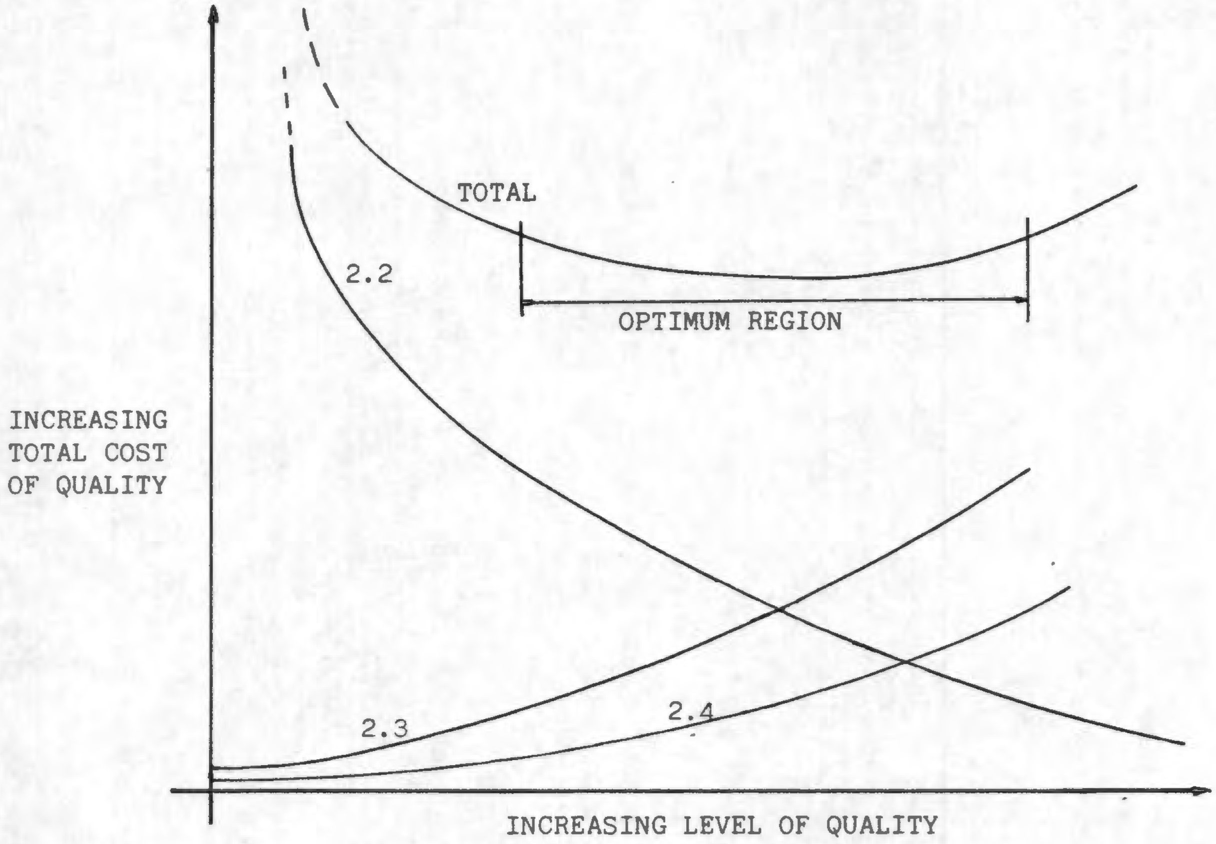


FIG 3.5 OPTIMUM OPERATING REGION WITH RESPECT OF QUALITY

One measure of the level of the quality could be percent good/defective. Fig 3.6 (16) shows how a typical cost curve showing the optimum operating area can be constructed. Once this has been constructed, the quality department has a target to obtain the most economical level of quality.

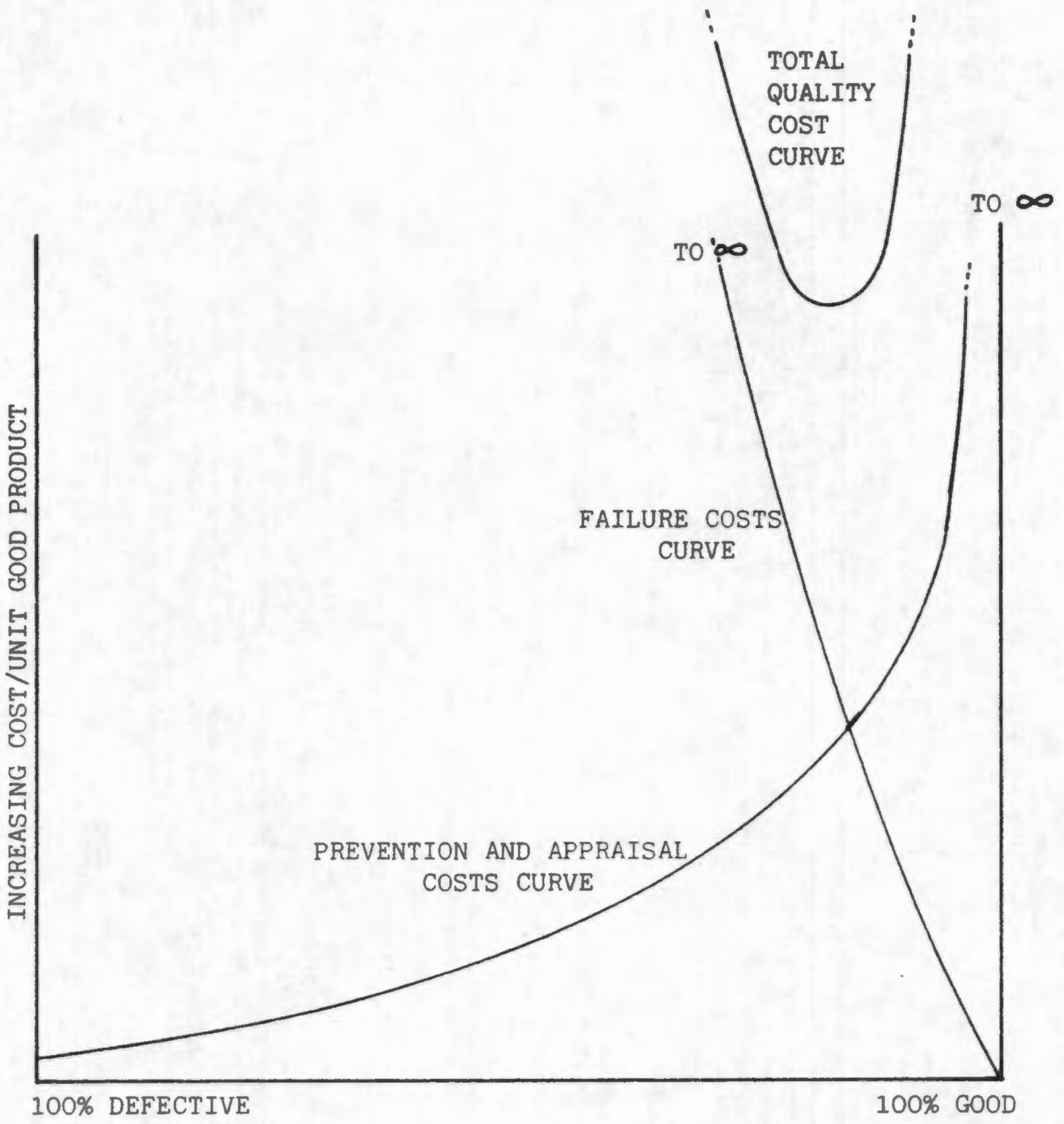


FIG 3.6 (16) MODEL FOR OPTIMUM QUALITY COSTS

Juran (16) divides the optimum cost curve into three operating zones (See fig 3.7). These are the zones of:-

- improvement projects
- indifference
- perfectionism

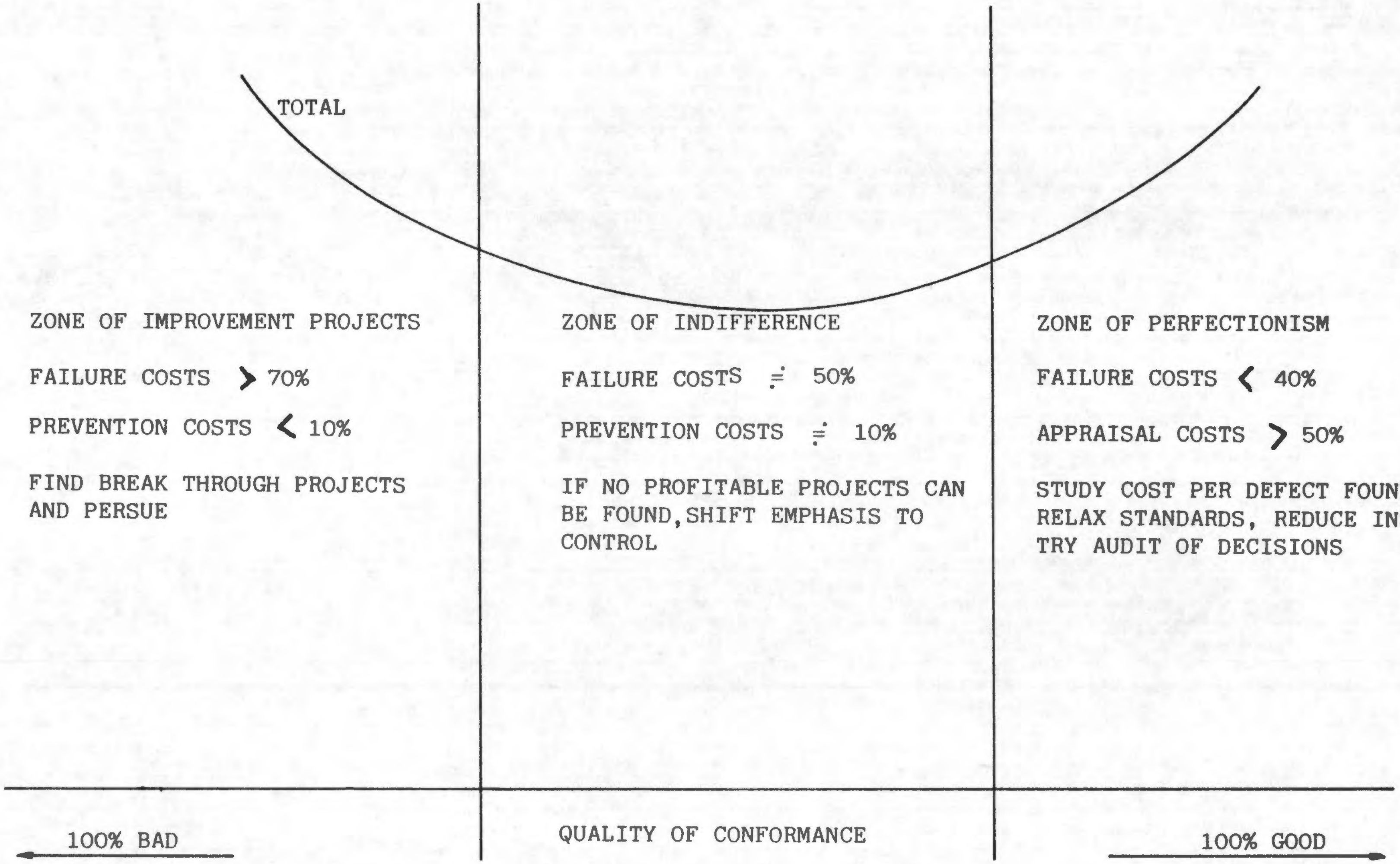


FIG. 3.7(16) OPTIMUM SEGMENT OF QUALITY COST MODEL (SEE FIG 3.6)

It is important to know which zone is being operated in, as the cost characteristics (as shown in fig 3.7), and the means of reducing the costs will vary accordingly.

The characteristics of the zones will be different for different products and they will also vary from company to company.

If the company is operating in the zone of improvement projects, there will be obvious projects that can be initiated to decrease the failure costs (16). If a lasting decrease in the failure costs is to be achieved it is usually obtained by an increase in the prevention costs.

At the other extreme in the zone of perfectionism,the quality improvement program has achieved the optimum, but it has not stopped there and the overall costs are increased by being too quality conscious, attempting to achieve 100% good product leaving the factory.

The zone of indifference is the region around the optimum, where it would not be profitable to initiate improvement projects, and it would be expensive to try to increase the level of appraisal and prevention.

### 3.2.2. ZERO DEFECTS THEORY

The theory of optimisation of quality costs is contradicted by the "zero defects theory" which postulates that there is no economical level of quality. It has been put forward that:-

> "Many tests try to demonstrate an optimum level of quality, that results in minimum quality costs. It is a falacious argument since it must always be cheaper to do the job right the first time." (51)

The theory agrees that costs are the only practical measurement of quality operations, but that zero defects is the only performance standard to work to. Proponents of the theory say that if some "standard of defects" is aimed at, it will be the maximum achievement of that plant, even if the plant is capable of improving on that level of quality (51).

Juran (16) states "zero defects .......... quality costs with the implication that they could be reduced to zero and that hence the total of quality costs is avoidable. This is simply not so. There is an optimum level of quality costs ......." This illustrates a failing of the zero defects theory, i.e. that zero defects is attainable and that the costs at this level will be zero.(36)

Zero defects is obviously an ideal state of affairs, but how does one measure it if no-one paid to do so? Possibly the specifications could be sufficiently wide that it would be almost impossible for the process to produce a failure - an extremely rare state of affairs. The level of zero defects is an ideal standard to aim for, but only practical if it pays to obtain it.

A possible reason for the contradiction that the zero defects theory seems to have set up could be explained by the fact that it does not recognise certain costs as costs of quality. This is possibly because the theory was put forward quite early in the development of the Q.A. theory. When some costs, currently attributed to quality in the optimization theory, would have been allocated to the production department. Examples would be the cost of planning the quality department, the additional cost of high precision machinery to manufacture within the required tolerances etc.

The argument that if a level is set the plant will not exceed it, is also faulty. Once the optimum level is found it sets the point of aim to obtain economic quality costs. As the operating parameters of the plant change, so the "optimum level of quality" will change. Thus the optimum level of quality should be reset as these changes occur, hence there should be a continuous monitoring and updating of the objectives of the system, how well these objectives are being met, and at what cost.

One of the primary functions of an audit of the quality system is to maintain the system, hence as the parameters change so the system can be changed accordingly.

### 3.2.3 QUALITY COSTS AND OVERALL COSTS

When striving for quality costs there is a danger of increasing the overall costs of manufacture. This can occur when costs not directly associated with the quality of the product are increased disproportionately in order to reduce the quality costs. Thus the effect on the overall costs should be carefully observed when attempting to lower the costs of quality.

One of the basic assumptions in Juran's (16) model (see figs 3.6 and 3.7), is that the basic manufacturing costs, i.e. labour, material, facilities, are almost constant,irrespective of the quality of conformance, as the same labour, materials, and machine time go into a faulty product as into a good one. As noted above, this cannot always be held as true.

The A.S.T.M. (52) philosophy on quality costs is evident from the following

"When you spend too much on the product quality, you only lose a little money. But when you spend too little you can lose everything because what you paid for was inadequate. The risk of failure must be evaluated." They also note that there is a danger of spending too much on the quality function with the result of an over-sophisticated quality system which produces a lot of data. The result being that this data is analysed and reanalysed with no conclusions drawn as the original use of the date has been lost due to the system being revised and re-revised data being produced for each sucessive system because it was produced for the last system, and much of which is now not necessary to run the system.

The first part of the philosophy could apply, but it is no hard-and-fast rule, as unless the costs are analysed the additional money could be spent on the wrong things with no improvement in the overall quality. The axiom could apply in buying production machinery, or measuring and testing equipment.

The A.S.T.M. philosophy underlines an important aspect, which is that it is better to spend more on preventing the failures occurring initially than to spend an equal or greater amount correcting for the failures once they have occurred.

## 3.3 BASES OF REFERENCE FOR COST COMPARISON

### 3.3.1 REPRESENTATION OF COSTS OF QUALITY

The volume of production of a plant will not remain constant over any period of time. This results in the costs of production varying from month to month, and the costs of quality will also vary accordingly. The question arises as to how to bring the costs down onto a common reference to compare them and to draw trends. The curves illustrated in figs 3.2 and 3.5 should then have a proviso added; that there has been some form of normalization of these costs with comparison to some reference base. Figure 3.6 shows the reference base as costs per good unit out. Thus the only representative means of monitoring the variation of the quality costs from period to period is as indices (16)(23)(43), isolating them from the effects of variation in the production volume.

There are a great number of operating parameters against which the quality costs can be related. Each has its advantages and disadvantages. Possible bases of reference include,(16)(23)(43)

- the quality cost per hour of direct labour in production
- the quality cost per unit cost in direct labour in production
- the quality cost per unit cost of standard manufacture
- the quality cost per unit sold
- the quality cost per unit value of sales

### 3.3.2 SELECTION OF REFERENCE BASES FOR INDEXING COSTS

There are a number of factors which must be considered when selecting the base from which to index the costs of quality. Each base will be sensitive to different variations in the operating parameters of the plant.

The sensitivity of the bases selected must be tested for the particular conditions which it is to be used in (23). The objective of using an indexed comparison is to insulate the variation of the quality costs from the variations in the amount produced. Unfortunately it is not as simple as indexing against units out or some similar measure. There are other distorting effects, among which could be variation in, the amount of mechanisation and the resulting labour hours/cost change, the cost of raw materials, and the selling price per unit.

Each base has its merits and demerits, and they change with each company. The most effective way to choose the bases which should be used is by application in that company (23). The relevant data is analysed and the costs are related to a number of bases. An example of this is shown in fig 3.8, (43) where the quality costs have been related to three different bases.

A minimum of three bases (23) is used, and there must be no more than one from each of the four general categories of bases. These categories of bases are those relating to labour, manufacturing cost, income and units sold (43). The three bases shown in fig 3.8 are:-

i) quality cost expressed as a percent of net billed sales,
ii) quality cost per equivalent unit of production output, and
iii) quality cost expressed as a percent of direct labour cost.

Cost per equivalent unit of production is often used in the case of multi-product plants. The development of the number of equivalent units in a fictitious case is shown in Appendix IV.

The principal aim of relating quality costs to bases is that the magnitude of the manufacturing activity is isolated.

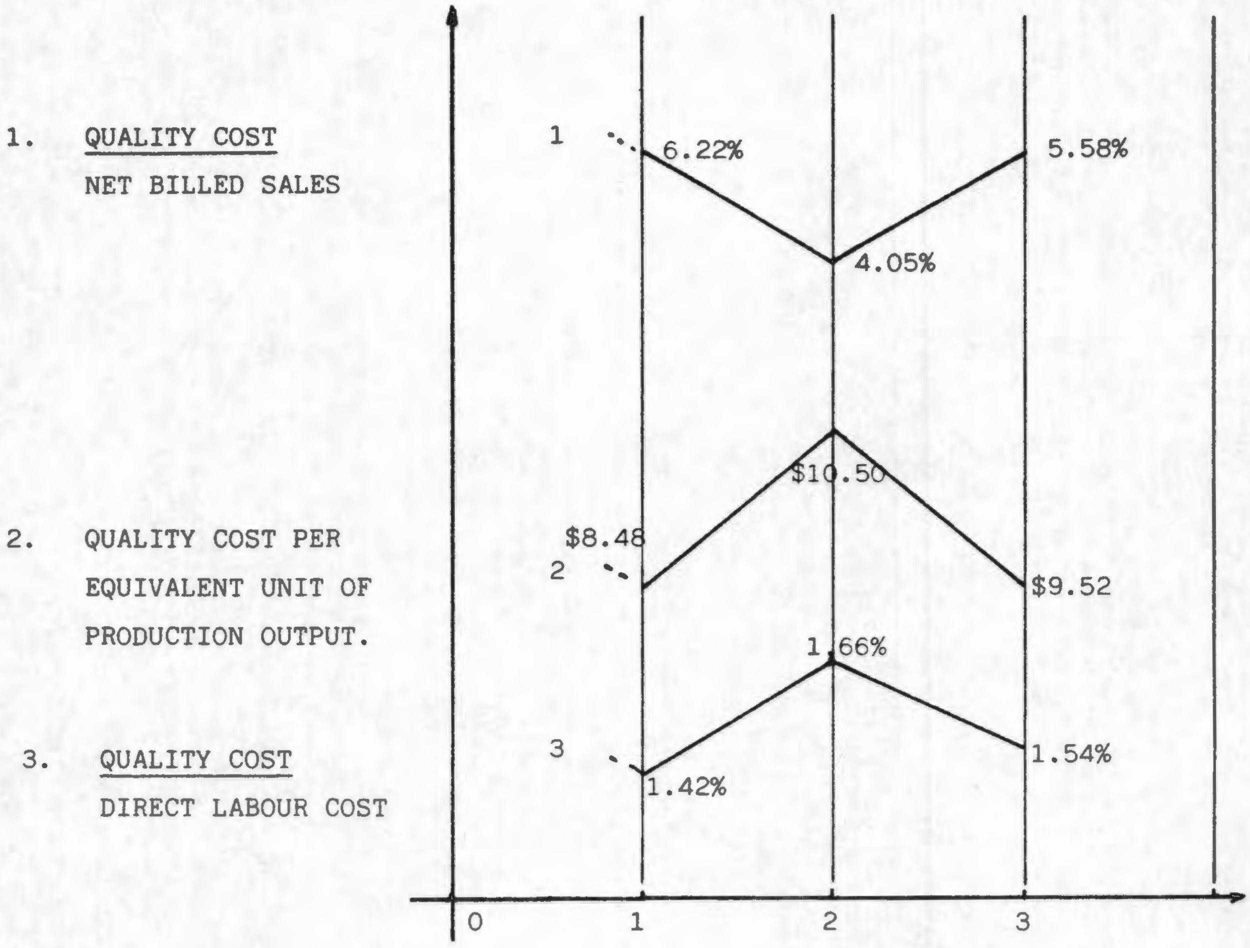


FIG 3.8 QUALITY COST COMPARISON USING THREE DIFFERENT MEASURING BASES (43)

Thus the base used must reflect the manufacturing activity, as the amount of quality costs will be related to the manufacturing activity. Some of the merits and demerits of some of the bases are outlined in Appendix V.

The selection of these bases will vary from company to company, but as noted above the best way to select the base is in use. Should the base fail to represent the manufacturing activity it should be discarded.

The variation in the trends shown on the plotted graphs is used to illustrate changes in the plant.

### 3.3.3 ANALYSIS OF TRENDS ON INDEXED QUALITY CURVES

By analysing the trends in the quality costs using three different bases, changes in one of the operating parameters will be highlighted. This happens because the three bases are independent from each other, hence the change will be highlighted in one or more of the plots. The trends shown in the plots should be the same, and if one of the plots shows a different trend from the others the reasons for this should be investigated. By accounting for these variations, the problems in the quality system should be highlighted.

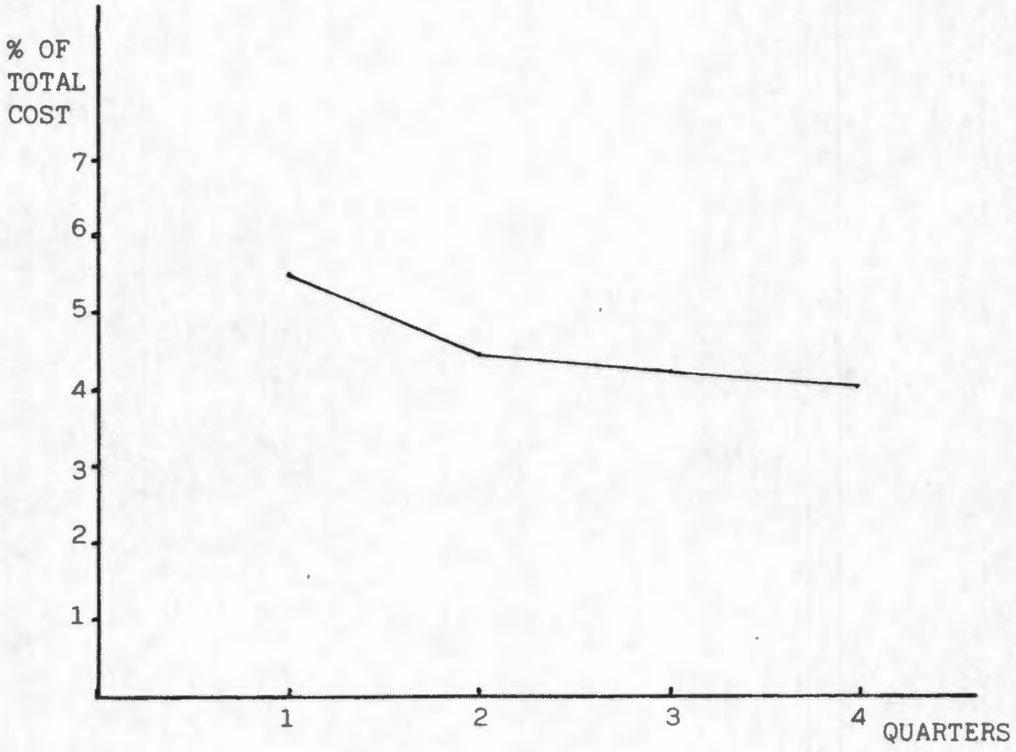
The base plot which is 'out-of-step' with the others will give an indication of where the change has been made. One should note that the disruption might be a factor which affects the other two plots and hence it is not always the initially obvious problem which has caused the variation. A further aspect to note is that a parameter change could effect all three indexed plots, and hence it will not come to light immediately on the plots. This sort of occurance should be rare if the bases are chosen well (23).

When the bases have been used over a period, the personnel using them will be able to have a very good idea as to what is going wrong by looking at how the three plots have varied over the previous few periods.

Fiegenbaum (23) suggests that each quality cost category be related to the respective bases. Examples of these curves are given in figs 3.9, 3.10, 3.11, 3.12 and 3.13 (23) related to the total operating cost. This would enable the trends developed within each cost category to be observed, as the parameters vary. It is only on this basis that an economic operating point could be drawn up.

In order to retain a relationship with how the overall costs vary against how the quality costs vary,a graph of total quality costs should be plotted against the overall costs of manufacture. A curve of this nature has been drawn in fig 3.14. This enables the analysist to see the effect that the variation in the overall quality costs has on the overall costs. One should note that the aim of the exercise is to reduce the overall operating costs, not just the costs of quality.

FIG 3.9 TOTAL $\frac{\text{QUALITY COST}}{\text{TOTAL COST}}$



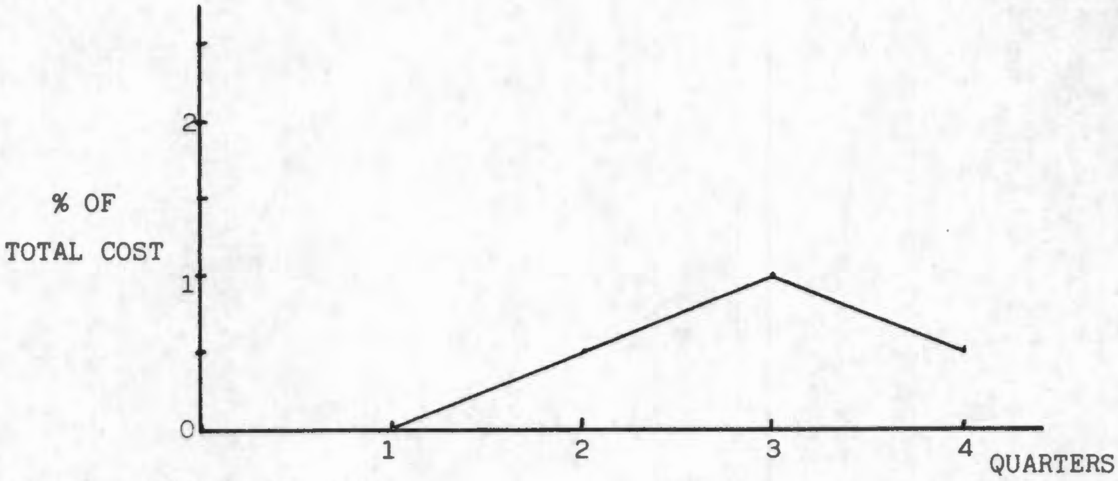


FIG 3.10 PREVENTION COST / TOTAL COST

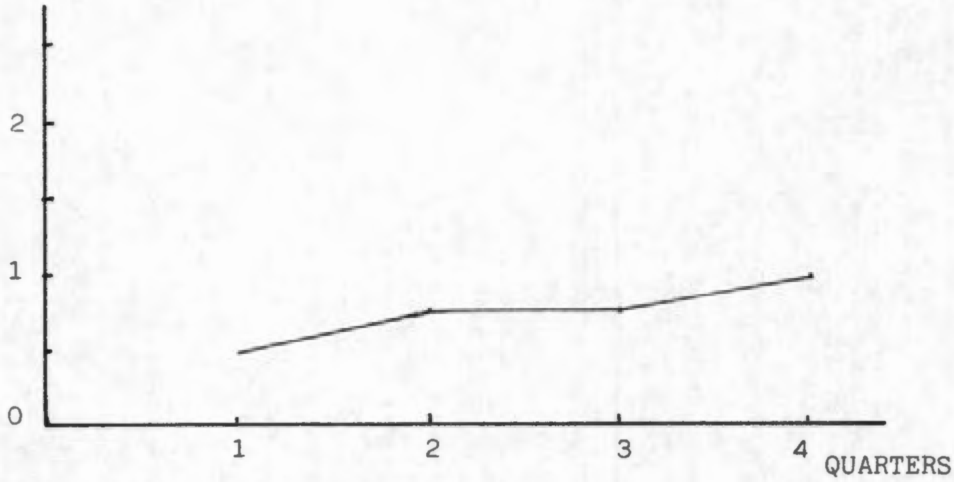


FIG 3.11 APPRAISAL COST / TOTAL COST

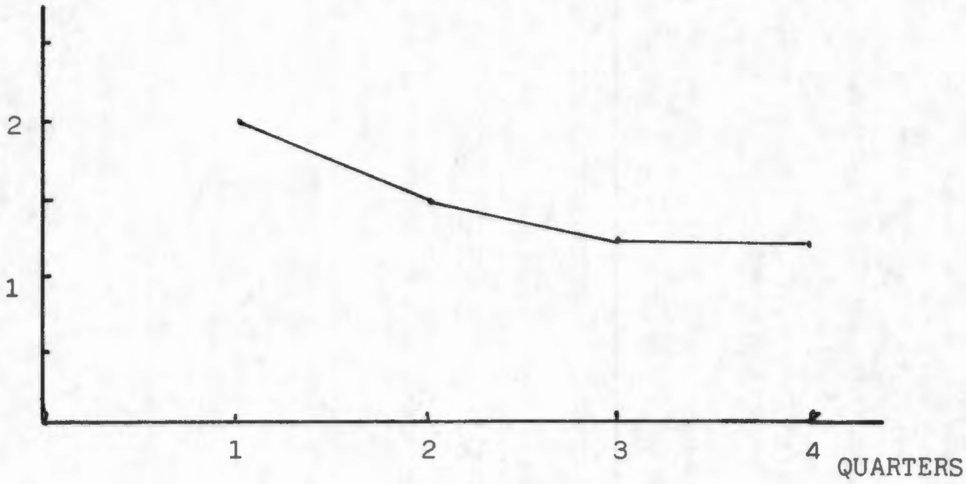


FIG 3.12 INTERNAL FAILURE COST / TOTAL COST

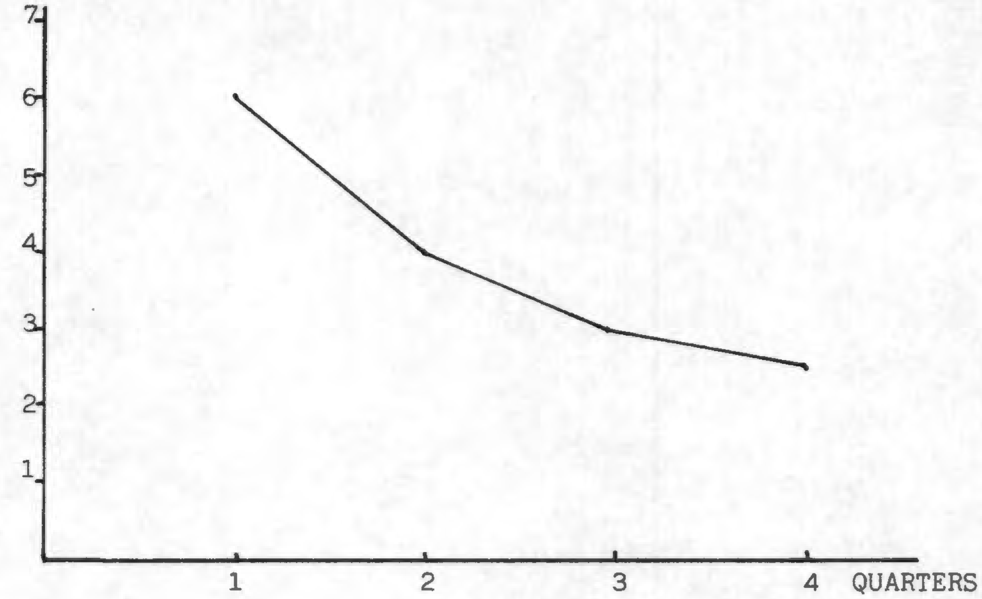


FIG 3.13 EXTERNAL FAILURE COST / TOTAL COST

Figures 3.9, 3.10, 3.11, 3.12, and 3.13 show curves of how the quality costs vary against the total cost over a period of improvement (23).

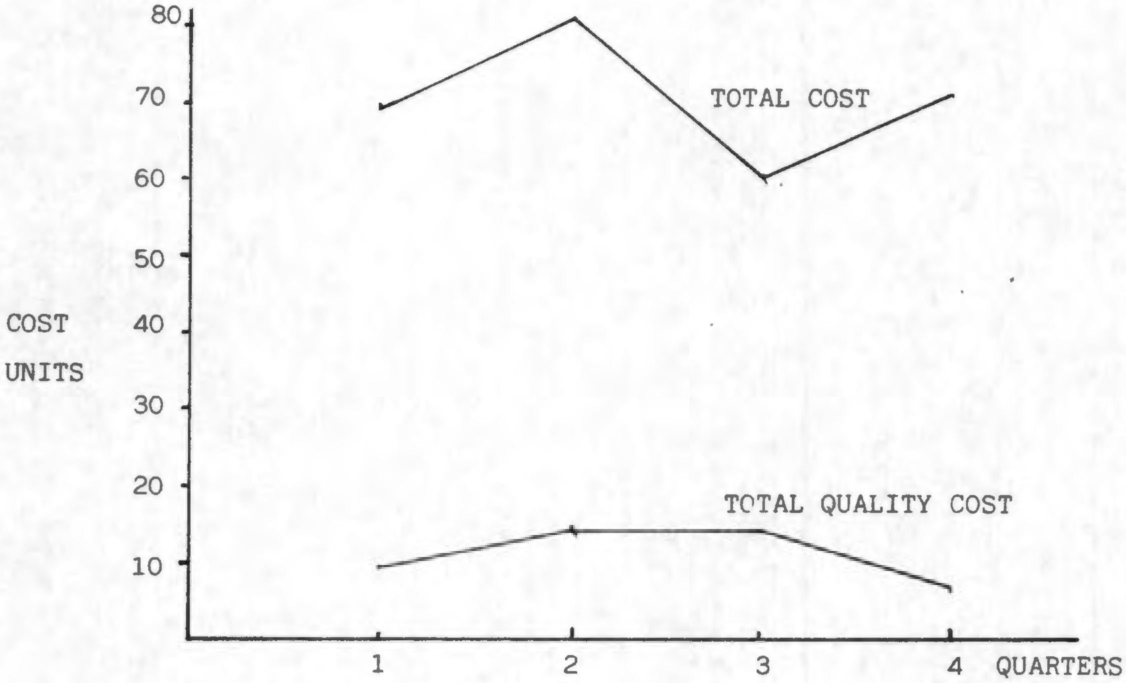


FIG 3.14 GRAPH OF OVERALL QUALITY COSTS AGAINST OVERALL COSTS

### 3.3.4 BAR CHART PRESENTATION

If the plant produces more than one product a bar chart in the form shown in fig 3.15 is an effective way of presenting the quality costs (23). By presenting the costs in this manner it is easy to see how the quality cost is apportioned for each product, and the overall effect the variation in the division of the quality cost between the categories, has on the overall costs. If the products are of a similar nature this would be a very good way of allocating the resources for correction of problems. The figure of quality as a percent of overall costs would then be related to the way in which the quality costs were broken down.

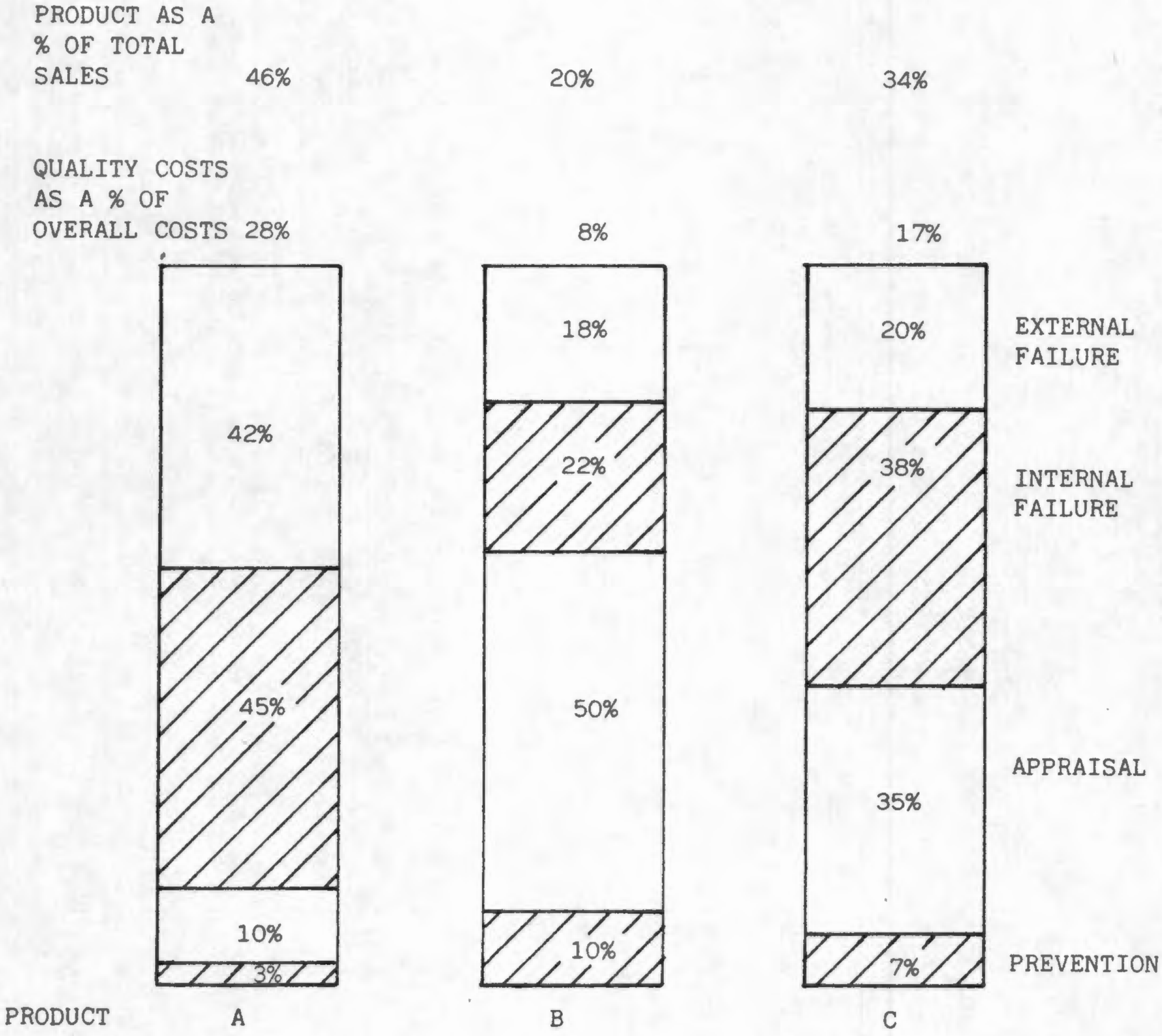


FIG 3.15 BAR CHART PRESENTATION OF MULTI PRODUCT QUALITY COSTS FOR A PERIOD (23)

Another way in which the costs can be presented is shown in fig 3.16. This is a method of presenting the costs related to any base, which will illustrate the effects of expenditure on prevention and appraisal, on the overall quality costs in relation to a selected base.

It should be noted that any base could have been used. It depends on the particular conditions in which it is being used, and what parameter is being varied in an attempt to reduce costs.

Further, the bases can be used to eliminate the effects of outside variations which the company has little control over. This will be expanded upon in Chapter 3.4

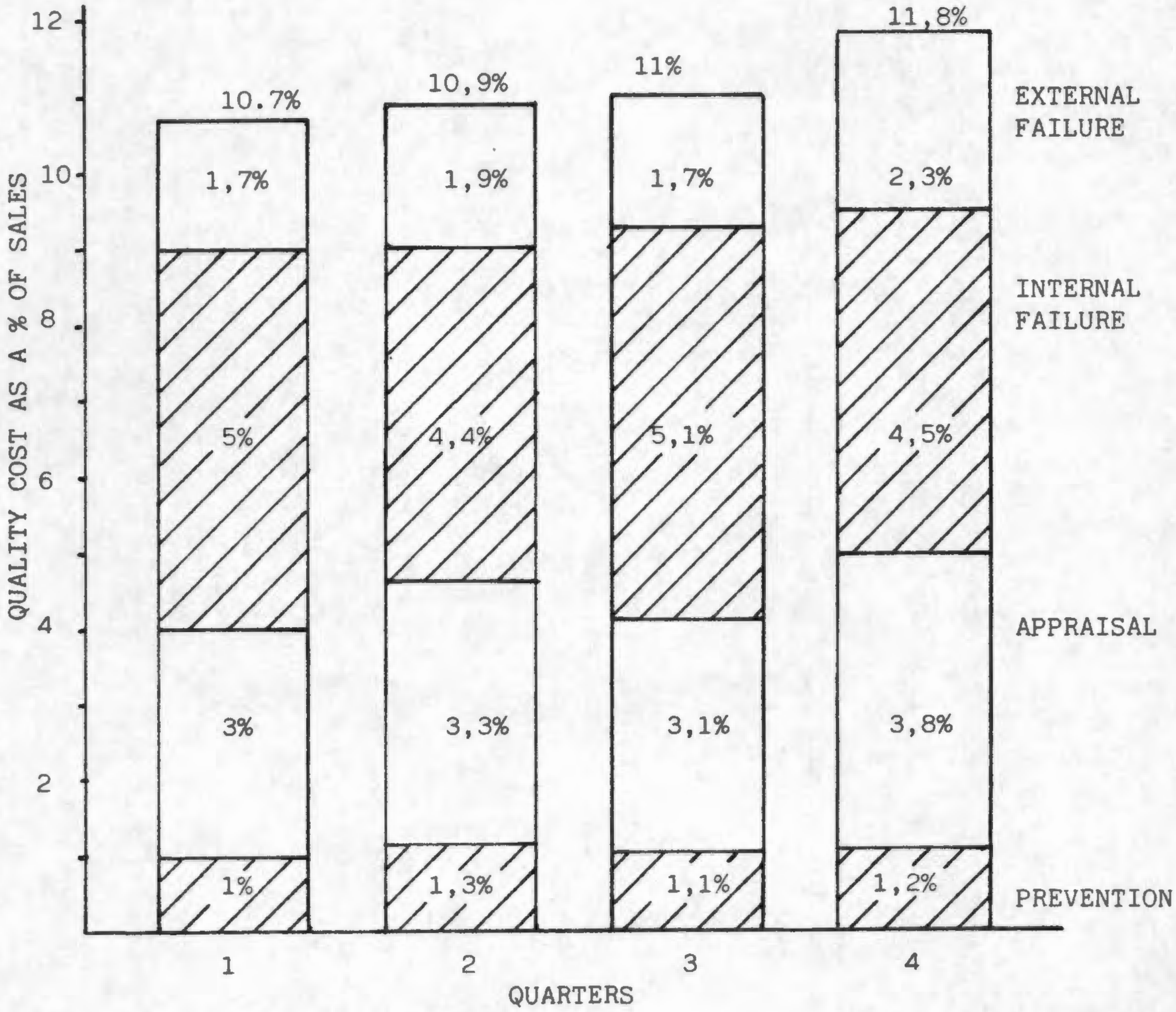


FIG 3.16 QUALITY COST CATEGORIES SHOWN AS A PERCENT OF SALES (23)

## 3.4 QUALITY COST EVALUATION

### 3.4.1 THE MULTI DIMENSIONAL NATURE OF THE SYSTEM

In developing the economic point of operation from the point of view of quality costs, Juran (16) made a number of assumptions, not all of which can be held valid for a general case.

One of these assumptions was that the cost of manufacture of the units was constant, irrespective of the quality of the product. Hence an optimisation of the costs of quality would be an optimisation of the overall costs, as the graph would only be shifted up with a constant per unit manufacturing cost added. This can be held valid for one evaluation period for a constant production amount, but it is not valid over more than one period as these costs do not remain static with time. The per unit cost will vary with the amount produced, as the overheads per unit will go down and quite likely the basic material cost per unit will go down.

It has also been observed that the market situation has a marked effect on the costs of quality (44)(53). Both the market into which the company sells its product and the market from which it buys its materiels will have effects on different costs of quality.

In a market where there exists excess capacity,the buyers have more control over the prices than the sellers. This results in an increase in the demands for a higher product quality. In a situation like this the quality of the product becomes a lever used by the buyers to reduce the selling price.

Often the customer complains about the quality of the product to reduce the price, and when the complaint is investigated it is found that the quality of the product is better than that of the competitors, but the price is higher. (Note the definition of quality as presented in Chapter 2.1 takes into account the overall fitness for use i.e. life-time costs). The user is trying to get the better product at a lower price.

One other aspect should be noted in a buyers market. This is that where capacity exceeds demand, the manufacturers tend to lower their prices, and sell their products at marginal prices, covering variable running costs with only a slight contribution to the fixed costs. This could be done to retain a position in the market, and in the case of a multi product plant the overheads could be carried by the other products. This has an effect on the quality costs, as the per unit external failure costs decrease.

On the other hand, the opposite trends are shown in a sellers market where the demand is higher than the supply. In this situation the complaints about the quality occur less often. In many cases the purchasing company will attempt to use the faulty product with some rework rather than return it. This situation often occurs in the case of motor vehicle companies in South Africa, where some of the parts are sent in from overseas, also where some of the local parts have long lead times between ordering and delivery.

In a situation where rework in the purchasers plant on bought-in materiels is possible an agreement could be made to charge the rework to the supplier. In the case of raw materials where the grade matters, the materiel might be down graded and a credit passed onto the purchaser.

The company could also be buying its materiels in a buyers or sellers market, and this would also have an effect on the costs of quality.

One should note that if a company markets more than one product it could be operating in both a buyers and a sellers market at the same time. This can occur if products of different qualities are made. Usually a high quality artical is sold in a sellers market and a low quality product in a buyers market (45). One reason for this is that a high quality product can be sold in a low quality market to defray expenses and to contribute marginally to overheads. Evidence of this may be seen in the "no-name" brands at the large supermarket chains. In some cases these are the same products as the original and are sold in competition with the manufacturers brand.

There are a number of other market influences, and the situation cannot be considered as static. The result of market changes means that over any period the 'economic operating point' will change as the different categories of quality costs are affected differently.

The quality cost will vary with the number of units made. The usual method of normalizing the costs of quality is to relate the costs on a per unit basis. This is discussed in chapter 3.3 above. The aim of relating the costs to bases is that the fluctuations in the cost of quality due to the effect of volume changes alone will be eliminated.

This is unfortunately not altogether true, as there are other volume effects which cannot be eliminated in the way, but attention should be drawn to them when the costs are analysed.

One of these effects is that the cost of materiels per unit produced goes down as the quantity produced goes up. This is due to factors such as discounts given by the suppliers for quantity orders. This variation in the per unit materiel costs has an effect on the internal failure costs, and trends in the per unit quality costs could be hidden.

Also if the number of units produced goes up, the fixed costs of production are spread over a greater number of products and hence the external failure cost per unit is less.

There is thus a multi-dimensional system rather than a two dimensional system as indicated in the 'economic quality cost theory'. The problem which this presents is how to minimise the costs of operation whilst maintaining a position in the market and an acceptible level of product quality.

### 3.4.2 HEURISTIC METHOD

It would be extremely difficult for a company to investigate all the possible levels of quality of the product with respect to the overall operating costs and the highest income.

The market options are usually limited by the nature of the product, but the level of quality of the product leaving the plant can vary between 100% faulty and 100% good, if defects is used as a measurement of the level of quality.

Initially the management have to decide as to what market they intend aiming for. Often this option is not extremely wide when the capabilities of the plant are considered. The quality policies must also be set with the market in mind.

Often the customer approaches the manufacturer to make a product to certain specifications. In a case like this the level of quality could be specified by the quality of conformance. The contract would be drawn up specifying the acceptable quality level, with the probability that this level will be maintained, usually by a standard sampling plan. Once the level of quality is specified the manufacturer has to make the product to this level, or the customer will reject the product and an external failure cost will be incurred.

The question that must be asked is, what is the true cost incurred to obtain a specified product quality level? Another question is, what is the quality level which will give the lowest overall costs, and is there a market for the product at this level of quality?

In order to optimize the overall costs by manipulation of the quality costs, these costs should be monitored in terms of each other. A means of achieving this is by relating the costs to quality bases. (See chapter 3.3 where these are discussed in detail).

By relating the quality costs to a number of bases, a means is given to analyse the costs of quality in two dimensions, as the effects of the multi dimensional nature of the overall system are cancelled out.

The question as to where on the optimisation curve (fig 3.6) the manufacturer is operating still remains. Unfortunately the manufacturer cannot vary his level of quality to see how the customer reacts, as this could be expensive. There rarely exists figures for specific industries as to how the quality costs should be apportioned, hence the manufacturer must find out for himself.

Juran (16) presents an approximate guide how the costs should be apportioned in the cost categories. He says that there are three general zones on the quality cost curves. These are illustrated in fig 3.17. It is important to know which zone is being operated in, as the cost characteristics will vary considerably from zone to zone.

Although the quality cost categories cannot be optimized on their own, there are a number of guidelines to obtain costs in the region of the optimum. These are given by various traits in the quality cost categories (16).

1) Failure costs are at their optimum when we are unable to identify profitable projects for reducing them.
2) Appraisal costs are at their optimum when,
    a) failure costs are at their optimum, and
    b) we are unable to find profitable projects for reducing appraisal costs, and
    c) we have established good work methods and standards for inspection and testing, and are meeting those standards.

FIG 3.17 CHARACTERISTIC COSTS OF EACH 'OPERATING ZONE' SHOWN AS A PERCENT OF THE OVERALL QUALITY COSTS (16)

| ZONE OF | CHARACTERISTIC COST APPORTIONMENT | |
|---|---|---|
| IMPROVEMENT PROJECTS | FAILURE COSTS | 70% |
| | PREVENTION COSTS | 10% |
| INDIFFERENCE | FAILURE COSTS | 50% |
| | PREVENTION COSTS | 10% |
| PERFECTIONISM | FAILURE COSTS | 40% |
| | APPRAISAL COSTS | 50% |

3) Prevention costs are at their optimum when

a) the bulk of the prevention work is being directed to authorised improvement projects, and

b) prevention work itself has been subject to analysis for improvement, and

c) the non project prevention work is controlled by sound budgeting (16).

Once the costs of quality have been analysed and allocated to the four categories the distribution between them can be seen. The analysis will indicate the possible areas for improvement, and the major cost causes.

### 3.4.3 PARETO METHOD

When the causes of the costs are found from the analysis the resources of the organization have to be applied to correct these causes. Not all of the cost causes will warrant attention, as the time and money spent on correcting the cause is more expensive than the cause.

In situations of this nature, Pareto's principle (6) usually applies. (See fig 3.18) Pareto's principle holds that the great majority of the costs are caused by a minority of the causes. Typical figures for this principle are 80% of the costs are caused by 20% of the causes (6).

By applying the principle, the top cost causes are found, and investigated to see whether a cost reducing project is warranted. Often the top cost causers are not as obvious as the top defect causers. The two are not necessarily the same, and a good deal of time and money could be spent reducing the problems which cause the greatest number of defects.

Usually companies have a minimum rate of return for money invested. It is logical then that any project to improve the costs of quality should be analysed for rate of return. The decision to implement the improvement project must then be made in competition with other projects on the basis of the highest return.

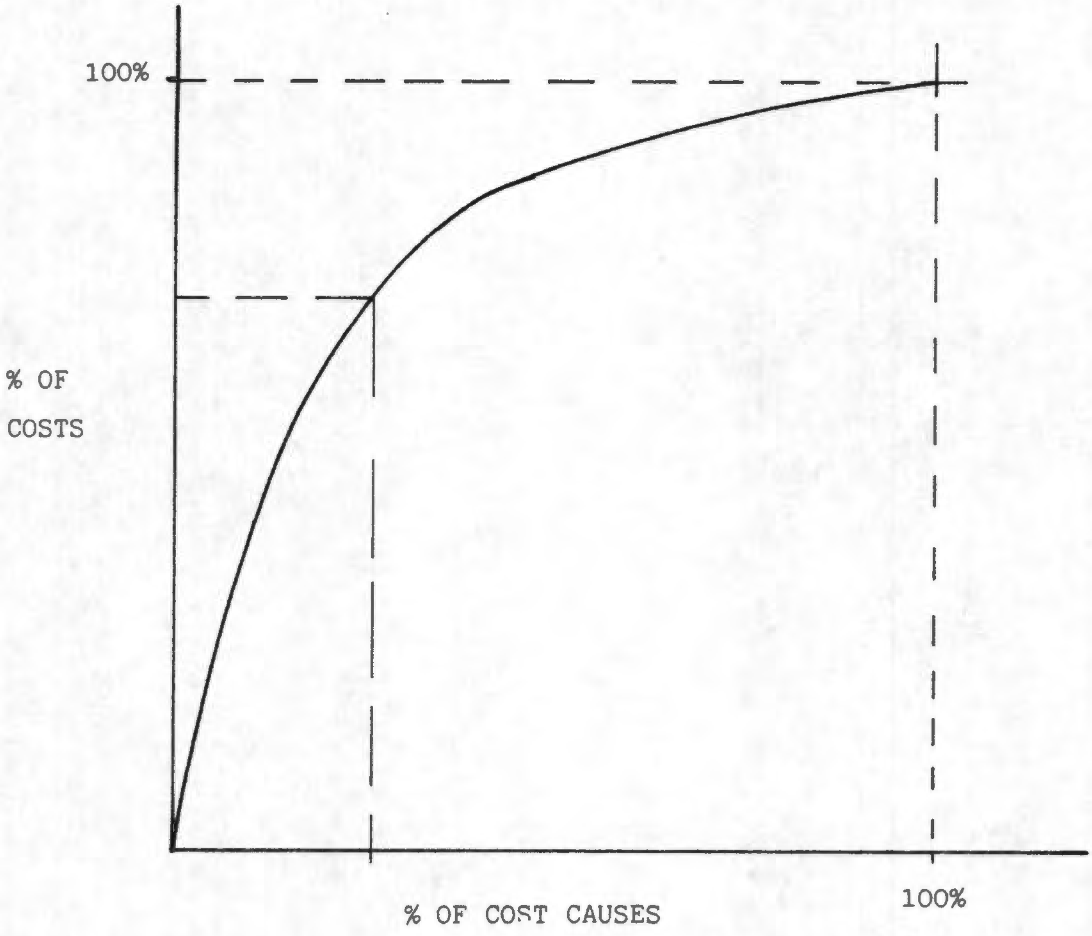


FIG 3.18 PARETO'S PRINCIPLE AS APPLIED TO QUALITY COST CAUSES

### 3.4.4 USES OF COST EVALUATION DATA

The cost data generated in a quality costs survey can be used for many purposes. Amongst these are (46):-

- measuring the overall quality activity
- identifying high manufacturing loss areas
- directing available staff for corrective action
- budgeting quality expenditures

Management is usually concerned with how the costs of their departments are varying as they usually have to account for these costs. Thus an analysis of the quality costs on a regular basis is useful.

To be useful the analysis should include an investigation by the technical department into the potential cost saving projects to evaluate the corrective action needed and the cost of this action.

The manager concerned would then have a factual base of costs on which to evaluate potential savings. He would also have to evaluate the action in terms of the staff available to carry out the corrective action, and the cost in terms of labour.

The cost analysis and subsequent evaluation of the results are a base which the management can use to budget for the next period's expenditure on quality improvement. The cost analysis could be used to justify employing people to correct the various problems.

An important use of the quality cost data and the quality ratios (quality costs related to the various bases) is that they form a feedback loop for improvement projects. When investigating an alteration to the process, with a capital expenditure, estimates are made as to what the benefits will be. These are often made from specifications supplied by the company making the sale. Using these estimates and the cost of the alteration a decision is made whether or not to proceed.

A benefit of evaluating the quality cost data is that the actual cost benefits can be evaluated against the predicted benefits. After this sort of investigation has been carried out for a number of projects a better "feel" will be obtained by all those concerned as to the possible benefits of certain actions.

Another aspect is that the actual performance of equipment can be compared against predicted performance. This enables the technical department to avoid 'bad buys' where equipment does not meet the given specifications.

An indirect benefit can be obtained in passing feedback to the supplier about the actual performance of his products. If the specifications were not met this could form a lever to be used in negotiations on future transactions, if there are any. The feedback to the supplier could be used by the supplier to improve his product, eliminating some of the product's problems, and hence reducing yours for little or no additional cost.

By analysing the data and evaluating the trends of the quality costs a form of filtering has been done. The graphs of the costs against the bases, and the trends on these graphs may be presented to higher management as a condensed version as to how the product quality and its associated costs have varied over the period in question.

One must note though, that no matter how well the data are evaluated and presented they cannot manage for the manager (56). They make his evaluation of a situation easier and he is able to make a balanced decision from a factual base.

It might be observed that the effort of evaluating the quality costs and the effects of projects is not really worthwhile. In the case of a poor capital investment, "which rarely occurs anyway" the money is already spent, and many of the quality costs are evaluated along with the production costs as part of their inefficiencies.

The belief that projects with poor returns rarely occur could well be due to the fact that poor data are presented to the management. The initial data on which the decision was made was poor, and hence a poor decision was made, as the overall picture was not known. The ironic aspect of the fact that it was a poor decision does not come to light, as there is no evaluation of the results, and the data presented is incomplete. (56)

By evaluating the results of the decision regarding quality, what is really being done is putting a quality control on the decisions made. The result is that there is pressure on the decision makers to make more cost efficien decisions.

Usually the quality system is audited on a regular basis, to see whether the system is achieving its aims. This audit usually includes an in depth study of the quality system, the relevance of and degree of conformance to the documents, and the sampling efficiency etc.

The audit can be a long and drawn out affair, and can be expensive. If it is done by people from outside of the department as it should be, (16)(54) pointers are needed to illustrate the main problem areas, so that the audit time is reduced.

One should note though, that the use of a cost means to isolate areas of high cost, does not preclude the use of standard audit methods to evaluate the system. This means is used as an indication of the high cost areas, but it cannot tell exactly what is going wrong, although it can indicate the region in which time spent will be most profitable. The audit should still include a basic investigation of the system using standard methods.

## 3.5 INDIRECT SAVINGS OF A QUALITY ASSURANCE SYSTEM

### 3.5.1 TIME BETWEEN CONCEPTION AND DELIVERY OF A NEW PRODUCT

As noted in Chapter 2.2.3 two important parts of the Q.A. system are control of the design period and of the interface between design and production.

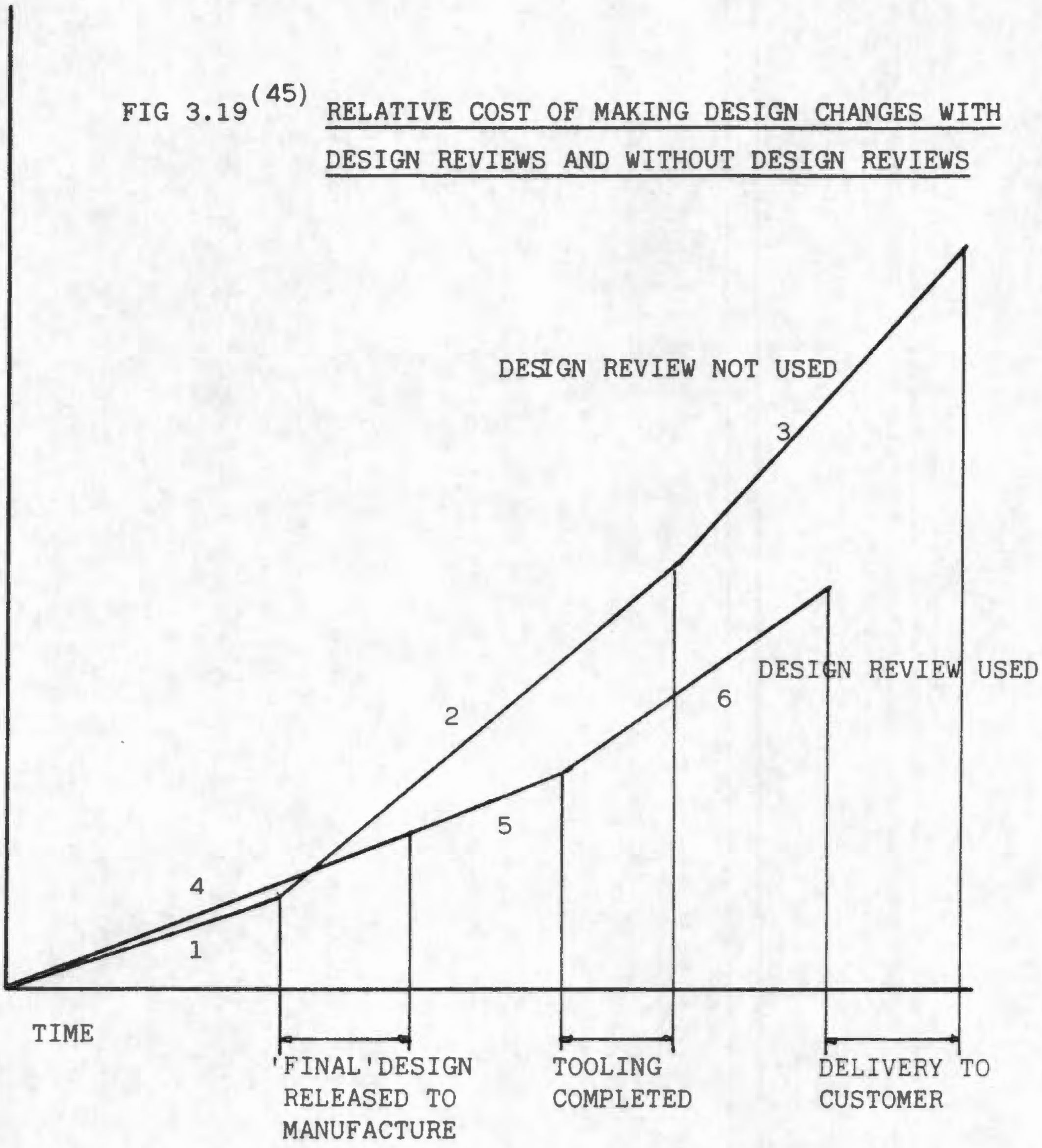
In most cases an original design needs a certain amount of 'debugging' before it can be put into production. There is a substantial cost difference between correcting the design before production starts and after it has started.

The cost difference is shown in fig 3.19 which illustrates the cost and time difference between the conception of a product and its delivery to the customer. This is shown for the cases of with and without design reviews.

A design review is a formal, documented, and systematic study of a new product design by specialists from every department of the production system (47).

In getting a representative from each department involved in the production, a major step has been made. A designer is rarely an expert in all the fields involved and often leaves out aspects which would have to be corrected later in the stage when expensive tooling has been made, and time taken to lay out and plan the production.

FIG 3.19(45) RELATIVE COST OF MAKING DESIGN CHANGES WITH DESIGN REVIEWS AND WITHOUT DESIGN REVIEWS



1. DESIGN STAGE 2. TOOLING AND MAJOR DEBUGGING STAGE
3. PRODUCTION STAGE WITH MINOR DEBUGGING STAGE. 4. DESIGN AND DEBUGGING STAGE
5. TOOLING STAGE. 6. PRODUCTION STAGE.

By using design reviews, each department is then able to contribute during the design stage. This results in the design stage taking longer and being more expensive than it would otherwise have been. On the surface this might seem odd, but not if one looks at the overall picture. The extra cost and time is more than made up for by the lack of need for design changes and associated tooling and production changes in the commissioning phases.

Not only are the savings in the overall costs of the product, but there is a saving in time. This means that using the same resources more output may be obtained, hence spreading the overheads.

An opportunity is also given for the informal communication network between the departments to develop . This means that other problems between the departments will be solved between the members without resorting to the official internal network (58).

### 3.5.2 EVALUATION OF SUPPLIERS PERFORMANCE

It is quite normal for there to be inspection of incoming goods for defects, but there are benefits of going beyond this, by analysing the suppliers service. Although this is a standard Q.A. procedure it is rarely done, and it is even more rare to find feedback to the supplier other than to transmit a complaint about the quality (18). As noted previously, benefits may be obtained by passing feed-back to the supplier, who can correct the faults at the source, hence reducing his and your quality costs.

Another benefit that may be obtained by analysing the suppliers service is that his level of service can be found. If a supplier is consistantly late in delivery, the lead time allowed for ordering should be increased. This means that the production hold-ups which could result from late deliveries would be eliminated to a large degree.

The costs of incoming inspection may be reduced by analysis of the quality of the incoming materiels.Should a supplier consistently supply materiels of a high standard the level of inspection could safely be lowered(12).This would be done using one of the standard multi-level sampling plans,and should conditions in the suppliers plant change and a higher level of defects occur,the original sampling plan could be re-installed.

### 3.5.3 PREDICTION OF PRODUCT QUALITY

In most cases when an order is made up, the production department will make a certain percentage over the order amount. This is on the assumption that a percent of the product will fail and that approximately the order size will pass final inspection.

If the amount produced varies from the order size,the customer can be approached to take slightly more or slightly less than the order. In most cases this is fine, but if it is a once off order the customer might not want more or less, and the plant is left holding excess product, or it has to make a small re-run to make up the order. Although this sort of happening is budgeted for by adding the "fudge-factor" to the raw materials, it would be cheaper if an accurate factor could be added.

By monitoring the quality costs, more specifically the internal failure costs, an accurate estimate could be obtained of the current 'material efficiency' of the plant. Hence the raw materials issued could be increased by the inverse of this efficiency, giving a far more accurate figure than an across-the-board increase.

The result is that the production schedule can be followed more accurately and hence the costs of squeezing in a short run, possibly during overtime, is avoided to a large degree.

## 4.0 DEVELOPMENT OF A SIMPLIFIED METHODOLOGY FOR QUALITY COST ANALYSIS

One difficulty of the costs of a quality system is to monitor all the costs of that system. The quality costs have to be identified and the cost data collected. When all the costs have been compiled, the evaluator must analyse how they were caused and what their implications are.

The use of bases and quality cost categories as discussed in Chapter 3 form part of the cost analysis methods available. The use of quality cost models is another method of analysing the quality costs.

In a mathematical model a general set of equations is developed to simulate the type of situation involved, looking at the possible inputs and outputs of the system. Depending on the aims of the model, the user should be able to simulate his situation by the input of his parameters and thus be able to analyse his position with relative ease. However, not all quality cost models are mathematical, as some situations cannot be reduced to a mathematical equation.

Hence a set of empirical steps will be laid down to aid the evaluator in his analysis of the quality costs.

## 4.1 TYPICAL QUALITY COST MODELS AVAILABLE

There are a number of basic types of quality cost models available. The four major types of models are (60) :-

- models used for the economic selection of a quality level.
- models used for the design of optimal sampling plans
- models used for the design of a sequence of sampling plans throughout a process
- models used to simulate a process for the purpose of controlling that process.

The first type of model has been discussed in Chapter 3. This is the model suggested by Juran (16) for analysing quality costs. As discussed the use of this model alone is inadequate.

The second type of model is unsuitable for the purpose of monitoring and controlling the overall quality costs as it does not take into account all the costs of the quality system, and hence developing plans based on a sub-optimised situation.

The third type of model is an attempt to develop the sampling plans of a quality system, but generally a series of sub-optimisations are combined together. An example of such a model is presented in reference 61, which uses the costs shown in fig 4.1 to calculate optimum sequential sampling plans. If the optimum quality level model presented by Juran (16) is referred to (see Chapter 3.2.1) it will be noted that the costs (see Appendices I, II, III) cover far more than the costs involved with inspection.

FIG 4.1 COSTS USED IN REFERENCE 61 TO SET UP OPTIMUM COST SAMPLING PLANS

1. Costs of inspection of one unit of product.
2. Costs of screening inspection of one unit of product.
3. Costs of screening of one unit of product.
4. Costs of accepting a unit with a dimension outside specification limits.
5. Costs of scrapping and replacing a defective unit found during sampling inspection or screening inspection.

One could argue that the costs shown in fig 4.1 account for more than the direct costs of inspection, and include such quality costs as the quality manager's salary as an overhead spread over all the units inspected. It is unlikely that such an exercise would be carried out, as these costs vary from period to period, hence the sampling plans would be changed each period. Not a satisfactory state of affairs if the costs are to be evaluated every month.

One could also note that a series of sub-optimisations is not an optimisation of the overall system, hence a series of 'optimum sampling plans' would not necessarily minimise the overall costs.

The fourth type of model involves simulating the process with a mathematical model. Often this is done using regression analysis (62). Regression analysis is used to relate an output to a series of empirical inputs, in the form of a single mathematical equation.

There are a number of useful advantages of using the technique to set up a cost model. Amongst these are (62):-

- relating the product quality to various factors. This enables the effect of these factors on the overall product quality to be observed.
- where the measuring of an aspect of the quality system is costly, takes a long time or requires destructive testing, This aspect may be related to a number of other variables, which could then be monitored, thus monitoring the aspect indirectly.

There are many disadvantages in using regression analysis. One of these is that a detailed study is needed to define the relevant variables and constants of the equation. Once these have been set and a model developed, they cannot be altered without another detailed study to set up a new model. This is because they have an effect on each other as they vary (12). The result of this is that if a variable is removed from the equation, due to a change in the production situation, the other aspects will vary differently, and the true position would no longer be represented.

This means that regression analysis could not be used as an active means to monitor and control the costs of the system.

Generally the quality cost models available have four major deficiencies (60):-

- they analytically difficult
- they are complex and, thus, difficult and costly to manipulate
- they take the approach of a fixed interval between successive samplings.

- the cost components are assumed to be constant throughout the period which the optimisation takes place.

If one takes a look at many of the cost models developed (59)(61)(63)(64)(65) the first two of the above comments are obvious. If the model is to be used as a current means of control it should be simple and cheap to use. One must note that many of the complex cost models are for the use of the quality manager in setting his quality practices, and hence simplicity is not imperative, but these models, as noted earlier, do not provide a means of monitoring the process.

The person who is to take any action, as the result of costs and cost trends indicated by the process control model, is the production manager (50). He is generally not an expert in quality costs and cost models, and this is the main disadvantage of presenting a complex model to him. It is thus essential that he understands the model and what it is indicating.

## 4.2 DEVELOPMENT OF THE AIMS OF A QUALITY COST METHODOLOGY FOR PROCESS MONITORING AND CONTROL

The primary aim, as stated by Juran (16), of evaluating the quality costs and expenditures is to calculate an optimum level of quality of the product, which will minimise the costs of quality (16). As observed earlier this could be a sub-optimisation, because the optimum economic quality level found by considering quality costs alone is not necessarily that level which minimises the overall costs of manufacture.

Thus one needs to relate the quality costs to the overall costs. Also the quality costs must be isolated from variations caused by production volume change,so that the trends in variations of the quality costs may be observed.

We may thus say that three of the aims of using a model to evaluate quality costs are:-

- to relate the quality costs to the overall costs in order to see how any variation in the quality cost affects the overall cost of production.
- to set a level of quality which will result in the minimisation of the overall costs.
- to isolate the quality costs from the variations in costs caused by different production volumes and mixes, in order that current trends in the quality costs may be recognised.

As noted earlier, it is the Production Manager who is going to take any action initiated by the results of the model. Therefore it is essential that he understands the model, and what it is implying.

Hence one can add another aim:-

- The model must be analytically simple and easily understood by all those who are likely to use it. At the same time it must not be too simple, such that the costs calculated become approximations of no real value for the purpose of controlling the costs.

It has been observed that in many cases the reason for the failure of a method or technique was that the paper work necessary to manipulate the data was excessive (66). Another aim can then be added:-

- the paper work and the data manipulation required should be kept to a minimum, and should preferably be done at the same time as the periodic production cost analyses, using data that is already being collected.

The information presented by the model should be periodically investigated to determine how relevant it is, and of what use it is to the user. This would be one of the duties of the auditing team during the periodic quality audits

## 4.3 DIFFICULTIES INVOLVED IN RECOGNISING THE COSTS AND ANALYSING THE TRENDS

### 4.3.1 DIFFICULTIES INVOLVED IN RECOGNITION AND ISOLATION OF THE COSTS

Before any analysis may be done on the costs of quality one must define what costs constitute the costs of quality. Typical costs are shown in Appendices I, II and III.

Many of the costs which are attributed to the attainment of a set level of quality (quality costs) are often recorded as production costs(7). For the purpose of monitoring the quality function they are considered as quality costs, even if they are not physically charged to the quality department. This is in itself a problem, as the production department could attempt to "pass the buck" by disassociating itself from the costs as they are now monitored as part of the Q.A. function.

This illustrates a major problem in searching for the quality costs, that of how to allocate them to cost centres. As the Q.A. function spans the operations of almost all departments in a company, the quality costs cannot all be assigned to one cost centre, but rather to a number of different cost centres.

Another problem arises, in that many of the costs allocated to the quality activity are costs which are divided into more than one activity. An example of this is the salaries of the technical staff. they spend time maintaining and improving the processes, but it is difficult to determine how much of this time can be allocated to improvement in the quality of the product.

The time and money spent maintaining the machinery cannot be directly attributed to quality improvement , as the machinery has to be maintained to remain in a state to produce an output, but also to produce a quality output. This makes some of the costs of quality difficult to define and obtain.

Besides being difficult to define some of these costs are difficult to calculate once they have been defined. One cannot put a stop watch on an engineer, and hence only an estimate can be made of his time spent on quality related work. The result of this is that every period a number of difficult cost searches and estimations are required to obtain the quality costs for that period.

According to Juran (16) one should not use estimates when evaluating the quality costs. He says that initially estimates are fine, but once the costs are defined, accurate figures should be obtained and the departments accounting practices should be altered to reflect the costs. As indicated above, this could prove to be difficult.

As usual accounting practice isolates costs as fixed costs and variable costs for the purpose of monitoring the costs of the production, it seems reasonable that the quality costs could be separated and analysed in a similar manner.

## 4.3.2 FIXED AND VARIABLE COSTS OF QUALITY

The primary object of relating the quality costs to bases (See Chapter 3.3) is to isolate the cost trends by eliminating the effect that production volume has on the variation in quality costs.

One cannot do this simply by dividing through the number of units produced. This is because there are fixed and variable costs of quality. The fixed costs will not be affected by a change in the number of units produced, hence if the total cost is divided through by the number of units produced there will be a different per unit cost for each production volume. This effect is illustrated in fig 4.2. This variation in the per unit cost distorts the quality costs, and hence the per unit quality costs.

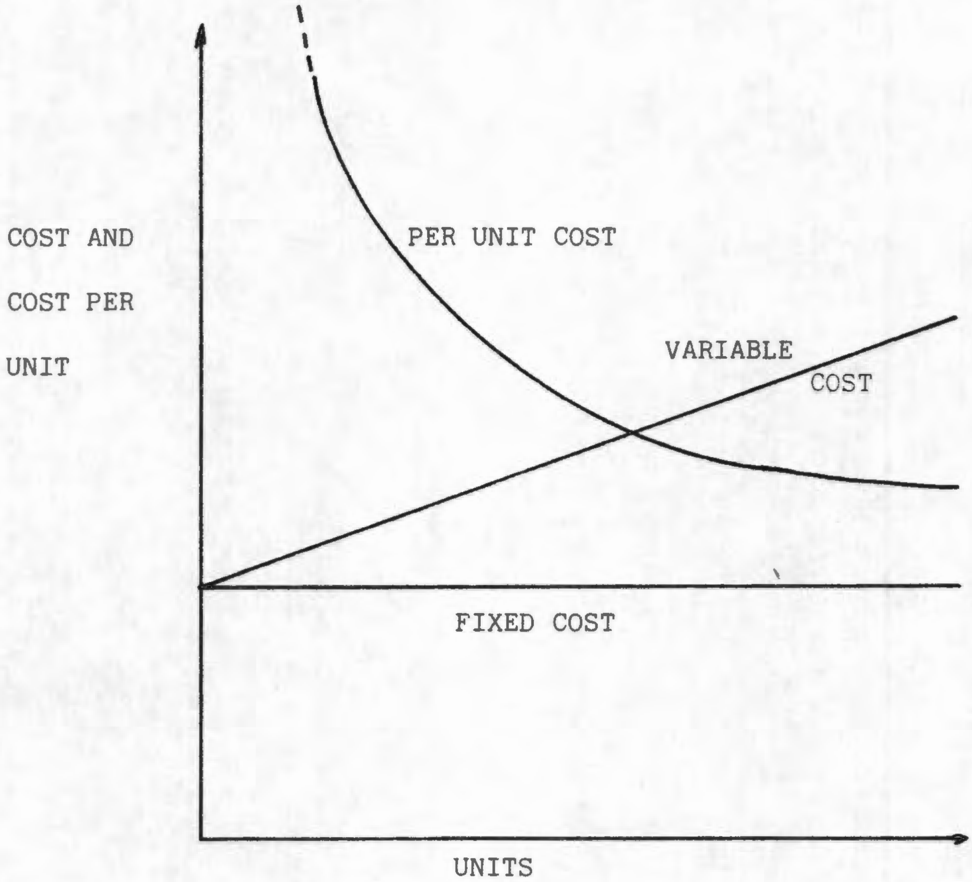


FIG 4.2 THE EFFECT OF VOLUME ON PER UNIT COSTS

In order to evaluate the costs of quality, to bring out the trends, the fixed and variable costs should be separated. The variable costs could then be evaluated on a per unit basis, and the fixed costs would be evaluated on an absolute basis. The trends in the operating quality costs of the department may be seen in the fluctuations in the variable costs. The fluctuations in the fixed costs would also be analysed for the reasons for changes.

An analysis of this nature would illustrate the costs which the production and quality departments have a control over, and those which they have little control over. Although they probably have control to a varying degree over almost all the costs, the degree to which these costs can be controlled is the important aspect.

This degree of control could be established by the continuous monitoring of the fluctuations in the quality costs observed after a control action has been made. Thus a type of transfer function for the plant may be established. This would enable the management to have a good idea of the result of an action, and the effect that the action has on the rest of the system.

Usually variable costs may be controlled more effectively than fixed costs, as they are normally incurred as part of the day to day running of the plant. On the other hand the control of fixed costs is on a more long-term basis. One should note that the variation in fixed costs could effect the variable costs, and hence they cannot be analysed in isolation from each other. This effect can be seen in the case where the fixed costs are increased by a capital expenditure on new machinery. This could have an effect of lowering the per unit production costs, hence affecting the variable costs.

When the costs are analysed, whether they are variable or fixed, another important aspect should be considered. This is whether or not the quality cost information falls into the "need-to know" or "nice-to-know" categories for purpose of monitoring the quality costs.

It is important that information, not just data, is presented to the respective managers for action (57). The crucial difference between data and information is that information contains facts which effect behavior (57). It is thus important that the data is filtered, and the information which the managers need to know is passed on. An investigation should be carried out to evaluate whether the quality cost information presented to the managers is of any value to them.

## 4.4 DEVELOPMENT OF A GENERAL SIMPLIFIED QUALITY COST METHODOLOGY

### 4.4.1 ASSUMPTIONS MADE IN CONSTRUCTING A SIMPLIFIED METHODOLOGY

The first assumption is that the department is currently operating in the zone of improvement projects (See fig 3.7) as defined by Juran (16). The result of this, represented in fig 4.3, is that the overall costs will decrease if more effort is put into improving the product quality.

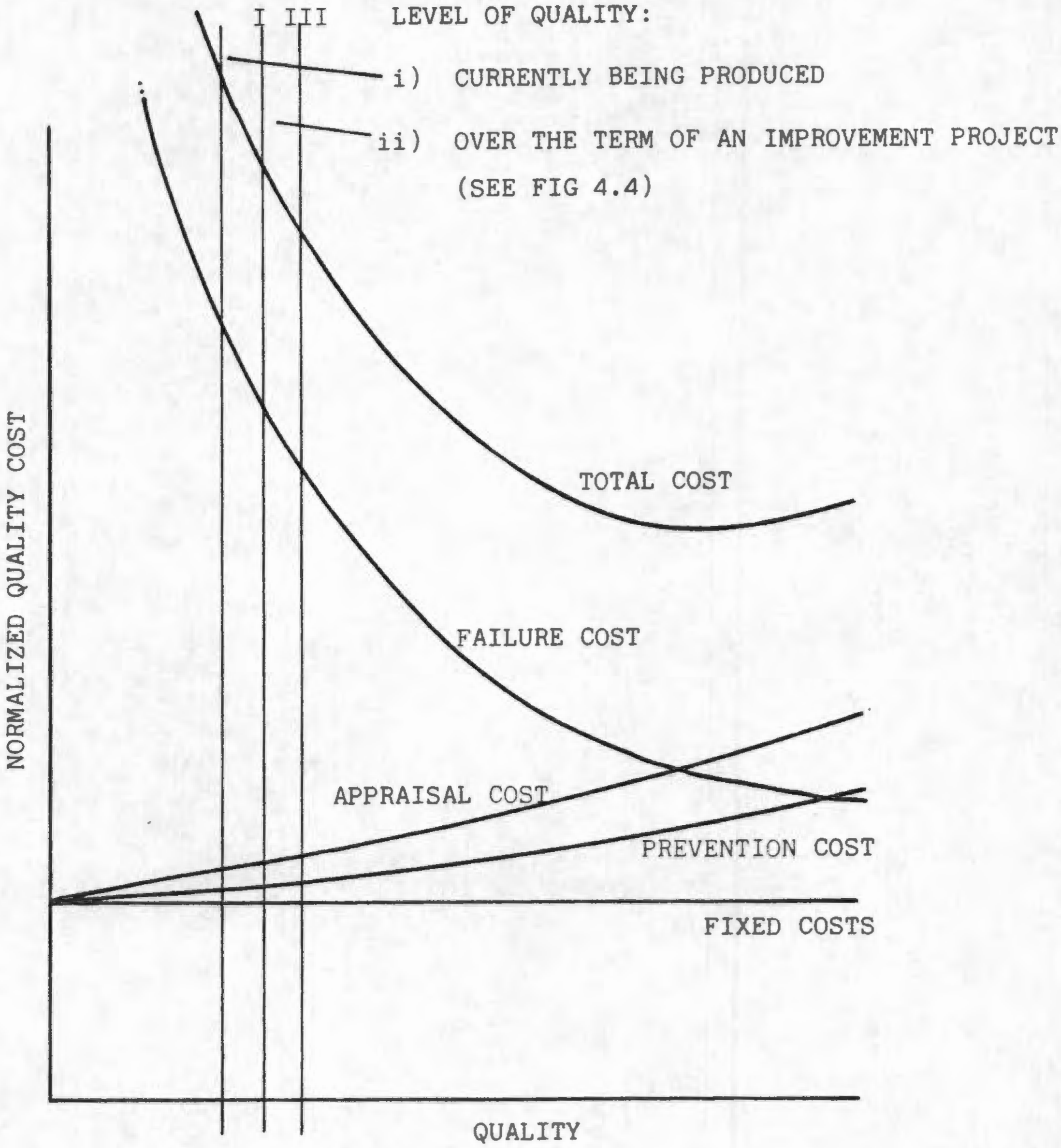


FIG 4.3 ASSUMED LEVEL OF QUALITY PRODUCED

The justification for this assumption may be found in almost any article on quality costs, where it is stated that generally companies are operating with too high failure costs and too low prevention costs. The recommended method of reducing the failure costs being to increase the expenditure on prevention (1)(15)(16)(27)(48).

The quality costs being evaluated are the normalized costs. Normalized costs being the cost of quality once the effect of varying production levels has been removed.

Related to the first assumption is the assumption that the quality costs will decrease in the next period, as the increased expenditure on prevention and appraisal reduces the overall costs. This will not always be true, as the benefits from an improvement project might not be evident in the review at the end of the next period. Thus the costs at the end of the next period could rise, due to the effect of increased prevention and appraisal costs and constant failure costs (See fig 4.4). As the effect of the improvement project becomes felt, the costs of failure will decrease. Thus one can assume that the costs will decrease, but not immediately.

The above assumption means that the manager will be able to see when the overall economic optimum point has been reached, from the point of view of expenditure to reduce costs.

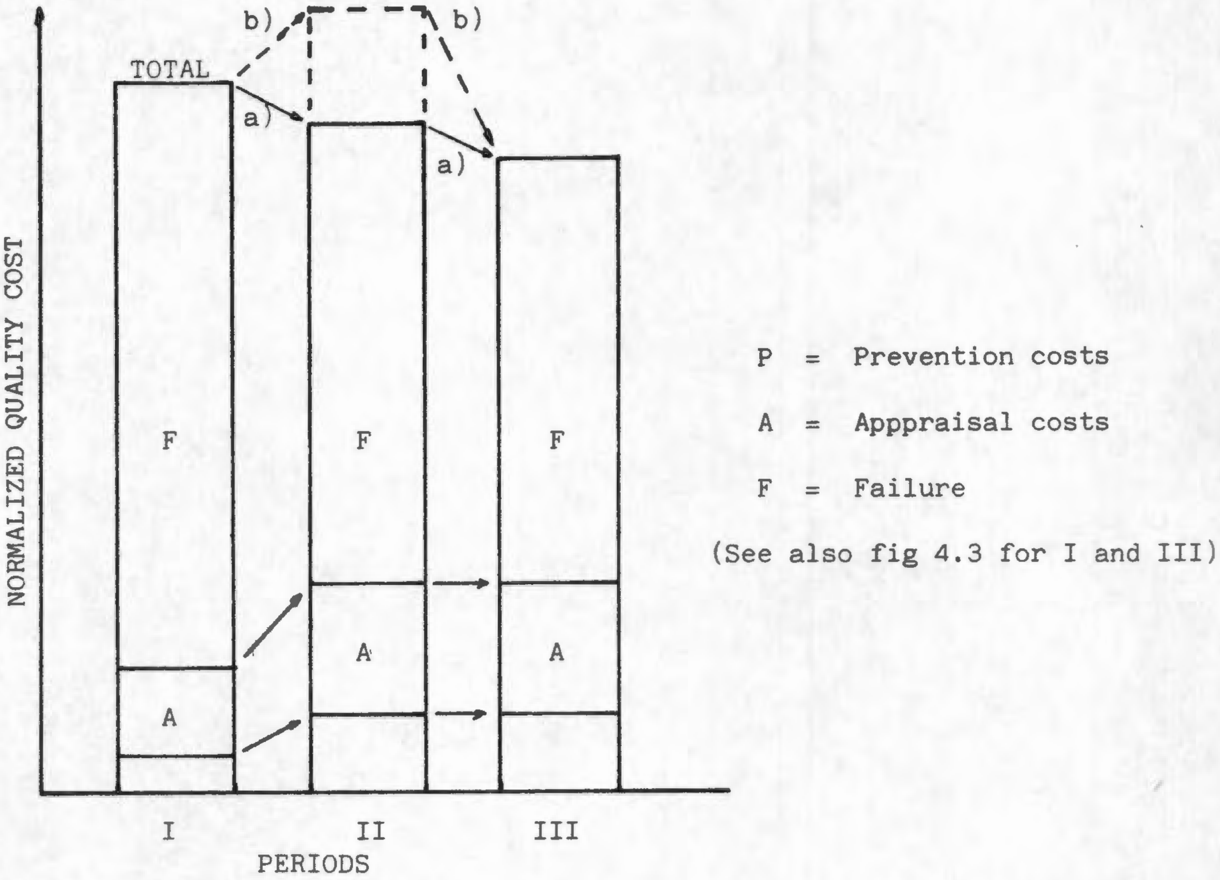


FIG 4.4 TRENDS IN TOTAL NORMALIZED QUALITY COSTS AFTER A QUALITY IMPROVEMENT PROJECT.

a) Assumed cost trend after a quality improvement project

b) Actual cost trend after a quality improvement project

He would then be able to attempt to reduce the appraisal costs much on the lines of the steps laid out on page 47. The costs would still be monitored, as reductions in either the prevention or the appraisal expenditures could lead to increases in the failure costs.

A third assumption is that the type of plant being discussed is a multi-product plant. Although the costs discussed here are applicable to services, with minor adjustments, the application to a service situation will not be considered.

## 4.4.2 GENERAL ISOLATION AND ANALYSIS OF THE COSTS OF QUALITY

As noted earlier, not all the costs of quality are easily found and if an extensive survey was required for each product in a multi-product plant, the method of quality cost analysis would soon fall into disrepair. Thus the quality cost information could save less than it cost to find and analyse the costs.

It would thus be advantageous if a simplified means were developed to find some of the quality costs from known cost information. Simplifications could include:-

- Allocating the particular cost to the fixed costs of quality. This would be done in cases like the salary of the quality manager. His time is directed to the quality of the products, in different proportions over different intervals. As mentioned previously these fixed costs would be analysed as a total, rather than allocated to individual products then analysed.
- the quality cost information which is difficult to obtain directly could be found indirectly by manipulation using other known costs (See section 4.4.4)
- difficult costs could also be found by relating the cost to

other known costs. As these known costs vary, the variation in the wanted cost could be found. This is a similar principal to that used in regression analysis.

The costs would be separated into their respective categories (See Appendices I, II and III), and into fixed and variable costs. Trends would then be shown from the variations in these costs once they have been normalized. (See Section 4.4.8)

### 4.4.3 OUTLINE OF THE STRATEGY FOR THE GENERAL SIMPLIFIED COST METHODOLOGY

A basic strategy of a general simplified model to monitor and analyse the costs of quality could be:-

- to identify the costs to be monitored, and allocate them to one of the four categories of quality costs.
- to attempt to devise simple and indirect means to find the costs which are difficult to monitor directly.
- to divide the costs up into fixed costs,(independent of production volume) and variable costs,for analysis.
- to reduce the variable costs to a per unit cost by using some form of a base, and analyse the trends of the per unit variable costs.
- to look at the fixed costs for reasons for variation in their magnitude.
- to attempt to relate the quality costs to the overall costs, and to investigate the effects that variations in the effort put into improving the quality have on the overall costs.
- to present the costs in a form that the trends may be easily picked out, and the products or processes which are the greatest cost causers would be highlighted.

In the next four sections the costs in each category are looked at, along with a simplified way of finding thest costs. Methods of finding the trends in the quality costs is discussed in section 4.4.8, with particular attention being paid to finding a way to eliminate the effects of varying production volume and mix.

### 4.4.4 INTERNAL FAILURE COSTS

Typical internal failure costs are shown in Appendix IA. Generally the costs allocated to this category are:-

- costs of scrap of the product and raw materials
- costs of reworking the product
- costs of handling the scrap and reworked product
- costs of the engineering and staff associated with scrapping, reworking and handling of the product.

Usually many of these costs are reported to the production department as part of the production costs, but often not in a form from which the quality costs can be extracted directly. It would, for example, be difficult to calculate how much raw material was lost in any process. Using an indirect approach with known costs, the cost of internal failure may be obtained.

When the constituent costs of the internal failure category are looked at one notes that many of them are costs which would have been added onto the manufacturing cost in the form of an overhead when the selling price of the product was found. An example of this is the cost of the engineering staff associated with production. It would therefore be representative to use a similar method to calculate the proportion of these costs which can be apportioned to the quality activity.

As many of the internal failure costs are difficult to obtain directly, an indirect approach, using known cost values to find the unknown values, is used. A diagramatic representation of the material flow during production is shown in fig 4.5

In any process there will be losses due to the quality requirements, and losses due to production factors such as set up waste etc. The two should be separated, as they are not both attributable to the achievement of the product quality.

If the process were 100% efficient the amount of first class product out (2. in fig 4.5) would account for all the raw materials which are put into the process ( 2.). This is never so, and the difference (3.) can be attributed to a number of causes. This difference can be found. as the amount of raw materials into the process is known, and the amount of apparently first class products (apparently because not all the faults are found. See external failures, section 4.4.5), which leaves the plant is also known. The difference can thus be found by subtracting the amount of first class product out from the amount of product that would have been produced with 100% conversion in the plant.

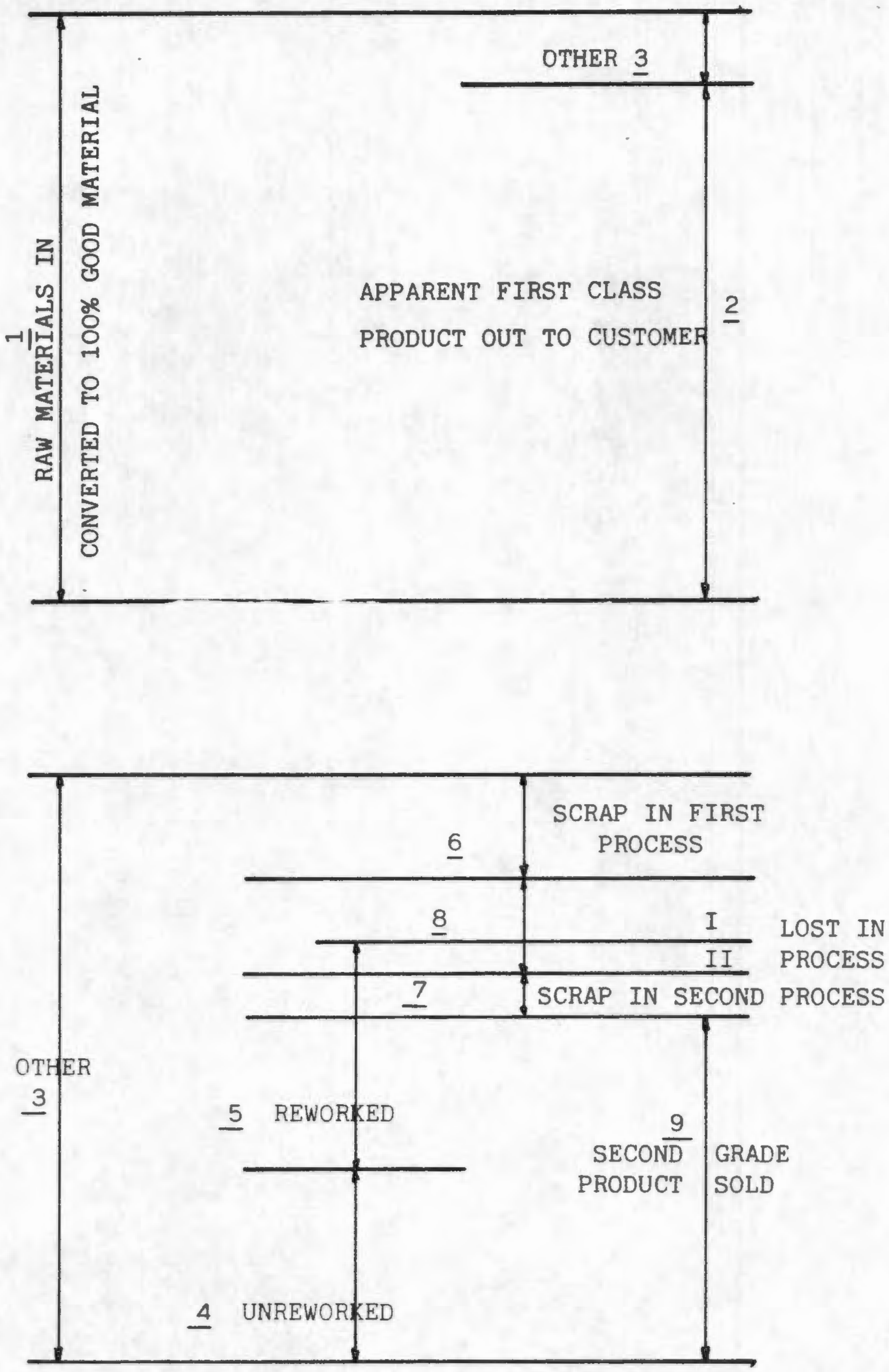


FIG 4.5 REPRESENTATION OF INTERNAL FAILURE COST CALCULATIONS BY A SIMPLIFIED METHOD: MATERIAL FLOW

NOTE: If the Q.C. tests are destructive, the cost of the raw materials and the value added in the process should be subtracted from this figure and from the equation set up in Fig 4.7. This is discussed in Section 4.5.4.

Also if a reworked product is sold as a first class product, it comes into group 2.

Of this 'other product' (See 3 on fig 4.5) some is sold directly as second grade material, without any rework ( 4 ), and some of it is reworked (5 ) As noted above not all the waste is due to quality, hence the production and quality waste must be separated. The production waste (8 ) is considered lost in the process, both on the initial run and on the rework run. These are split up and shown as 8 I and 8 II in fig 4.5. After both processes there will be a certain amount of material scrapped by the quality department as unsuitable for sale or rework. This loss is shown as 6 for the initial process and as 7 for the rework process. The total of the second grade material sold is shown as 9 in fig 4.5. The "knowns and unknowns" of fig 4.5 are shown on fig 4.6, along with how the "unknowns" are calculated rather than measured.

| KNOWN | TYPICAL SOURCES | UNKNOWN | HOW CALCULATE |
|---|---|---|---|
| 1 | PROCESS INPUT RECORDS | 3 | 100% CONVERSION OF 1 MINUS 2 |
| | | 8 | 3 - (9 + 7 + 6) |
| 2 | PACKING/DISPATCH RECORDS | | |
| 4 | PROCESS OUTPUT/ DISPATCH RECORDS | | |
| 5 | PROCESS RECORDS | | |
| 6, 7 | Q.C. RECORDS | | |
| 9 | SALES/ Q.C. RECORDS | | |

FIG 4.6 CALCULATION OF THE UNKNOWNS OF FIG 4.5

Having calculated the costs associated with the material flow through the plant, the internal failure costs associated with this material flow must be found. As noted above, the "overhead-type" quality costs may be accounted for by adding them to the direct quality costs as an overhead on a pro-rata basis i.e., units of overhead are proportioned to units of product.

Fig 4.7 shows an indirect means of calculating the overall internal failure costs using data drawn from figs 4.5 and 4.6. The material lost due to quality failure is A - E as shown on fig 4.7. This is the overall material loss minus that loss due to production, not quality related factors.

The engineering, staff, handling costs due to scrapping and reworking the product are covered for by the terms B and D in fig 4.7, in the form of a loss of contribution. The direct cost of reworking the product through any number of processes is accounted for by term C . This would account for reworking any product, which has been reworked and has failed again, if this is economically viable.

By approaching the internal failure costs indirectly in the manner described above there is a slight distortion due to the inclusion of a profit loss in terms B and D . If one wanted to be exact, the profits could be cut out of the terms in B and D , but to retain a simple model using known data, this is not done. The effect should not be significant, even if the company is making a large profit on its products. Also, loss of sales has a greater impact on management than an internal loss .

FIG 4.7. MATHEMATICAL REPRESENTATION OF INDIRECT MEANS OF CALCULATING INTERNAL FAILURE COSTS

$$\text{INTERNAL FAILURE COSTS} = \overset{\underline{A}}{\left(\text{Total raw material cost}\right)\left(\frac{100 - \%\text{ Product Sold}}{100}\right)}$$

$$+ \overset{\underline{B}}{\left(\begin{array}{l}\text{Total possible selling value - Total selling value realized}\\ \text{(second class product un-reworked and sold)}\end{array}\right)}$$

$$+ \left\{ \sum_{1}^{i} \overset{\underline{C}}{\left(\text{Labour Cost + Process Cost}\right) \Big/_{\text{unit}} \left(\begin{array}{c}\text{Units rerun through}\\ \text{process } i\end{array}\right)} \right.$$

$$\left. + \overset{\underline{D}}{\left(\begin{array}{l}\text{Total possible selling - Total selling value realized}\\ \text{(second class product reworked and sold)}\end{array}\right)} \right\}$$

$$- \overset{\underline{E}}{\left(\frac{\%\text{ Production loss}}{100}\right)\left(\text{Raw material cost}\right)}$$

Note:

1. This figure should be looked at in conjunction with fig 4.5 which lays out the costs diagramatically.
2. This evaluation could be used for each product individually, or for all the products together, and the costs could be normalised using equivalent units of production (See Appendix IV for a sample calculation of equivalent units of production).
3. This general representation will not hold in all cases, and minor adaptions might be needed to retain its simplicity.

This method by its approach has included both the fixed and variable costs of internal failure as a variable cost. For internal failure costs, this is not unreasonable as one would expect to find the internal failure costs varying in proportion to the volume of manufacture.

### 4.4.5 EXTERNAL FAILURE COSTS

Typical external failure costs are shown in Appendix IB. Generally the costs allocated to this category are those which are incurred by the product failing once it has left the factory. In the previous section in fig 4.5 it was noted that the amount of apparent first class product was known. "Apparent", because the final inspection of the outgoing product is not 100% foolproof and there will be a certain amount of faulty product which will leave the plant undetected.

This undetected faulty product is the cause of the external failure costs. The category comprises not only the cost of replacement of the product, but the associated costs of handling, investigations, fitting of replacement etc. There are also the costs of damages resulting from liability suits. These damages are caused by the failure of the product, and could be awarded in court (See introduction).

The external failure costs of each company vary with that company's policy. Most companies investigate the claims to some degree. This involves sending a man to where the product has failed, or arranging for the product to be returned to the plant or to an agent. The salaries of the investigations would be a fixed external failure cost, as they will not vary directly with volume, only with the number of investigations necessary.

Sometimes the people who do the external failure investigations are technicians from the production department. If they were investigating failures full time, their salaries would be considered a quality cost, however, often the number of failures does not warrant a full time investigator, and in this case the salary of the technician could not be directly attributed to quality costs. If the selling value of the product is 'charged' to the external failure quality costs the salaries of the investigators will have been accounted for when the department's overheads were added, to the manufacturing cost, to obtain the selling price of the product.

When analysing external failure costs, each case will be different, hence a simplification of the cost search would be to identify the possible costs when a failure occurs, and look for these in each case, rather than to attempt to mathematically simulate the situation. A combination of a number of costs would be investigated Amongst these are:-

- costs of the investigation into the failure, including salaries and travel costs of investigators, and the costs of testing the failures to ascertain the reasons for the failure. This would also include the cost of negotiating credits and reworking in the customer's plant.
- the credits given to the customer. This might be the full or part of the selling value of the failed product.
- the cost of disposing of the product, either paid to the customer or incurred in returning the product to the factory. This would include the additional handling charges incurred.

- the cost of replacing a product, including the cost of fitting and testing of the replacement.

The investigation of some of these costs will be discussed with respect to the case studies in chapter 5.

There a number of intangible external failure costs, which cannot be measured and hence have been excluded. An example would be, lost sales due to poor quality. One way to find this cost would be to improve on the quality and monitor the sales variations.

### 4.4.6 APPRAISAL COSTS

When a production manager thinks of quality costs it is usually part of the appraisal costs that he thinks of. This is because many of the costs which can be directly attributed to obtaining a level of quality fall into the Appraisal category. Typical appraisal costs are shown in Appendix II.

A great many of the cost models which have been developed are used to find optimum cost sampling procedures, by considering some of the external failure costs and the costs of sampling. As noted earlier these models tend to be sub-optimisations as they usually do not consider all the costs involved. Typical examples of such models may be seen in references 60, 61, 64 and 65. Generally these models are complex and difficult to use, and they usually are not constructed to be used for monitoring.

As the actual costs of appraisal are wanted, the use of complex probabalistic theory is minimised. This is a major simplification, as the theories of quality costs using probabilities can be difficult to use, and for the control model to be current the probabilities have to be up-to-date. The maintenance of current probabilities can be costly, as the process has to be analysed on an ongoing basis to find them, but they cannot be totally excluded as some of the operating parameters of the plant relevant to quality costs can only be estimated. An example of this would be the actual number of inspections needed in the period. These will vary with the percent of product which passes the inspection, and how much has to be inspected at a higher level due to failure at the first level of inspection. (See fig 4.8 1b)

The appraisal cost category is possibly the easiest of the four categories to monitor, as it is mostly directly under the control of the Q.A. department. The costs of this category are summarized in fig 4.8.

The most obvious cost is that of the inspectors and the related costs of inspection. In many cases each inspection has an associated material cost. This includes the cost of the sample taken for sheet inspections and if the test is destructive the value of the part tested is included. (See fig 4.8 1a) The cost of the inspectors includes his wages and also any benefits which the company gives him, like pension fund contributions. The actual number of inspectors needed to carry out the work load can be found from the number of inspections required to assure the quality of the production volume. The minimum number for the work load has been calculated (See fig 4.8 1b), but the actual number should be greater than this to allow for factors such as sickness and leave. A short time-study would give the production manager an idea of the staff levels needed to fulfil the inspection requirements. The wages etc, of the direct supervision also falls into this category. Usually Q.A. personnel who are not directly involved with the supervision do not fall into the appraisal cost category, rather into the prevention category.

When analysing the appraisal costs for trends they are split up into fixed and variable costs. A great many of the costs involved are unrelated to the volume of production, and hence are considered to be fixed. These costs consist of the salaries of the supervisors and staff of the department directly involved in the inspection etc, of the product, and costs of many of their related activities (See fig 4.8)

## FIG 4.8 SUMMARY OF ACTUAL APPRAISAL COSTS

### 1. INSPECTION AND TESTING

a) MATERIAL COST OF INSPECTIONS

$$= \sum_{1}^{i} \left( \text{MATERIAL COST} \big/ \text{UNIT INSPECTION} \right)_{i} \left( \begin{array}{c} \text{NO OF INSPECTIONS} \\ \text{OF TYPE } i \end{array} \right)$$

Note: If the test is destructive the material costs and value added in the process comes into this category.

b) COST OF INSPECTORS

$$= \sum_{1}^{i} \left( \begin{array}{c} \text{WAGES ETC OF INSPECTORS} \\ \text{OF CLASS } i \end{array} \right) \left( \begin{array}{c} \text{NO OF INSPECTORS} \\ \text{IN CLASS } i \end{array} \right)$$

Note: There is a minimum number of inspectors needed to carry out the inspection load effectively without going into overtime. A sample calculation for two cases is shown below.

A. PRODUCT = UNITS IN LOTS
SAMPLE SIZE = $n$
LOT SIZE = $N$
NUMBER OF LOTS/PERIOD = $L$
ASSUME 2 LEVELS OF INSPECTION
1. SAMPLING 1. 100%
OVERALL AVERAGE PROBABILITY OF FAILURE OF A LOT = $p$
MINIMUM NUMBER OF MEN NEEDED = $S$

B. PRODUCT = SHEET
ASSUME A 3 TIER SAMPLING SYSTEM, INITIAL, STEPPED UP, EFFECTIVELY 100%
INITIAL SAMPLING FREQUENCY = $f_1$ TIMES/UNIT
STEPPED UP SAMPLING FREQUENCY = $f_2$ TIMES/UNIT
100% SAMPLING FREQUENCY = $f_3$ TIMES/UNIT
OVER AVERAGE PROBABILITY OF FAILURE
OF INITIAL INSPECTION = $p_1$
STEPPED UP INSPECTION = $p_2$

FIG 4.8 cont.......

TIME/INSPECTION = $t$

NO OF WORKING HOURS/PERIOD/MAN = $T$

REQUIRED INSPECTIONS/PERIOD = $M$

$$M = nL + pL(N - n)$$

$$S = \frac{tM}{T} \text{ MEN}$$

NO OF UNITS/PERIOD = $U$

NO OF INSPECTIONS/PERIOD = $M$

$$M = Uf_1 + UP_1 f_2 + UP_1 p_2 f_3$$

$$\therefore S = \frac{tM}{T} \text{ MEN}$$ ($t_1 T$ as for case A

---

c) COST OF DIRECT SUPERVISION

$$= \sum_{i}^{i} \left(\text{WAGES ETC OF SUPERVISORS OF CLASS } i\right)\left(\text{NO OF SUPERVISORS IN CLASS } i\right)$$

Note: Usually the cost of a man to a company is more than just his wages. Things like pension benefits, medical aid, etc paid by the company should also be included.

2. MAINTENANCE OF INSPECTION AND TEST EQUIPMENT

a) CALIBRATION

- cost of time taken by instruments technicians
- cost of outside contractors for instruments which cannot be handled internally

b) REPLACEMENT OF PARTS

- the cost of the spare parts used to maintain and replace the instruments

3. LABORATORY SERVICES

- the company's type of operation will dictate how the laboratory is charged. It could also come into the cost of the inspection and testing 1(a) above.

FIG 4.8 cont.......

4. SHORT TERM ASSURANCE AND TESTING

a) RETESTING AND REINSPECTION

$$= \sum_{1}^{i} \left( \text{MATERIAL COST} / \text{UNIT REINSPECTION} \right) \left( \begin{array}{c} \text{NO OF REINSPECTIONS OF} \\ \text{TYPE } i \end{array} \right)$$

$$+ \sum_{1}^{n} \left( \begin{array}{c} \text{WAGES ETC OF INSPECTORS} \\ \text{OF CLASS } n \end{array} \right) \left( \begin{array}{c} \text{NO OF INSPECTORS OF} \\ \text{CLASS } n \end{array} \right)$$

$$+ \sum_{1}^{m} \left( \begin{array}{c} \text{WAGES ETC OF DIRECT SUPER-} \\ \text{VISORS OF CLASS } m \end{array} \right) \left( \begin{array}{c} \text{NO OF DIRECT SUPER-} \\ \text{VISERS OF CLASS } m \end{array} \right)$$

Note: Often the retesting and reinspection is not done by the the inspectors, but rather by an indirect supervisor, and hence the cost would fall into the fixed costs of the department.

b) CHECKING OF CALIBRATION OF INSTRUMENTS AND RECORDS

- this is usually done by the staff of the quality department, and hence is a fixed cost of the department.

c) TESTING ON THE QUALIFICATIONS OF THE INSTRUMENTS USERS

- a fixed cost of the department, to find out if the instruments can be used, and used properly.

### 4.4.7 PREVENTION COSTS

This category of costs is the most difficult to measure and evaluate, (67) as most expenses are incurred by time spent on the activities by staff who do not work full time on quality problems. These people also spend varying times on quality each period. Typical examples of these costs may be seen in Appendix III.

Most of these costs are costs incurred by planning, designing and evaluating the quality system, and designing the product and implementing the design to prevent the failures from occurring. The exception to this is the case of incoming materiels inspection, which is a prevention cost as it is incurred in preventing the faults entering the system. Some argue that it is an appraisal cost, but by definition it is a prevention cost (22).

The costs of incoming inspection may be found by using the same type of format as shown in Fig 4.8 for in-process and final inspection, but it would apply to incoming inspection instead. The laboratory costs which are incurred testing the incoming materiels are also allocated to this category.

A part of the costs in this category are incurred in quality improvement projects which have been initiated as the result of previous cost analyses and subsequent investigations. As noted earlier one of the aims of evaluating quality costs is to see the effect that improvement projects have on the overall costs.

A large portion of the costs allocated to this category are fixed i.e. independent from production volume. This is because many of them are caused by staff functions, as a part of the introduction of a new product, for example the costs of design reviews and planning of the quality system for that product. This sort of activity will involve a high initial cost, tailing off once the product is successfully introduced. If the company is continually introducing new products, this tendancy would not occur as there would be a continuous flow of new product design evaluations and implementations.

Although these costs are usually independent from production volume, and hence can be allocated to the fixed cost category, they still have to be measured as they vary from period to period. It has been stated (5)(16)(42) that more effort and expenditure on prevention reaps greater benefits in the form of reduced failure costs. Thus one has to monitor these costs closely.

A basic summary, of some of the activities which comprise this category, is shown in Fig 4.9. The difficult activities to monitor are those executed by staff from departments other than the quality department. The salaries of the quality staff and the costs incurred by the quality activities, other than those involved directly with appraising the quality of the product (See section 4.5.4), come into this category. As the quality staff are involved in these activities one does not need to identify their individual contributions, as when they are summed they will equal the whole quality department cost (less the costs of appraisal).

FIG 4.9 SUMMARY OF FIXED* PREVENTION COST ACTIVITIES

1. Planning of the system.
2. Design and testing of inspection and testing equipment.
3. Supplier evaluation.
4. System audits.
5. Training of Quality and Production personnel.
6. Product design and implementation surveys.
7. Quality improvement projects.

* Fixed from the point of view of production volume.

Usually within a company some of the activities allocated to this category are budgeted for in other departments. An example of this could be the costs of training quality staff and production staff in quality methods. If the company has a training school this will come under the budget for the school rather than as a quality activity. The resulting cost could then be obtained from the cost of the training course and the total of the time spent by staff on the course.

When attempting to evaluate the costs of prevention, one should keep in mind one of Juran's (16) statements. He said that the costs of prevention are optimised when they are all controlled by a budget, and accounted for by planned projects. This means that there would be very little 'fire-fighting' type situations, where the faults have to be corrected due to a lack of preparation. Thus to be able to evaluate the costs of prevention with a minimum of estimations the activities should be controlled by a budget, hence they would be reported as they occur.

One of the most difficult costs in this category to isolate is that of maintenance to the machinery, attributable to quality improvement. It has already been observed that the machinery has to be maintained in order to produce, but also to produce a quality output. Often much of the maintenance is initiated for reasons which can be directly attributed to the attainment of the specified level of quality. This would be when the machine was still capable of producing the specified amount of product, but the quality of the product would not be first class. This would be considered a variable quality cost, as the amount of maintenance to produce the specified product quality would be related to the amount of product made on that machine.

By isolating the costs of maintenance incurred for quality reasons, the amount of effort put into attaining the level of quality can be found. Also a relationship between the quality of the product and the maintenance needed to attain the quality level may be found. Thus if there is a relationship, the quality can be directly controlled by varying the amount of quality related maintenance.

### 4.4.8 ILLUSTRATION OF TRENDS

In order to evaluate the trends in the costs of quality, from period to period, these costs have to be compared independantly from production volume. It was noted earlier that only part of the costs of quality vary with the production volume, hence for the purpose of trend analysis the dependent and independent (variable and fixed) costs should be separated.

As the overall quality cost trend is wanted, these costs have to be recombined to draw trends from the overall quality cost variations. Shown in Fig 4.10 is a means of recombining the fixed and variable sections of the costs for a multi-product plant, so that the recombination is independent of actual production volume. In order to 'normalize' the variable costs, and to recombine the fixed and variable costs, the actual variable costs per unit product for the period are multiplied by a constant number of units. This constant number of units is a typical production volume, which is kept constant for say a year, then revised. Thus, the variable costs that would have been incurred for a constant volume of production can be found, and hence the total of the normalized quality costs is independent of production volume, and trends may be drawn. (See Fig 4.11 for a typical plot of Nj)

The reason why a typical production amount was selected to normalize the variable costs, was to bring the magnitude of the variable costs back up to the same order as that of the fixed costs. This is so that the two can be combined to draw trends from the total quality costs, independent of production volume. A disadvantage of this approach is that the actual total quality costs are not shown, but as noted these are not independent of production volume, hence trends cannot be directly drawn from them. One would also display the total quality costs against the total production costs, as this relationship is also important.

FIG 4.10 NORMALIZATION OF FIXED AND VARIABLE COSTS OF QUALITY FOR THE PURPOSES OF PERIODIC COMPARISON

ACTUAL FIXED COSTS IN PERIOD j = Fj

ACTUAL VARIABLE COSTS FOR PRODUCT GROUP i IN PERIOD j = vij

ACTUAL UNITS OF PRODUCT GROUP i PRODUCED IN PERIOD J = aij

*REPRESENTATIVE PRODUCTION VOLUME OF PRODUCT GROUP i (CONSTANT) = mi

NUMBER OF PRODUCT GROUPS PRODUCED = n

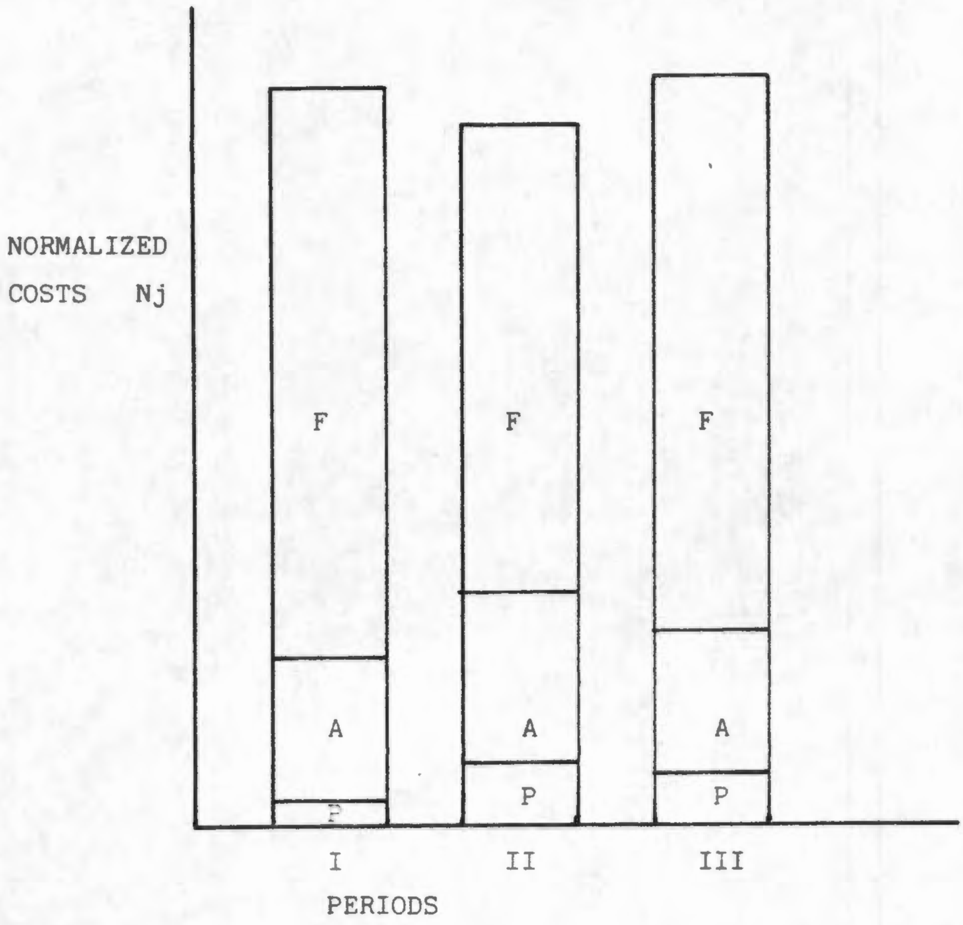
NORMALIZED QUALITY COSTS FOR PERIOD j = Nj

$$Nj = Fj + \sum_{i=1}^{n} \left( \frac{vij}{aij} . \ mi \right) \qquad \text{PLOT Nj for PERIOD j}$$

ACTUAL FIXED COST + NORMALIZED VARIABLE COST

NOTE: The figure selected as a typical month's production remains constant, unless the volume of that product changes significantly. If the volume varies widely from month to month, the value used could be the previous year's production averaged out to an average monthly production.

FIG. 4.11 A TYPICAL PLOT OF NORMALIZED COSTS



As the fixed quality costs in a multi-product plant are incurred in the manufacture of all the products, they cannot be divided up for the purpose of analysing trends in individual products. Hence to do a trend analysis for individual products/product groups, trends in the variable costs should be analysed. These should be done on a per unit basis, so the costs may be compared from period to period, independent from production volume.

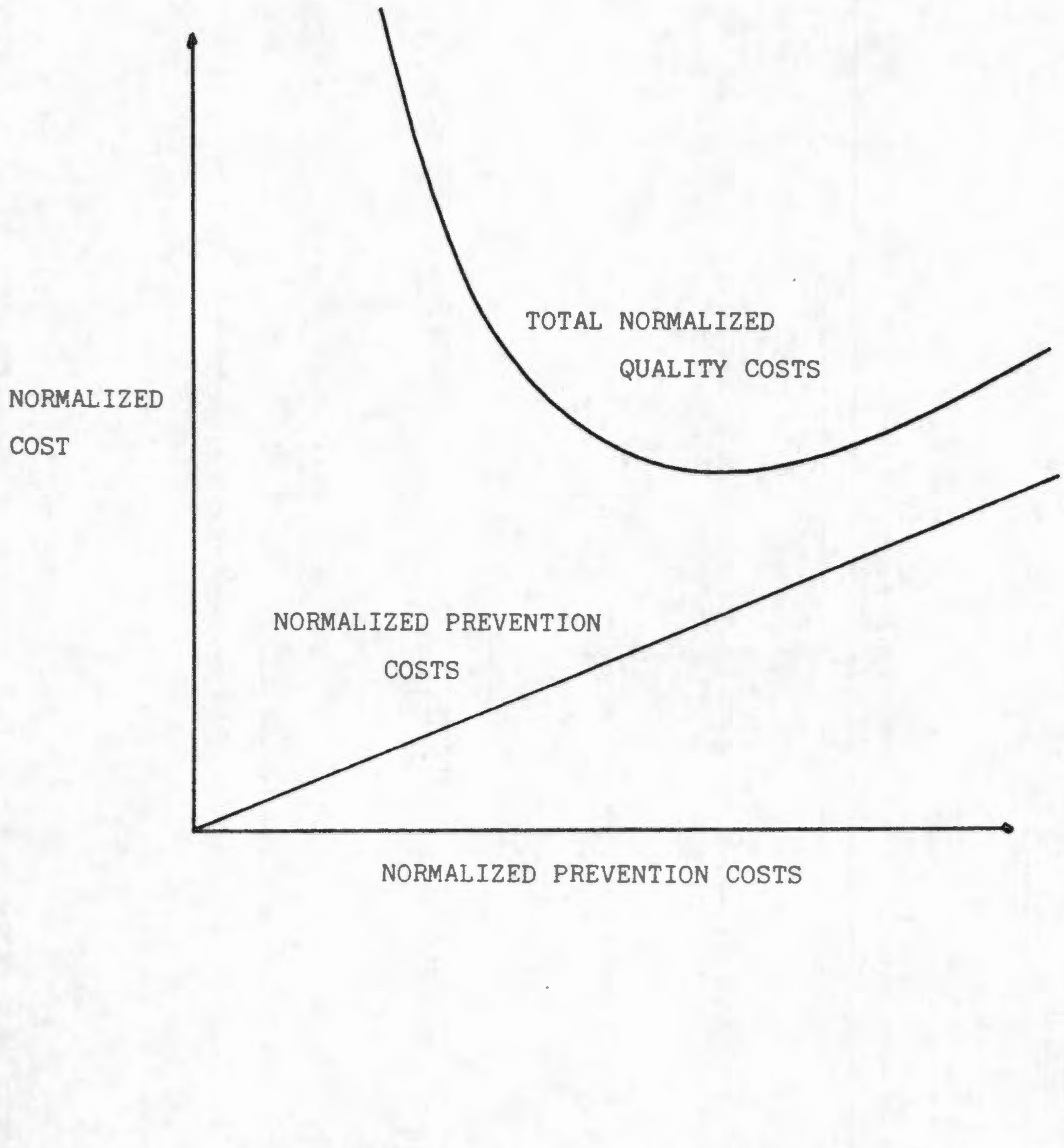
The disadvantage of the analysis of the cost trends using only the variable costs, is that the failure costs are mostly variable costs (See Section 4.4.4 and 4.4.5), while the prevention costs are mostly fixed with respect to production volume (See Section 4.4.7). As the effect of increasing the expenditure on prevention on the failure costs is the major trend which we wish to illustrate, this can make the trend analysis difficult. If the report to management is well documented with details of the efforts in prevention and appraisal expenditures for the products detailed, this disadvantage should not prevent the trends from being illustrated. Even so, the trends should be illustrated when the overall quality cost trends are drawn in relation to the overall costs of manufacture, using graphical methods similar to those shown in fig. 3.15 and 3.16.

The main trend which we wish to establish from plotting the normalized quality costs is to observe how the quality costs vary against the effort put into improving the product quality. Thus the normalized costs should be plotted against the normalized prevention costs. If the general theory that an increase in prevention costs holds in the case being analysed, a curve similar to that in Fig 4.12 will be obtained.

This will indicate an optimum amount of prevention effort necessary to minimise the quality costs. One could also plot the total normalized quality costs against the sum of the normalized prevention and appraisal costs, to show similar trends.

FIG. 4.12 PLOT OF TOTAL NORMALIZED QUALITY COSTS AGAINST NORMALIZED PREVENTION COSTS

NOTE: The curves are shown through points found over a number of periods of varying prevention effort



One should note that time lags are a big problem in an analysis of this nature. The time lags effect the cost analysis in a number of ways:-

- the delay between the product leaving the factory and the fault being discovered by the customer, can mean that the external failure costs are reported out of phase with the other costs.
- there is also a delay between the reporting of a fault and action being taken to investigate the fault, and if necessary the crediting of the customer's account. This further delays the reporting of the external failure costs.
- once the quality improvement projects have been initiated, the effect on the failure costs will not be felt for some time, but the overall costs will rise, as there is more being spent preventing the failures from occurring. This effect has been noted earlier (See fig 4.4).

Thus, when the trends are being drawn at the end of a period, care should be taken to ensure that the costs used are relevant to the period being evaluated. A delay might be necessary to allow for failure costs to be gathered, but one cannot delay too long for a potential failure, or the current value of the trend analysis is lost.

### 4.4.9 SUMMARY OF THE STEPS USED IN A SIMPLIFIED QUALITY COST ANALYSIS

One of the objectives of the thesis is to establish a simplified methodology for analysing the costs of quality. The following is a summary based on the arguments of the previous two chapters.

1. The first step is to identify the costs which constitute the costs of quality for the department being investigated. These can then be allocated to the respective quality cost categories which have been discussed in Chapter 3.1 and Appendices I, II and III.

2. Secondly, the source of each cost must be studied to ascertain whether the data can be easily collected and whether they are currently reported routinely. See chapter 4.3 where the difficulties in isolating the costs are discussed.

3. If the costs which are not being currently monitored/reported cannot be directly isolated, then indirect techniques such as those presented in section 4.4.2 can be used. These techniques are briefly summarized as follows:-

    - Indirect methods of finding the costs by manipulating other known costs (See fig 4.6)
    - relating the cost to other known costs and monitoring those known costs (the principle of regression analysis, see Chapter 4.1)
    - monitoring a number of quality costs as a single sum which can be found,rather than isolating the constituent costs of the sum. (See fig 4.8, part 4b and c)

4. The next step, where possible, is to develop heuristic 'models' for each quality category, in order to simplify the isolation of the costs, for example the model shown in fig 4.6 and 4.7 for internal failure costs. The type of heuristic model will vary with each situation. This will be demonstrated using the case studies in the next chapter. In the situation where a simplified method cannot be developed, for example in the case of external failure costs (see section 4.4.5,) a list of all the possible costs should be drawn up, and each case investigated using this list. The output of these heuristic 'models' would be used to compile the quality costs for analysis.

5. For the purpose of analysing the trends, the costs are then subdivided into fixed and variable costs i.e., those independent of, and those dependant on production volume.

6. The quality cost data is plotted, and analysed by observing the variations(See figs 4.11 and 4.12). To analyse the trends, the distorting effects of variations in the production volume and mix must be removed. A suitable method, manipulating the fixed and variable costs, is shown in fig 4.10. The trends in both the normalized costs (independent of production volume and mix), and the actual costs are wanted, hence both must be plotted in a suitable form (See figs 3.15 and 3.16, and figs 4.11 and 4.12).

7. Finally these costs and cost trends must be analysed and inferences made. The aims of such an exercise can be briefly summarized:-
    - to find an optimum level of product quality which would become the target for the production department. (See figs 3.5, 3.6, 3.7 and 4.12)

- to highlight aspects of the production systems which are causing the highest quality costs. Hence indicating areas where further quality improvement projects would probably be most beneficial as discussed in chapters 3.4 and 3.5.
- to monitor the results of prevention projects in terms of actual benefits against predicted benefits (See section 3.4.4)
- to establish the optimum amount of effort to be put into quality improvement which would result in the lowest overall costs (See fig 4.12). The quality of the product being improved by more expenditure on defect prevention.

## 5.0 APPLICATION OF THE SIMPLIFIED COST EVALUATION TECHNIQUES

Some of the simplified techniques for isolating and evaluating quality costs, (as discussed in Chapters 3 and 4 and summarized in section 4.4.9), are now illustrated using case studies. By kind permission of AECI, Somerset West, a study was made of two different production departments:-

- the vinyl products (VP) department and,
- the blasting explosives 'flats' (BE) department,

which may be considered as separate factories. They operate within AECI as such, but many of the services, i.e. maintenance, are charged to the departments as if they were contracted in from outside the 'factory'.

Each 'factory' operates in a different market with different quality requirements and as a result the quality department's activities and therefore the costs incurred are very different.

The simplified cost isolation techniques discussed in the previous chapter will be applied to each factory, and the differences in the applications will be discussed. The format laid down in section 4.4.9 will be followed. No actual costs will be collected for a number of reasons, which include:-

- some of the costs and cost ratios (i.e. selling price to manufacturing price),are confidential.
- not all the data necessary for this analysis are currently available, but will soon become available due to changes in the methods of charging for services, i.e. for the laboratory.

- cost of defect prevention projects have not been isolated and recorded when they have occured, hence a correlation made, using historical data would be meaningless.

Although no actual cost data will be found, the costs and the sources from where the cost data may be obtained will be identified. The principle aim of this chapter is to illustrate the techniques and difficulties in collecting the costs discussed in the previous chapters. The techniques will be applied to each cost category in turn, then the trends which can be drawn will be discussed.

Note:- The situations in which the costs are caused will not be discussed in detail, but where it is relevant Further details will be supplied in the Appendices.

## 5.1 BRIEF PROCESS OUTLINES

### 5.1.1 VINYL PRODUCTS (VP)

There are seven broad product categories, produced in VP, by a number of processes. The most important of these is the calendering operation, and a brief outline of this operation, along with a number of 'finishing' operations, eg. printing, is shown in fig 5.1.

The raw materials for a specific product are weighed out and combined to form a pre-mix powder. The pigment and lubricant are then mixed in to form a thermoplastic, which is filtered and extruded before calendering. After calendering,the product is rolled and sent to either final inspection or for further processing, and then to final inspection. Preliminary samples are taken after calendering to ensure the product meets specifications. At final inspection, the material, currently on large rolls, is unrolled, inspected and cut up, and re-rolled into smaller rolls. Samples are cut from a specified number of these rolls and sent to the laboratory for testing.

The quality activity associated with the processes in VP can be divided up into three sections:-

- the laboratory tests the raw materials as they arrive in the factory, as well as the samples taken after calendering and at final inspection.
- the operators of the processes act as their own inspectors, briefly scanning the sheet as it is made.

At 'final inspection' the inspection is carried out by the operators as part of the unrolling and cutting process.

- the activity is controlled by a quality manager whose duties include planning the tests and sampling schemes, and auditing the system etc.

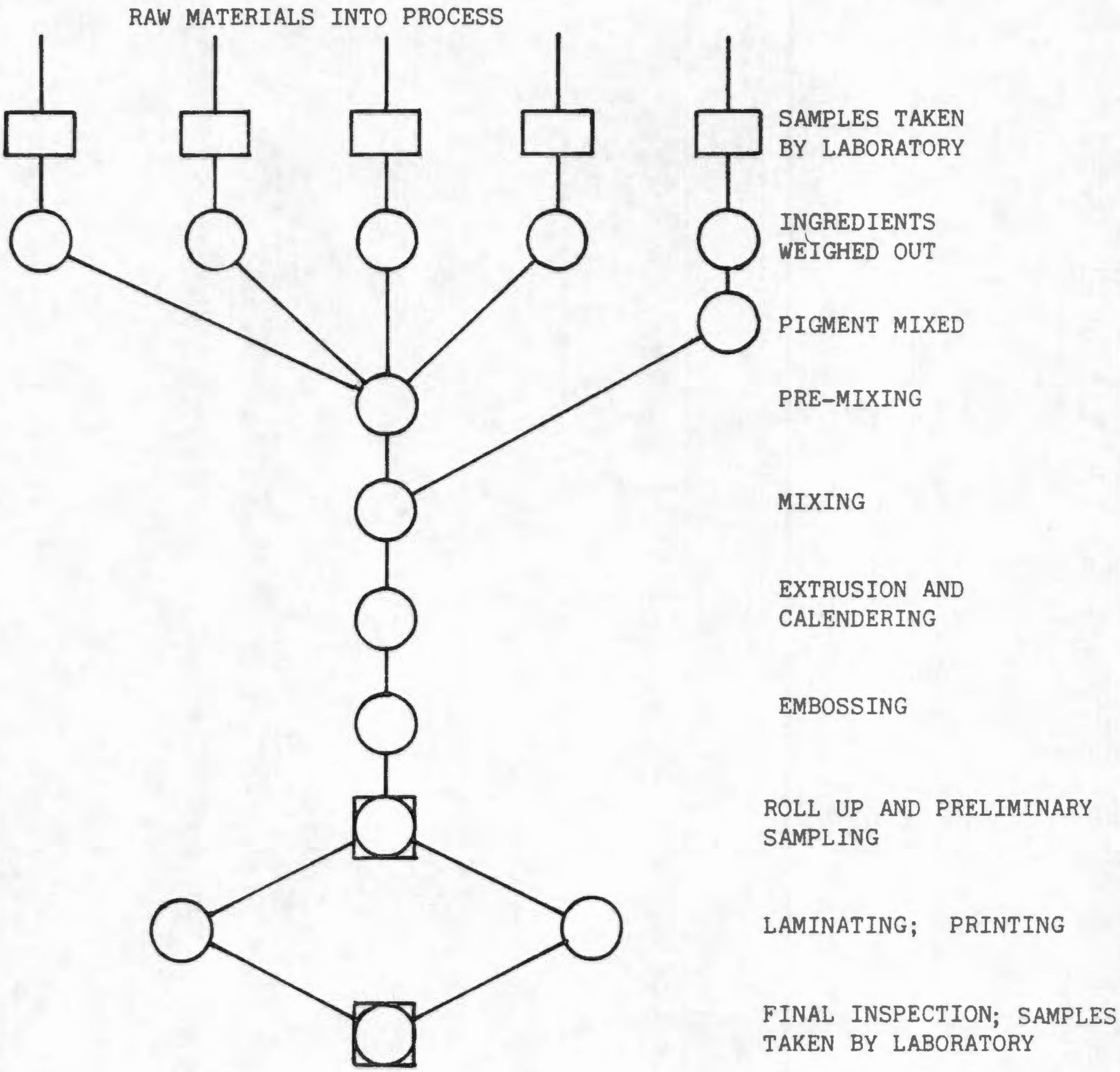


FIG 5.1 OUTLINE PROCESS CHART OF THE CALENDERING PROCESS IN V.P, CONSIDERED AS A TYPICAL PROCESS

### 5.1.2 BLASTING EXPLOSIVES 'FLATS' (BE)

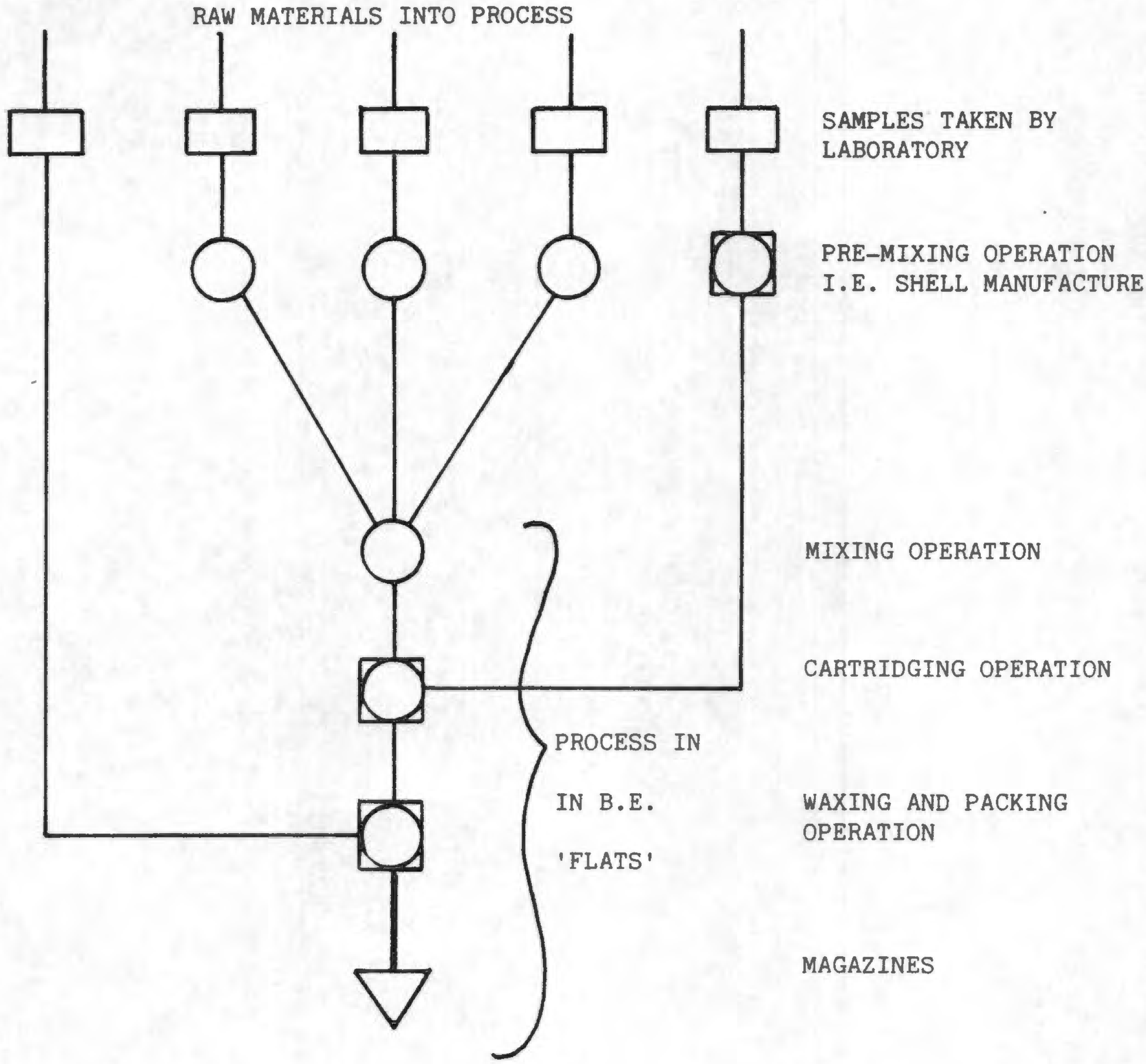
A rough outline of the manufacture of a typical product made in BE is shown in fig 5.1 Initially the constituents are brought in and processed before mixing to form the 'raw materials' of the product. An example of such a 'raw material' is nitroglycerine, which is made on site from constituents (including acids from AECI) obtained from outside the factory.

A strict 'recipe' is used when mixing the explosive, and the masses of raw material put into the batch, are used to determine the overall material usage. Once the ingredients have been mixed, they are moved into the cartridging houses, where the mix is packed into empty shells. The manufacture of the shells is one of the pre-mixing processes mentioned above. The final process is sealing the cartridges with wax and packing the completed product into cartons, and storing those cartons in the magazines.

The quality activity associated with this process is divided into three basic sections:-

- the laboratory test the raw materials as they arrive at the factory, and they also test some of the products for chemical composition.
- there are three inspectors per shift, who take samples and assure that the operators are carrying out the correct checks on the product during and after manufacture.
- the operators, who check the product as they make it.

The operation of the quality section of BE will be discussed in later sections.



○ OPERATIONS

⊡ COMBINED OPERATIONS AND INSPECTION

▭ INSPECTIONS

▽ STORAGE

FIG 5.2 OUTLINE PROCESS CHART OF A MANUFACTURING PROCESS IN B.E.

## 5.2 INTERNAL FAILURE COSTS

The internal failure costs of both VP and BE will be found by different methods, due to the different types of process and methods of recording the various parameters of these processes. Note, one of the aims of a simplified model (See section 4.2) was to use data already being collected, hence attempts will be made to isolate the quality costs using known data. The steps detailed in section 4.4.9 will be used to compile the costs in the following sections.

### 5.2.1 INTERNAL FAILURE COSTS : VP

The first step is to identify the costs of attaining the specified level of quality, which fall into this category.

The costs are; raw material lost, for quality, not production reasons; labour and process time for reworking product which does not meet the specifications; and additional staff time necessary to plan for the rework etc.

Most of these costs are not directly reported, but if we refer to the model developed in fig 4.7, with a few minor alterations, we are able to find the internal failure costs indirectly. The costs involved and the manipulations necessary to find the 'unknowns' are shown in Appendix VI, and summarized in fig 5.3.

FIG 5.3 SUMMARY OF INTERNAL FAILURE COSTS FOR VP.

$$
\begin{aligned}
&\text{TOTAL INTERNAL FAILURE COST} = \text{A VARIABLE COST OF QUALITY} = \\
&\left(\begin{array}{c}\text{COST OF TOTAL RAW MATERIALS INTO}\\ \text{PROCESS}\end{array}\right)\left\{\left(\begin{array}{c}\text{NUMBER OF METRES POSSIBLE}\\ \text{TO PRODUCE}\end{array}\right)\right. \\
&- \left(\begin{array}{l}\text{NUMBER OF METRES RETURNED TO}\\ \text{RAW MATERIAL STORE}\end{array}\right) - \left(\begin{array}{l}\text{NUMBER OF METRES SOLD: BOTH}\\ \text{FIRST CLASS AND AS SECONDS)}\end{array}\right) \\
&\left.- \left(\text{NUMBER OF METRES LOST DUE TO PRODUCTION REASONS}\right)\right\} \\
&+ \left(\begin{array}{l}\text{TOTAL RUNNING COST OF COST OF}\\ \text{PROCESS AND LABOUR}\end{array}\right)\left(\frac{\begin{array}{l}\text{NO. OF METRES REWORKED + NUMBER OF}\\ \text{METRES SCRAPPED FOR QUALITY REASONS}\end{array}}{\text{NO. OF METRES MADE}}\right) \\
&+ \left(\begin{array}{r}\text{TOTAL POSSIBLE SELLING VALUE OF METRES SOLD AS SECONDS - TOTAL VALUE}\\ \text{REALIZED}\end{array}\right)
\end{aligned}
$$

NOTE: THIS SUM WOULD BE CALCULATED FOR EACH PRODUCT GROUP SEPARATELY, AND COMBINED TO OBTAIN THE TOTAL

The simplifications used to find the costs in this department are as follows:-

- the amount of material lost due to process and quality reasons was calculated using other known material figures.
- the additional process time and labour necessary to rework the product was assumed to be proportioned to the total running costs of the process and labour, hence the cost of reworking the product can be found by a pro-rata allocation of the total costs. Account is taken of the process cost of the product which is scrapped for quality reasons in the same way.

- the time spent by the staff of the department, planning and controlling etc for the reworking of the product is found indirectly. The costs of engineering, and management staff etc are usually added on to the direct material and running costs of a process when obtaining the selling price of a product. Thus, if the value of lost contribution of the product sold as second class material were to be included in the internal failure costs, the cost of the effort of the engineering and management staff will be accounted for.

The internal cost of failure found in this way is a variable cost.

### 5.2.2 INTERNAL FAILURE : BE

The internal cost of failure of BE can be found in a more direct manner than that of VP, because the product is not sold as second grade, and many of the costs are reported, as part of the production costs.

The costs are summarized in fig 5.4, and in Appendix VI. The only cost which is not being recorded is the fraction of the direct process costs which are attributable to quality reasons. These are found using the total running cost of the process, and the fraction of cases made, which are reworked (See Appendix VI). The assumption made, is that the additional work load or reworking will cause no costs over and above the costs normally incurred. In the cases of VP and BE, this assumption holds, but if costs such as overtime were incurred, these would be included in the costs attributable to quality.

FIG 5.4 SUMMARY OF THE INTERNAL FAILURE COSTS FOR BE.

**Note:** Refer to Appendix VIB for detail of costs

| DETAIL OF COST | SOURCE | FIXED OR VARIABLE |
|---|---|---|
| 1. LABOUR COST OF STRIPPING | WAGES AND BENEFITS | V |
| 2. PACKING MATERIAL COST 'DIRTY WASTE' | DAILY FIGURE REPORTED | V |
| 3. PACKAGING 'CLEAN WASTE' FROM | DAILY FIGURE REPORTED | V |
| 4. PROCESS COSTS OF REWORK | SEE APPENDIX VI | V |

In BE there are negligible indirect costs of production i.e., staff etc, involved when the product is reworked. This is because the operators fail and strip most of the product as they make it, and process it with the remainder of the particular batch.

All of the internal costs of failure for BE are variable (See fig 5.4).

## 5.3 EXTERNAL FAILURE COSTS

No attempt can be made to model the external failure costs of a company, due to the random occurance and nature of these failures. Hence, an approach is to test the costs which could occur, with external product failure and record the costs as they occur. (See section 4.4.5) Thus, a list of the possible external failure costs for each department will be found. The method would then be to evaluate which of these costs actually occur when a failure is reported.

### 5.3.1 EXTERNAL FAILURE COSTS : VP

The costs of external failure are identified in Appendix VII, and are summarized in fig 5.5. They constitute the costs of the credits given to the customer when the product fails to meet the customer's specifications, and the direct part of the costs of the investigations of the failures.

The indirect costs of the investigations have been excluded. These are the costs of the regional sales offices. The staff are primarily salesmen, but one of their duties is to investigate the failures in the field. The staff of the sales office would be necessary even if there were no failures, thus to avoid attempting to estimate how much time is spent by these men on random quality investigations, their salaries are excluded. But the direct costs, such as the investigator's travelling expenses and the necessary testing involved with a product failure are included as a variable external failure cost.

FIG 5.5 SUMMARY OF THE EXTERNAL FAILURE COSTS OF VP.

| DETAIL OF COST | SOURCE | FIXED OR VARIABLE |
|---|---|---|
| 1. CREDITS PASSED DUE TO PRODUCT FAILURES | RECORDS OF ACTUAL CREDITS GIVEN FOR QUALITY CAUSES | V |
| 2. TRAVELLING EXPENSES OF THOSE INVESTIGATING QUALITY RELATED COMPLAINTS | RECORDS OF TRAVELLING EXPENSES CLAIMED | V |
| 3. COSTS OF TESTS ON SAMPLES OF FAILED PRODUCT | RECORDS OF TESTS MADE TO FIND FAULTS | V |

The costs of testing the sample taken in the customer's factory are also included.

### 5.3.2 EXTERNAL FAILURE COSTS : BE

There are not many complaints of failures of the product in service. this is due to the nature of the product, as it is difficult to assess the magnitude of a blast when it has occurred. Usually other problems such as faulty accessories and bad laying of the charge are blamed. Each complaint is investigated, and credits are passed if faulty product has been supplied.

As for VP, only the direct costs of the investigations are considered to be quality costs. The costs of failure are shown in Appendix VII and summarized in fig 5.6.

FIG 5.6 SUMMARY OF EXTERNAL FAILURE COSTS FOR BE.

| DETAIL OF COST | SOURCE | FIXED OR VARIABLE |
|---|---|---|
| 1. CREDITS PASSED DUE TO PRODUCT FAILURES | RECORDS OF ACTUAL CREDITS GIVEN FOR QUALITY CAUSES | V |
| 2. ADDITIONAL TRANSPORT COSTS INCURRED IN REPLACING A PRODUCT | COSTS OF TRANSPORT OF REPLACEMENTS | V |
| 3. TRAVELLING EXPENSES OF THOSE INVESTIGATING QUALITY RELATED COMPLAINTS | RECORDS OF TRAVELLING EXPENSES CLAIMED | V |
| 4. COSTS OF TESTS OF SAMPLES OF FAILED PRODUCT | RECORDS OF TESTS MADE TO FIND FAULTS | V |

## 5.4 APPRAISAL COSTS

An attempt to isolate the true costs of appraisal for either department is difficult, because both departments rely heavily on the production operators for much of the appraisal effort.

### 5.4.1 APPRAISAL COSTS : VP

All the inspection of the product, both in-process and final, is carried out by the operators of the production department as an integral part of the manufacturing operations. Thus the salaries of these operators would not be an appraisal cost. The testing of the samples is carried out by the laboratory, and the associated cost is a variable cost of quality (See note in Appendix VIII).

Often, much of the laboratory's equipment is dedicated to testing one particular aspect. The maintenance of this equipment is a fixed cost of appraisal.

The costs of appraisal for VP are summarized in fig 5.7.

### 5.4.2 APPRAISAL COSTS : BE

The laboratory costs associated with appraisal of the product in BE are similar to those in VP (see fig 5.7, fig 5.8 and appendix VIII). Although most of the appraisal effort is carried out by the production operators (see Internal Failure Costs Section 5.2.2), 3 inspectors are employed each shift to check on the effectiveness of the 'inspection'. The inspectors report to the 'quality superintendant' (See Appendix VIII), whose duty is to ensure that the respective

FIG. 5.7 A SUMMARY OF THE APPRAISAL COSTS FOR VP.

| COST | SOURCE | FIXED OR VARIABLE |
|---|---|---|
| 1. LABORATORY TESTING OF PRODUCT: IN PROCESS AND FINAL | LABORATORY RECORDS (SEE APPENDIX VIII) | V |
| 2. MAINTENANCE OF LABORATORY EQUIPMENT DEDICATED TO TESTING THE PRODUCT | INSTRUMENTS, LABORATORY AND CONTRACTORS CHARGES | F |

FIG. 5.8 A SUMMARY OF THE APPRAISAL COSTS FOR BE.

| COST | SOURCE | FIXED OR VARIABLE |
|---|---|---|
| 1. INSPECTORS | WAGES AND BENEFITS | F |
| 2. SUPERVISOR | SALARY AND BENEFITS | F |
| 3. LABORATORY TESTING OF PRODUCT : IN PROCESS AND FINAL | LABORATORY RECORDS | V |
| 4. MAINTENANCE OF LABORATORY EQUIPMENT DEDICATED TO TESTING THE PRODUCT | INSTRUMENTS AND CONTRACTOR'S CHARGES | F |

corrective action is taken. Both the costs of the inspectors and the supervisor are fixed appraisal costs.

The appraisal costs for BE are summarized in fig 5.8.

## 5.5 PREVENTION COSTS

It has been generally held (See section 4.4.7) that the overall quality costs can be reduced by increasing the effort made to prevent the defects occuring, hence it is important to isolate the prevention costs. The amount of defect prevention effort in the two departments differs widely, due mainly to the market requirements. VP is operating in a competitive market, whereas currently BE is the sole supplier for most of its products.

### 5.5.1 PREVENTION COSTS : VP

The laboratory costs of prevention are much the same as those for appraisal, but are incurred in testing materiels as they arrive into the factory (See fig 5.9). The activities of the laboratory and production inspectors are monitored and controlled by the quality manager (See Appendix IX), whose salary etc is a fixed prevention cost. As it is currently the sole responsibility of the quality manager to plan the quality tests and sampling procedures for the products, carry out audits, write the quality documents etc, his salary covers the cost of all these activities and hence one does not need to isolate the cost of each activity.

The costs of any projects initiated to improve the product quality are a fixed cost in this category. The effects of quality improvement projects are one of the trends which are looked for (See section 5.6).

In VP, most of the maintenance is initiated for 'quality reasons', i.e. the process is quite capable of producing, but only second grade material. Hence the maintenance which is initiated for quality

FIG 5.9 A SUMMARY OF THE PREVENTION COSTS OF VP.

| DETAIL OF COST | SOURCE | FIXED OR VARIABLE |
|---|---|---|
| 1. RAW MATERIALS TESTING | LABORATORY CHARGES | V |
| 2. MAINTENANCE OF LABORATORY EQUIPMENT DEDICATED FOR TESTING OF THE QUALITY OF THE RAW MATERIALS. | INSTRUMENTS AND CONTRACTORS FEES | F |
| 3. QUALITY IMPROVEMENT PROJECTS | COST OF PROJECT - LABOUR ETC. | F |
| 4. MAINTENANCE OF PRODUCTION MACHINERY DIRECTLY ATTRIBUTABLE TO QUALITY REASONS. | MAINTENANCE RECORDS | F |
| 5. QUALITY MANAGER | SALARY AND BENEFITS | F |

reasons is a prevention cost. Another trend which would be useful would be that of percent first grade product produced against amount of 'quality initiated' maintenance carried out.

The costs of prevention of VP are summarized in fig 5.9.

### 5.5.2 PREVENTION COSTS : BE

The prevention effort in this department currently consists of laboratory testing of raw materials , (See fig 5.10), with its associated cost of testing and maintenance of dedicated instruments. The main reason for this low key effort is that there is little pressure to improve the product, due to its low external failure rate. (See section 5.3.2)

FIG 5.10 SUMMARY OF PREVENTION COSTS FOR BE.

| | DETAIL OF COST | SOURCE | FIXED OR VARIABLE |
|---|---|---|---|
| 1. | RAW MATERIALS TESTING | LABORATORY CHARGES | V |
| 2. | MAINTENANCE OF LABORATORY EQUIPMENT DEDICATED FOR TESTING OF THE QUALITY OF THE RAW MATERIALS | INSTRUMENTS AND CONTRACTORS FEES | F |
| 3. | QUALITY IMPROVEMENT PROJECTS | COST OF PROJECT - LABOUR ETC. | F |

The costs of any improvement projects initiated, would also fall into this category as a fixed cost.

The maintenance of the production machinery in BE is rarely initiated for quality reasons, as production is the criteria against which the process is judged, with product quality having a low priority.

The costs for prevention for BE are summarized in fig 5.10.

## 5.6 SUMMARY OF SIMPLIFICATIONS USED IN COLLECTING AND COMPILING COSTS FOR THE CASE STUDIES

The techniques used to simplify the methods of collecting and isolating the costs gathered for the case studies are discussed below.

1. Use of contribution: Usually when a product fails final inspection, there are costs incurred by production and technical staff. The amount of effort will vary in each case, as the failures and the methods of correcting the causes, vary. Also if the product has to be reworked, there are costs of handling the failed product, downgrading it to sell it as second class product, planning and controlling the reworking of the product etc. These activities are usually carried out by the production and technical staff as part of their normal jobs. As there are no regular periodic patterns to the failures, the costs incurred in each period will not be the same. As has been observed earlier, (See Section 4.3.1) that an accurate estimation of these costs cannot be found for each period by direct measurement.

   Most of these costs are budgeted for in the overhead costs of the department, and are added onto the direct cost of manufacture to obtain the selling price. As the amount of overhead added per unit is difficult to isolate, the contribution lost (possible selling price minus actual selling price) is used. this is slightly inaccurate, due to the inclusion of the profit, but a large error is not included, and it has the added effect of impact on management. The figure of profit lost is more impressive then the losses in the factory. Also, both the possible selling price and actual selling price are currently recorded.

2. Process cost of reworking: An indirect method was used to obtain the processing cost of reworking the product for both 'factories'. As a direct method of measuring the process cost for each unit reworked would have needed a drastic change in the accounting systems for each department, an indirect 'pro-rata' method was used. The assumption made was that the total process costs (direct running costs only, as the overheads have been accounted for; see 1 above), are proportioned to the number of units processed. Thus, the process cost which can be attributed to quality can be found using the following known figures:-

   - total process cost
   - total units made
   - number of units re-run.

   Thus, the process cost due to quality can be found simply. The only errors would be:-

   - if overtime was necessary to rework the product, and
   - if the process had to be set up specifically for the re-run.

   In the cases we are considering, overtime is regulated, and if any was necessary to rework the product, it would be a variable quality cost.

   Costs of setting the process up are included in the variable costs of VP and are not relevant for BE.

3. Quality Manager: Within VP the only member of the quality assurance section is the quality manager (officer). His main duty is to liaise between the laboratory, the production department and the customers on quality related matters.

His duties also include planning the sampling schemes to be used by the production 'inspectors', selection of testing methods to be used by the laboratory, short term auditing of the product etc. Instead of isolating the cost of each of the activities in turn, the salary and benefits of the quality manager, and any expenses that are incurred by the quality section are collected, and allocated as a fixed cost to the prevention cost category.

4. Production Operators: Both the 'factories' used as case studies make extensive use of the production operators as 'inspectors'. The costs of these inspectors have not been included as a quality cost, as the in-process inspections are carried out as the product is being made, and suitable adjustments are made to the process to correct for defective product immediately.

Within BE the defective cartridges are eliminated and stripped as they are made, as part of the process, by the process operators. The only activity which can be charged to quality costs is that of stripping. The final inspection operation in VP is a 100% inspection for surface defects. It is carried out as the large rolls are unrolled and cut up. The operation would be carried out, whether the inspection was included or not, hence the operation is considered to be part of the production process, and the costs incurred are not considered to be quality costs.

5. Wax and paper loss: In BE the 'clean waste' and 'dirty waste' (See appendix VIB) is weighed to obtain the amount of material lost in the process for quality reasons. The materials which are weighed are paper and waxed paper. This does not induce much of an error, as the cost of thepaper and wax by weight is very similar, (both in the region of 75c/kg).

6. Salary etc of Quality Superintendent' for BE: This is the only staff activity which was estimated. This is because he spends approximately 20% of his time carrying out quality related activities. These activities do not vary from period to period, as they are the routine checking of the results of the inspector's activity, hence this assumption is justified.

7. Salary of Sales office personnel: Although the salesmen at the respective sales offices spend part of their time investigating quality related complaints, this is only a small part of their work, as they are primarily salesmen. Also, the number of complaints for both'factories' is low, hence the exclusion of part of the salesmen's salaries is justified.

## 5.7 TREND ANALYSIS FOR VP AND BE CASE STUDIES

The sixth step (See section 4.4.9) is to plot the quality cost data such that the trends for which we are looking, will be illustrated.

Initially we have to decide on the trends which we wish to illustrate. The principle objective in monitoring the variations in quality costs is to minimise the overall costs, thus the initial trend which we wish to establish is how the overall costs of quality vary with the level of quality produced. The parameters which we have direct control over are appraisal and prevention efforts. Thus, the quality of the product produced can be improved by increasing the prevention and appraisal efforts, and the effect on the overall costs noted (See Assumptions, section 4.4.1).

Before attempting this, there are a number of aspects which we have to consider:-

- what is a representative measure of quality for each factory.
- how to eliminate varying production volume and mix.
- whether the overall optimum quality level found is applicable to each product.

A suitable measure of quality for the products in VP would be the percent of first class material that passes final inspection. Although this is slightly incorrect, as the inspection is assumed to be 100% efficient, this is representative, as the external failure rate is usually less than ½%. A suitable measurement for BE would be the precent of cases made which are not sent for reworking, i.e. 100% - % of cases made that are reworked (measured).

The method of eliminating production volume has been discussed in section 4.4.8. This method is applicable when all the variable costs can be found as per unit variable costs. When we look at some of the variable costs found for the two 'factories', we can see that some of these are found as a single cost for all the products (See fig 5.12), thus a simple division by the total number of units produced would not be representative, as the mix of the units changes. This effect can be eliminated if the method in fig 4.10, and the method of using equivalent units of production (see appendix IV) are combined.

A mathematical representation of this 'normilization' is shown in fig 5.11. It should be read in conjunction with Appendix X, where the method of calculating the equivalent number of units for both the actual and the representative production volumes, (See section 4.4.8), is shown. Figure 5.12 divides the costs found in figures 5.3 to 5.10 into fixed, lump sum variable and per unit variable costs. Thus, the total normalized quality costs can be plotted, and the trends observed. The trends in the normalized costs in the cost categories could be observed at the same time, by plotting them on the same graph, as percents of the total. As the quality is increased, so the optimum operating point would be obtained. (See under assumptions section 4.4.1)

As most of the products made on the BE 'flats' are similar, this overall level of quality is valid. The products made in VP are not all similar, but the level of quality, as defined earlier in this section, of each of the processes is similar, also the

## FIG 5.11 MODEL TO ELIMINATE EFFECTS OF BOTH PRODUCTION VOLUME AND PRODUCTION MIX

(NOTE: VARIABLES NOT TO BE READ IN CONJUNCTION WITH FIG 4.10)

VARIABLE COSTS OF QUALITY FOUND AS A LUMP SUM IN PERIOD j = Vj

VARIABLE COSTS OF QUALITY FOUND ON A PER PRODUCT BASIS FOR PRODUCT i IN PERIOD j = Vij

ACTUAL EQUIVALENT UNITS SOLD (SEE APPENDIX VI) PRODUCT i = Aij

STANDARD EQUIVALENT UNITS SOLD (SEE APPENDIX VI) PRODUCT i = Sij

FIXED COSTS OF QUALITY FOUND AS A LUMP SUM IN PERIOD j = Fj

TOTAL NORMALIZED QUALITY COSTS INDEPENDENT OF VARIATIONS IN PRODUCTION VOLUME AND MIX FOR PERIOD j FOR TREND ANALYSIS = Qj

NUMBER OF PRODUCTS OF PRODUCT GROUPS = n

$$Qj = Fj + Vj \frac{\sum_{i=1}^{n} Sij}{\sum_{i=1}^{n} Aij} + \sum_{i=1}^{n} \frac{Vij\ Sij}{Aij}$$

PLOT Qj FOR EACH PERIOD AND DRAW TRENDS

NOTE: THIS CALCULATION SHOULD BE DONE FOR EACH QUALITY COST CATEGORY IN TURN, AND THEN THE TOTAL PLOTTED. THIS WILL ENABLE TRENDS IN THE COST CATEGORIES TO BE MONITORED AT THE SAME TIME AS THOSE OF THE TOTAL QUALITY COSTS.

FIG 5.12 DIVISION OF THE QUALITY COSTS FOR VP AND BE INTO FIXED 'LUMP SUM' VARIABLE, AND PER UNIT VARIABLE COSTS

| CATEGORY | FIXED COSTS | LUMP SUM VARIABLE COSTS | PER UNIT VARIABLE COSTS |
|---|---|---|---|
| 1. VINYL PRODUCTS | | | |
| A. INTERNAL FAILURE (FIG 5.3) | | | TOTAL EQUATION |
| B. EXTERNAL FAILURE (FIG 5.5) | | NO. 2 | NO. 1, 3 |
| C. APPRAISAL (FIG 5.7) | NO. 2 | | NO. 1 |
| D. PREVENTION (FIG 5.9) | NO. 2,3,4,5 | | NO.1 |
| 2. BLASTING EXPLOSIVES | | | |
| A. INTERNAL FAILURE (SEE FIG 5.4) | | NO. 1,2,3 | NO. 4 |
| B. EXTERNAL FAILURE (FIG 5.6) | | NO. 2, 3 | NO. 1, 4 |
| C. APPRAISAL (FIG 5.8) | NO. 1,2,4 | | NO. 3 |
| D. PREVENTION (FIG 5.10) | NO. 2,3 | | NO. 1 |

aim is an overall optimisation rather than a sub-optimisation. Hence it can be assumed that the overall level of quality found by plotting Qj (fig 5.11) would be valid. The analysis of trends in individual products for VP will be discussed further below.

It has been noted earlier (See section 3.4.4 ) that the actual benefits of quality improvement projects, as compared to the predicted benefits, could be found by monitoring the quality costs. Thus the variation of the overall normalized quality costs should be plotted with the expenditure on quality improvement projects for both BE and VP for each period. (See fig 5.13) A similar graph should be plotted for VP with the expenditure on quality initiated maintenance plotted against quality. Thus the benefits of quality improvements can be found, as well as any relationship between quality and maintenance.

As the quality improvement projects and quality initiated maintenance are often carried out on specific processes, trends should be drawn between these expenditures and the quality of the product from that process. Thus relationships between quality and maintenance can be found for each product, (See fig 5.14 for a typical plot). Also, the effect of the quality improvement projects on the product quality can be found.

The actual quality costs should also be plotted against the total the total costs of production, absolutely and as a percent to ensure that reductions in the quality costs do not increase the overall costs.

## 6.0 COST SAVING TECHNIQUES OF QA

As the philosophy of QA developed (See Chapter 2 for a brief resumé), a large number of techniques were developed to facilitate the application of the basic principles of QA. Many of these techniques were also cost saving as they made it easier to obtain a good quality product. A few of these principles and techniques are discussed in this chapter with references to examples, using the case studies used in chapter 5.

Just as the application of the techniques can be cost saving, so the misapplication can be costly. The reasons why some of these techniques can fail are given with possible ways to avoid the failure of the techniques.

## 6.1 INVESTIGATION OF THE BASIC ELEMENTS OF THE QUALITY SYSTEM

Once a quality system has been installed to monitor and control the production operations, it has to be maintained or some of the procedures will fall away. One of the techniques used to maintain the system is a quality audit, which is a planned assessment of the quality system, investigating the need for quality activities, and the effectiveness of the execution of these activities. As the quality system usually covers the activities of most of the departments in the company, the inspections of the audit are often done on a sampling basis, with the extent of the sampling depending on the scope of the audit (35).

Part of the audit is to investigate the paperwork of the quality and production systems. Some of the aspects investigated are the procedures,instructions and specifications used. These are looked at to see whether they are relevant, carried out, and effective.

The specifications are looked at to see if the tolerance zones are necessary, too tight or loose, and to see whether they can be held on the existing machinery. Savings can be made if tolerances are set to the correct level, and a comprimise must be drawn between the costs of having tight and loose tolerances. Cost Factors which will effect the decision regarding tolerances are shown in fig 6.1. These factors are amongst those which have to be considered when the basic quality level is set to obtain a 'minimum' manufacturing cost (55). By auditing the specifications, expensive practices such as; "we always machine to within......" will be avoided. Also, if the specification is not necessary, savings could be made by dropping it.

FIG 6.1 FACTORS TENDING TO INCREASE/REDUCE TOLERANCES (16)(49)(50)

| REDUCE | INCREASE |
|---|---|
| 1, Product function, durability, and appearance requirements (accomplished by maintaining correct fit, alignment and clearance of component parts proper material characteristics, surface finishes etc)<br>2. Maintenance of in plant interchangeability with a minimum of fitting or adjustment on assembly.<br>3. Interchangeability in the field.<br>4. Need for a tolerance reserve or factor of safety to cover engineering uncertainty regarding maximum variation compatible with satisfactory product performance.<br>5. In-process interchangeability required to establish intermediate tooling locations.<br>6. Other special manufacturing requirements. | Unnecessarily restrictive tolerances generate serious increases in time and cost absorbed in some or all of the following production factors:-<br>1. Production planning, tool design, and tool fabrication.<br>2. Tool and process set up.<br>3. Tool adjustment and regrinding.<br>4. Tool maintenance and replacement.<br>5. Extra manufacturing operations needed to achieve specification.<br>6. Process yield.<br>7. Inspection and guage supply, control and maintenance.<br>8. Scrap and Salvage operations.<br>9. Direct labour and associated line supervision.<br>10. Proportion of indirect to direct labour. |

The use of, and relevance of, the procedures is also looked at. The procedures should define the interrelated responsibilities of the various departments (12)(68). They are essential for the operating of the quality department, as its functions are usually executed in conjunction with other departments, and for everyone to know what they are to do in a particular situation, the steps to be taken must be formally defined. This ensures that jobs at the interface between two departments are carried out, and the "buck is not passed.(69)"

In some cases the procedures are not necessary, and can cause unnecessary work, but the opposite is more usual, where the procedure is not used, causing potentially expensive mistakes. Take, for example, the tanker borne raw material receiving procedures for VP. The usual procedure is that a sample is drawn from the tanker and preliminary tests made and the lot rejected of accepted into the storage tanks. Further samples are then taken and more detailed tests made in the laboratory, and the material is then released into the plant, or rejected.

Although the material officially has to be released into the plant, this procedure is sometimes by-passed when the production department need the raw material before the tests have been completed. This happened in January when the laboratory was behind in their tests due to staff shortages, and when the raw material failed, it was found to have been used. In this case it had no effect on the product, but it could have been an expensive mistake. The supplier would have been liable for replacing his faulty product, but that is all.

A number of anomalies are illustrated by this example:-

- the production department should not be able to draw the raw materials without clearance from the relevant authority.
- is it necessary to test the raw material, and are the specifications correct? The raw material failed the test, yet the product was not affected.
- the raw material was pumped into a tank which was partially full. If the raw material failed, the supplier would not be liable for the good stock which was contaminated, hence an empty tank should be used to receive raw materials.

This example illustrates the faults in a number of procedures, which would come to light if a thorough audit was initiated. The cost of the audit can only be justified after the audit has been completed and the costs saved have been evaluated.

The audit is not limited to the paperwork, it extends to all the quality activities, and is essential if the quality assurance system is to remain current. If the quality system is not maintained, it will become ineffective, and hence cease to be a means of reducing operating costs.

One cost saving principle of a QA system is the control of documentation, known as configuration management. This is essential if the correct items are to be made to the correct specifications. Unless there is a tight control over the documentation, ensuring that only the current documents are available to the relevant people, expensive mistakes can be made. Take the control of production drawings for example. If the drawing is altered by the drawing office without the knowledge of the production department, an incorrect item could be made, thus wasting both time and materials. If the documents were controlled, this type of needless error would not occur. The control of the quality documents is usually 'mapped out' in the quality manual which details the quality system, authority structure, and where all the instructions and details of the system can be found. The quality manual is thus an important document, which is essential for the efficient running of a quality system, and hence for the production system. The manual should be periodically reviewed to ensure that it is current, and it reflects the system as it is. Thus it can be used as the basis for a quality audit, saving the auditors' time in assessing the quality system.

## 6.2 MAINTENANCE OF INSTRUMENTS

In order to control a system, there must be some form of measurement of that system. It is thus important that the instruments used to measure the system are accurate, and display what is actually happening.

The maintenance schedule should make provision for regular checks and maintenance of the instruments and the records of these checks should be audited to see if they are being carried out regularly.

If the instruments are not maintained correctly, there cannot be any effective control over the system, hence expensive mistakes can be made. Certain instruments have to be accurate to within a set tolerance by law, eg. assize scales,and hence there can be legal implications of instrument error.

Maintenance alone cannot ensure that the instruments are accurate throughout the intervals between services, and it should be part of the quality activity to check that the instruments are still accurate and precise. This comes under short term assurance testing (see appendix II), where the quality staff check on the instruments on a random basis.

The quality instructions should detail how the instruments are checked. It has been said that if a measurement is to be made it must be made with an instrument which can measure at least to a degree of accuracy greater than the measurement to be made (55)(70).

This principle is often not used in industry, as can be illustrated in BE where many of the measurements are made by extrapolation beyond the graduations of the scale. Also, many measurements were made on scales of a degree of accuracy lower than the measurement to be made.

## 6.3 TOTAL INVOLVEMENT IN QUALITY

It has generally been accepted that "prevention is better than cure". With regards to quality, we have added the proviso, "only if it is economical to prevent the defect occurring". Thus it is logical to attempt to find inexpensive ways to reduce defects.

One of the basic principles of the zero defects theory is to "make it right the first time" (71). Although the zero defects theory has been benerally rejected, (see Chapter 3) this principle cannot be rejected. One way in which an attempt may be made to achieve the minimum number of defects is to involve everyone in the company with the reduction of defects. Everyone need not be actively involved in a 'quality drive', but they could all be 'quality minded' (24), and be aware of any problems as they occur and attempt to correct them or report them instead of leaving them.

There are many advantages to be obtained by involving the workers in the improvement of the product quality. Amongst these are:-

- they deal with the 'raw facts' as they occur, and hence the knowledge is first hand (41).
- they are usually experienced with the process, and are thus able to to suggest useful changes to the process. Also, they have a motive to reducing trouble causing defects (41), as they are the ones who will operate in the changed circumstances.
- their sheer number helps in fact finding, and they can consider all the aspects when combined together in a group (41).
- they see the fault causers while on the job, hence reducing the need for detailed investigations by various members of the staff.

The benefits of involving all the members of the company were seen by the Japanese 20 years ago (24), and they developed the concept of quality circles. These usually comprised of voluntary groups of workers, involved in a section (72) who attempted to solve a quality problem without specifically being on a project to solve the problem, hence avoiding the costs of a project. The benefits can be seen, as the people who have the authority to make the changes, usually do not come into direct contact with the raw facts, unlike those who do, but do not have the authority to institute a change.

It has been said that quality circles would only work in Japan, due to the dedication of their workers, but they have been applied to western countries, and are succeeding in the U.K. (72). Although the labour situation in South Africa is very different, much can be learned from the concept of quality circles, and the involvement of all the workers in achieving a higher quality level.

As the workers are directly involved with the process, they can see defects as they occur. If they are motivated to correct the problem, rather than to overlook it with the knowledge that someone else will correct the process, large savings can be made. The workers can thus become their own quality controllers. Although the original reason for introducing inspection (See chapter 2.2.1) was that the labourers employed were not producing a high quality product, the level of inspection need not be as high if the workers are motivated to produce a high quality product. Thus, savings may be made, not only by reducing the level of inspection necessary for the same assurance, but also by the lower level of defective product which is produced.

There are numerous ways to motivate the labourers, one of which is to increase their level of skills by training (See next section). The subject of motivation will not be discussed, as there are many standard texts and theories on this subject.

In both the 'factories' used as case studies, extensive use is made of the operators, as their own quality control. It may be seen in BE where the level of inspection is very low and it is left to the production operators to estimate the faulty product as it occurs. As noted in the discussion on the internal failure costs for BE, there are 11 men stripping the faulty cartridges every day. With three inspectors to cover the premixing operations as well as the manufacture of the explosive, little assurance could be given to the level of quality of the final product, without the use of the labourers as their own QC.

Thus it seems that the use of production men as their quality control is necessary with the inspectors acting as a short term assurance that the production men carry out the necessary checks on each lot. Even so, the aim is not to have the production men checking that the product is defect free, but to have the production men making the product correct in the first case. The important aspect is that he must have some control over his environment, i.e. be able to correct a defect causing fault, and it is essential that he knows what he is committed to make, what characteristics need close attention, and what quality levels to adhere to (22). Juran (16) calls this a state of self control, and he says it is essential for an operator to be in a state of self control if he is to be able to do the job effectively.

For a man to be in a state of self control, he has to understand what is required of him, and how he is to do it. Thus he needs to be trained.(25)

## 6.4 TRAINING FOR QUALITY

Juran (16) has noted that unless a person has his skills updated regularly he becomes obsolete in less than a decade. This is especially true when the technology of the equipment with which he works is also changing. Old methods are often no longer valid when carried out in conjunction with the new equipment, and they have to be updated.

As noted earlier, one method to save costs is to make the operators quality conscious. If the operators can become involved in improving the product quality they are more likely to be quality conscious (41). Thus it is beneficial to train the operators as well as the inspectors in the relevant quality techniques, i.e. control charts.

A great many factors effect the performance of inspectors. These include the working conditions, the type of fault, the time given to find the fault etc. It has been found that under any given set of conditions, training an inspector increases his efficiency substantially (73).

Many mathematical models have been developed to take inspector efficiency into account. The effect which inspector inefficiency has, is to make a sampling plan less effective, hence the sample size has to be increased to attain the same level of product assurance. Inefficient inspectors would allow more defective product out of the plant, hence increasing the external failure costs. Inspector inefficiency can increase internal failure costs, as during in-process inspection, defects are missed and value is added by the rest of the process to a faulty product. Also an inefficient inspector will reject a certain amount of good product, increasing costs.

Within many production situations, the inspectors are used as a policing force to check up on the operators (20), hence friction can build up between the production and the quality sections. Pressure is then put on the inspectors by his fellow workers not fail the product, defeating the object of having an inspector in the first place. This tends to be more prevalent in situations where there are production incentives.

In BE the inspectors are drawn from among the workers, hence there is even greater social pressure on them not to fail product. Often if the production department is short of operators, the quality inspectors are put back to work as operators, dispensing with any checking. Thus the inspection system in BE is not very reliable, and the inspectors are not inclined to fail the product due to 'social' pressure.

Within BE, only a low grade employee may be used as a quality inspector. this is due to a union agreement. Hence the position of inspector is not considered to be a good one, and the production staff would rather return to the production lines, where they can be promoted. It is not surprising then, that the quality activity in the department is not very effective. If the operators were trained in quality techniques, an attempt could be made to improve the quality of the product using the operators, and dispense with the formal inspection activity.

Within VP, the operators also act as their own inspectors, inspecting the product as it is made, and as it proceeds through the finishing operations, (See section 5.2.4) as there are no formal inspectors. The present training is 'on the job', with the emphasis on production rather than on quality. If the operators are trained in quality methods as well as production methods, they would be more able to improve the quality while 'on the job', but improvements would be limited by production criteria.

## 6.5 USE OF STATISTICAL METHODS

As the use of statistical methods form a very large section of the QA theory,only a few aspects will be briefly discussed.

The most obvious cost saving statistical method is that of sampling. By using set sampling plans, a level of quality can be guaranteed with a probability. From this, the risks of failure can be obtained. By using sampling methods, a level of confidence as safe as 100% sampling can be given, at a far lower cost. One should note that 100% sampling is usually no more effective than 85% sampling, due to inspector inefficiency (21).
The inspections made using sampling plans are also subject to inspector inefficiency, less units have to be tested, often giving more time per inspection and hence a more efficient inspection. One should note that too much time should not be given, as if given enough time, an inspector will be able to find a fault with almost any product (74).

One of the main reasons why the inspections are not carried out efficiently is production pressure. This is due to a number of factors, amongst which are:-

- the increase in the number of units which have to be inspected, reduces the amount of time available per inspection, hence only a superficial inspection is possible.
- the production department requesting that batches are passed even if they have failed the specifications.

One should note that if enough samples are taken, a sample which fulfils the specifications can be found to 'justify' acceptance of the batch.

The second of the above points illustrates an important aspect involved with statistical sampling, that of maintaining the integrity of the sampling (16). If the inspector sees the system being bent to suit the needs of the production department, and 'failed lots' released for dispatch, he will start to let bad product through. (75) This is often because there is extra work involved when a part fails, and even more work when a batch fails. Juran (16) indicates graphically how there is an unusually high number of batches which have one failure less than the batch rejection number, in what would otherwise have been a normal distribution of failed batches. A situation like this can be avoided to a large degree by training of the managers as well as the inspectors.

Training,as mentioned in the previous section can be an important aspect of the maintenance of the quality system. If an inspector is trained in quality methods, he will not mindlessly follow the instructions, but use some sound judgement as well.

Another statistical method used to reduce costs is the operation of control charts. These are used to differentiate between chance variations, and those variations which can be assigned to specific causes. They can be used to pinpoint problems with materials, operators, process and measuring equipment. By using control charts, it can be seen whether the process needs to be altered or whether the failure was a random occurance. Control charts can be used to indicate when the process is 'out of control' i.e. no longer able to produce within set limits. Thus the need for maintenance, process adjustment or a tool change can be indicated.

The use of control charts is an integral part of the feedback loop involved with QC and QA. Hence faults in the parameters of the process will be indicated earlier, enabling corrective action to be taken earlier, thus reducing the amount of faulty product made.

## 7.0 CONCLUSION

Although many of the costs of quality are difficult to isolate, the use of methods such as those illustrated in this thesis, enables a simplified analysis of these costs to be carried out with little effort.

One of the most important uses of these costs is to measure the effectiveness of the activities of the quality system. The reference for measurement is the level of quality which optimises the overall costs of production. The optimum level of quality is found by heuristic methods. The level of quality is increased, and the trends in the quality costs observed (See fig 4.3 and section 4.4.8). The optimum level of quality can only be found over a period during which the quality is being improved as the way to reduce the costs of quality is to spend more on reducing the occurrence of the defects, hence improving the product quality. The trends in the quality costs are observed, and the quality level to be aimed for is that of the optimum.

The trends in the quality costs can only be drawn from period to period if the distorting effects of the production volume and mix are removed. The method of dividing the quality costs into those independent (fixed) from, and those dependent on (variable) production volume, has been suggested. To draw trends in the costs, the variable costs are found as a per unit cost and 'normalized', i.e. they are multiplied by a typical production volume, to bring the variable costs back up to the same order of magnitude as the fixed costs.

The method of equivalent units of production (See Appendices IV and X) is used to eliminate the effect of varying product mix. The method of eliminating the combined distorting effects is shown in fig 5.11.

Other trends can be drawn from the variation in the quality costs. Some of those which could be found for the case studies are:-

- the variation of the quality produced by a process against how much quality initiated maintenance was carried out on that process, during the period in question (See fig 5.14)
- the variation of the quality costs during and after a quality improvement project. (See fig 5.13)

Another aspect which was considered was that of the cost saving quality assurance principles and techniques. A few of these were discussed, with some of the costs of not applying the principles and techniques correctly.

To conclude, a few of the aspects of quality costs which were discussed in this thesis are mentioned below:

- the optimum level of quality could not just be set as has been assumed in all the texts read. The quality cannot be varied from very low to very high without having drastic effects on the costs of the system. Thus the quality should be gradually improved and the effects on the overall costs monitored.

- not all the 'quality costs' can be easily isolated. Simplified methods of isolating them, with minor inaccuracies, can be developed (See Chapters 4 and 5). Costs which were currently collected were used, to further facilitate the cost analysis operation. The simplifications used in the case studies are summarized in chapter 5.6. One should note that different simplifications could be used in other cases, but that those presented would apply in most cases.
- the division of the costs of quality into fixed and variable to analyse trends. The method of analysing the running costs of the factory are divided into fixed and variable costs for analysis. Hence the quality costs should be as well. Also, to eliminate the variations of production volume, a division through by units produced will introduce an error, as not all the cost are proportioned to the production volume.
- the methodology summarized in section 4.4.9 to analyse the costs to obtain the data from which the trends may be drawn.
- the cost saving techniques and principles of quality assurance. Many of these techniques and principles can be applied to areas other than those influenced by the quality department, eg. the control of production drawings (See chapter 6).
- indirect savings of quality. some of these are mentioned in Chapter 3.5, but there are other immeasureable savings of installing a QA system. These include the lack of extensive insurance cover; customer trust,(if the customer knows

every attempt is being made to produce a high quality product, he is less likely to reject a rare faulty batch);

- a higher level of re-sales, where the customers return as they are satisfied with the products quality.

Thus, we may conclude by saying that it pays to spend money on improving the level of product quality - up to a limit, which can be found with little effort.

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# APPENDICES

## APPENDIX I. COSTS OF FAILURE

Typical costs of failure are given, with a brief definition of what the cost entails.

### A. INTERNAL FAILURE COSTS

1. SCRAP; represents the losses incurred in obtaining the required level of quality. It should not include material thrown away for other reasons i.e. overruns, obsolescence. Scrap costs can be sub-divided into that due to the manufacturer, and that due to the supplier. A contract could be drawn up with the supplier for compensation over the latter sub-section.
2. REWORK; represents the costs incurred by the respective manufacturing departments to improve the quality of a product which has failed inspection at some stage. It includes additional wages, salaries, materials, process time, and lost income if product down graded, amoungst others. Often when a purchased part fails incoming inspection the purchaser negotiates with the supplier to do the rework and then charges the supplier. This is a typical state of affairs when the transport costs are high, or the purchaser needs the part immediately, or there is a long lead time between re-order and delivery. There is also the cost of the time taken by the various members of staff in associated activities such as design, changes, down grading and classification.
3. HANDLING; costs represent those costs incurred in the additional handling and storage space required for the faulty products. As those products which have failed inspection must be kept apart from those which pass,additional stores and

and procedures for handling and disposing of these failures are required. This cost also includes the handling and storage used when the product is reworked.

4. ENGINEERING AND STAFF ; costs represent the costs of the engineering or production staff investigations into the reasons for the failures, and the time spent on corrective action.

## B. EXTERNAL FAILURE COSTS

1. COMPLAINTS; represent all the expenditures involved in the investigation and correction of the complaints. It includes the railage of the failed goods to and back from the respective factory, the disposition charges, the credits claimed under warranty, the replacement costs, the expenses of the investigation and analysis of the failure, amongst others.

2. LIABILITY; costs are those costs incurred as a result of the failure in service of your product. These are usually damages awarded for injury, or for destroyed property which was caused by the failure.

3. INSURANCE COVER: represents the cost of the insurance cover needed to cover the products for the possible damages resulting from a failure.

NOTE: The following references were used in compiling Appendices I, II and III : 8, 12, 14, 16, 19,23,50

## APPENDIX II COSTS OF APPRAISAL

Typical costs of appraisal are given, with a brief description of what the cost entails.

1. IN-PROCESS INSPECTION AND TESTING; represents the time and cost of inspecting and testing the product during the process. It includes the costs of materials destructively tested to ascertain the level of conformance. It also includes the costs of supervision and clerical work associated with the inspection and testing.

2. FINISHED PRODUCT AND FINAL INSPECTION AND TESTING; represents the same costs as discussed above, but at the end of the process before shipping.

3. INSPECTION AND TEST EQUIPMENT MAINTENANCE; represents the costs associated with the setting up, calibration, and maintenance of all the inspection and test equipment. This also includes the cost of outside companies contracted to calibrate and maintain instruments associated with inspection and testing, and the cost of maintaining all the records associated with the instruments.

4. SHORT TERM ASSURANCE TESTING; costs are those associated with the retesting and reinspection of products passed by the inspection department as part of the assurance of the product.

5. LABORATORY SERVICES; are those costs associated with the in-process and final inspection and testing of the product.

6. FIELD TESTING; costs are those which are incurred by the inspection and testing of a product in service before hand over. This would include all the travelling expenses associated with the staff testing the product on site.

## APPENDIX III. COSTS OF PREVENTION

Typical costs of prevention are given with a brief description of what the cost entails.

1. INCOMING MATERIELS INSPECTION AND TESTING; costs are allocated to the costs of prevention. These costs are often associated with the costs of appraisal, but they are a prevention cost, as they occur before the process, and are incurred to prevent defects getting into the system.

2. LABORATORY ACCEPTANCE TESTING; represents the cost of testing and analysing the incoming materiels for defects.

3. QUALITY PLANNING; represents the costs associated with the time that personnel in the Q.A. and production functions spend in planning the quality system and in translating product design and customer quality requirements into specific manufacturing controls on quality of materials, processes, and products through formal methods, procedures and instructions. This includes the time and money spent, proving sampling techniques, trials and tests on prototypes, reliability studies, writing instructions and procedures for testing and inspecting, updating these instructions, amongst others. These costs include the time spent by other departments, notably production engineering on these activities.

4. PROCESS CONTROL; represents costs associated with the time spent studying and analysing manufacturing processes for the

purpose of establishing a means of control as well as improving existing capability, and in providing technical support to shop personnel for the purposes of effectively applying or implementing quality plans and initiating and maintaining control over manufacturing operating processes.

5. DESIGN AND DEVELOPMENT OF TESTING AND INSPECTING EQUIPMENT; cost represents the time and money spent in designing and testing measuring equipment. This does not include the capital cost of the equipment, or the associated depreciation.

6. QUALITY TRAINING; represents the time and cost of developing and running of the formal training scheme. It does not include the training costs of the operations which form part of the normal production activities.

7. QUALITY AUDITS; represent the time spent on periodic evaluations of the quality system. This includes the time spent developing the procedures of the audit, the analysis of the system for failures, and the analysis of the system for potential failures.

## APPENDIX IV. QUALITY COST PER EQUIVALENT UNIT OF PRODUCTION

This development is taken from Reference 42, and was used to calculate the figures shown in fig 3.8.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| PRODUCT | NET BILLED SALES $ | DIRECT MATERIAL COST $ | VOLUME OF PRODUCTION | CONTRIBUTED VALUE $ | UNIT CONTRIBUTED VALUE $ | FACTOR | EQUIVALENT PRODUCTION OUTPUT |
| A | 500 000 | 80 000 | 10 000 | 420 000 | 42 | 1.00 | 10 000 |
| B | 200 000 | 50 000 | 5 000 | 150 000 | 32 | .71 | 3 550 |
| C | 50 000 | 8 000 | 7 000 | 42 000 | 6 | 0.14 | 980 |
| | | | TOTAL : 22 000 | | | | TOTAL : 14 530 |
| HOW CALCULATED (FIGURES AER COLUMN NUMBERS FROM ABOVE) | | | | | | | |
| - | - | - | - | 2 - 3 | 5 ÷ 4 | $6 \div \hat{6}$ | 7 x 4 |

$\hat{6}$ = HIGHEST VALUE IN COLUMN 6

In fig 3.8 the bases used were:-

1. Net billed sales (Column 2)
2. Equivalent units of production (Column 8)
3. Direct labour cost (Not shown here)

## APPENDIX V. TYPICAL MERITS AND DEMERITS OF VARIOUS COST COMPARISON BASES

| BASE | MERITS | DEMERITS |
|---|---|---|
| A. LABOUR BASES | | |
| 1) TOTAL DIRECT LABOUR<br>2) TOTAL STANDARD LABOUR<br>(BOTH HOURS AND DOLLARS) | NOT SENSITIVE TO:<br>NUMBER OF PRODUCTS.<br>MATERIAL PRICE CHANGES.<br>SALES LAGGING PRODUCTION.<br>LONG MANUFACTURING TIME. | SENSITIVE TO:<br>PROCESS AUTOMISATION AND MECHANISATION.<br>MACHINE BREAKDOWNS |
| | STANDARD LABOUR (HOURS) PUT INTO A UNIT PRODUCT IS A CONSTANT AMOUNT, AND HENCE FORMS A STABLE BASE FROM WHICH TO COMPARE COSTS. | LABOUR VARIANCES TEND TO INTRODUCE UNDUE FLUCTUATIONS IN THE RELATED QUALITY COST TRENDS |
| B. MANUFACTURING COST BASES | | |
| 1) TOTAL MANUFACTURING COST OF OUTPUT.<br>2) TOTAL DIRECT MANUFACTURING COST<br>(MATERIALS, LABOUR)<br>3) STANDARD MANUFACTURING COST | AS THE DESIRE IS TO REDUCE OVERALL COSTS, GIVES EXCELLENT MEASURE OF THE RELATIONSHIP BETWEEN COSTS AND THE OVERALL COSTS. | IF THE MANUFACTURING CYCLE IS LONG, THE MANUFACTURING COSTS COULD NO LONGER BE CURRENT.<br>SENSITIVE TO:<br>PRICE VARIATIONS IN THE RAW MATERIALS, AND THE COST OF LABOUR<br>PROBLEM OF COST INCURRED BY WORK IN PROGRESS NOT BEING REFLECTED. |

APPENDIX V. continued

| BASE | MERITS | DEMERITS |
|---|---|---|
| C) <u>SALES INCOME BASES</u> | | |
| 1. NET SALES INCOME | GOOD IF MANUFACTURING CYCLE IS SHORT. | SENSITIVE TO:<br>LENGTH OF MANUFACTURING CYCLE.<br>TIME BETWEEN COMPLETION AND SALE OF PRODUCT MARKET VARIATIONS. |
| 2. CONTRIBUTED VALUE (NET SALES INCOME - DIRECT MATERIAL COST) | AS THE HIGHEST NET CONTROBUTION IS THE OVERALL AIM, IT IS GOOD TO USE AS A REFLECTION TO SEE HOW QUALITY COSTS VARY AGAINST THE CONTRIBUTION.<br>CONTRIBUTED COST USED TO REMOVE THE VARIATIONS, INDUCED IN A PRODUCT WHICH HIGH MATERIAL COSTS, BY FLUCTUATIONS OF THESE COSTS. | |
| D) <u>UNIT BASES</u> | | |
| 1. UNITS OUT OF PLANT | UNITS OUT IS THE REAL MEASURE OF PLANT ACTIVITY. | SENSITIVE TO:<br>LENGTH OF PROCESS<br>CHANGE IN PRODUCTION<br>AMOUNT OF WORK IN PROGRESS |
| 2. EQUIVALENT UNITS OUT OF PLANT. | ACTUAL COST OF QUALITY PER UNIT FOUND GIVING AN IDEA OF HOW MUCH TO ADD ON TO THE MANUFACTURING COST TO REACH A SELLING PRICE.<br>EQUIVALENT UNITS OUT CAN BE USED TO ALLOCATE QUALITY COSTS TO THE UNITS. | |

## APPENDIX VI INTERNAL FAILURE COSTS OF CASE STUDIES

### A. VINYL PRODUCTS

| DETAIL OF COST | REPORTED OR UNREPORTED | REFERENCE TO FIGS 4.5 AND 4.6 |
|---|---|---|
| 1. Raw material lost for quality reasons | U | |
| a) total raw materials into process | R | |
| b) total materials back from process into 'raw material' stock | R | |
| a) - b) = total material used which gives the total possible metres from the process | | 1 |
| c) Number of metres of sheet sold as first grade | R | 2 |
| d) Number of metres sold as 'seconds' | R | 9 |
| e) Number of metres re-run | R | 5 |
| f) Number of metres thrown away for quality reasons | R | 6 and 7 |
| g) Number of metres lost due to production faults, found using figs 4.5 and 4.6. | U | 8 |
| Thus the raw material cost for quality reasons can be found using A – E in fig 4.7 (See fig 5.3) | | |
| 2. Process and labour time for rework | U | |
| a) metres of product made | R | |
| b) metres of product reworked | R | |
| ∴ Process of labour time necessary for rework = (total running cost of the process and labour) x $\left(\frac{\text{m re-run}}{\text{m made}}\right)$ | | |
| 3. Staff time lost for quality reasons (See B and D in fig 4.7 and text) | U | |

## B. BLASTING EXPLOSIVES

| DETAIL OF COST | REPORTED OR UNREPORTED |
|---|---|
| 1. Raw material lost for quality reasons | |
| a) Pre-processes - only paper and wax lost due to quality. Recorded as 'clean waste' in central areas. | R |
| b) Packaging of explosive lost when product fails to meet specifications and is stripped. The explosive is all reworked.<br>- the cost of paper and wax is almost the same, so the error induced by weighing the losses together is negligible.<br>Recorded as 'dirty waste' in BE. | R |
| 2. Process and labour time for rework | |
| a) Labour stripping | R |
| b) Number of cases reworked for quality reasons | R |
| c) Total number of cases made | R |
| Process cost due to quality = | U |
| $\left(\frac{\text{Number of Cases reworked for quality reasons}}{\text{Total number of cases made}}\right) \times \left(\text{Total Direct Process Cost (labour etc.)} + \text{Wages and Benefits of Strippers}\right)$ | |

## APPENDIX VII EXTERNAL FAILURE COSTS

### A. VINYL PRODUCTS

| DETAIL OF COST | CAUSE AND CIRCUMSTANCES |
|---|---|
| 1. Credits passed to customer | Product failing to meet customer's specification, and the subsequent tests made by AECI. |
| a) Handling costs | The use of the failed material is negotiated. If the customer cannot use the product it is returned to the factory, incurring handling charges. |
| b) Testing | Samples from the failed material are tested to check if the claim is justified. |
| c) Investigation | The staff of the regional sales office investigate the failures. The travelling costs are considered to be a quality cost, but not the salesman's wages. |
| B. BLASTING EXPLOSIVES | |
| 1. Credits passed to customer | Complaints by customers are rare due to the nature of the product, which is destroyed when used. Rare failures occur when the product is chemically unfit for use (exudation), the packaging and product is damaged in transit, or if critical dimensions are not met, i.e. holes in pentolyte. If the product can be used, the amount of credit is negotiated. If not, it is destroyed on site. |
| a) Investigations | As for Appendix VII part A. |

## APPENDIX VIII APPRAISAL COSTS

**LABORATORY**: The laboratory services are currently charged to the departments as overheads, but this is due to be changed, and the production departments will be charged for the laboratory services as they are used. Thus, the laboratory activities become a variable cost of production.

The cost of testing the samples taken in process and at final inspection is thus a variable appraisal cost, and the cost of testing raw materials is a variable cost of prevention.

### A. VINYL PRODUCTS

| DETAIL OF COST | CAUSE AND CIRCUMSTANCES |
|---|---|
| 1. LABORATORY<br>a) Testing - in process and final product. | The cost per test will be found and charged to the production departments. i.e. the cost of testing = $\sum_{i=1}^{n} \left( {}^{\text{Cost}}/_{\text{Test}}\ i \right) \left( \text{No. of Tests of Type } i \right)$ |
| b) Maintenance | Much of the laboratory's equipment is dedicated. The maintenance on that equipment dedicated to testing in-process and final product is also included in this cost. These costs can be obtained from the charges of the instruments workshop, and from outside contractors' charges, and are a fixed cost. |
| B. BLASTING EXPLOSIVES | |
| 1. INSPECTORS | 3 inspectors/shift with 2 shifts per day.<br>$\therefore$ cost of inspectors = 6 x(Wages + .. ..benefits) |

APPENDIX VIII B. continued

| DETAIL OF COST | CAUSE AND CIRCUMSTANCES |
|---|---|
| | The inspectors are supervised by a superintendant who routinely spends approximately 20% of his time on quality activities, hence 20% of his salary and benefits are considered to be a quality cost. |
| 2. LABORATORY | See part A. |

## APPENDIX IX PREVENTION COSTS

### A. VINYL PRODUCTS

| DETAIL OF COST | CAUSE AND CIRCUMSTANCES |
|---|---|
| 1. QUALITY MANAGER | The quality manager (officer at AECI) is responsible for the planning of the quality activities, writing the quality documents, quality audits etc. He also rechecks the test results to assure their accuracy. |
| 2. LABORATORY | The cost of testing materiels as they arrive into the factory is considered to be a prevention cost. |
| a) Testing of incoming materiels | ∴ the cost of testing<br>$= \sum_{i=1}^{n} \left(\text{Cost/test}\right)_i \left(\text{No. of tests of type } i\right)$ |
| b) Maintenance | The cost of maintenance of dedicated testing equipment. (See Appendix VIII A) |
| 3. QUALITY IMPROVEMENT PROJECTS | The costs associated with quality improvement projects, i.e. staff salaries, materials used for tests etc. |
| 4. QUALITY INITIATED MAINTENANCE | That maintenance initiated for quality reasons. This is a variable cost, as it is assumed that maintenance is proportioned to use. |
| B. BLASTING EXPLOSIVES | |
| 1. LABORATORY | See part A |
| 2. QUALITY IMPROVEMENT PROJECTS | See part A |

## APPENDIX X METHOD OF CALCULATION OF EQUIVALENT UNITS OF PRODUCTION USED AS A BASE FOR TREND ANALYSIS FOR BE. AND VP.

This base is used to eliminate the effects of both varying product mixes and production volumes.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| PRODUCTS OR PRODUCT GROUPS | UNITS SOLD IN PERIOD | UNIT SELLING PRICE | FACTOR | ACTUAL EQUIVALENT UNITS SOLD | STANDARD NO. OF UNITS (SET) | STANDARD EQUIVALENT UNITS SOLD |
| | | | COLUMN MANIPULATIONS | | | |
| DATA | DATA | DATA | 3 ÷ 3* | 2 x 4 | SET | 4 x 6 |
| A | | | | Aaj | | Saj |
| B | | | | Abj | | Sbj |
| I | | | | Aij | | Sij |
| | | | | ΣAij | | ΣSij |

3* = maximum per unit selling price

This appendix must be read in conjunction with figure 4.11. The standard number of units as noted in section 4.4.8 is a set value representing a typical month's production, and is liable to be reset after a period of say a year.