A Dynamic Model of Quality Costs and Benefits System for Design Quality

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Abstract

The importance of quality costs and benefits is sometimes not fully recognised by industrial managers. Quality costs money. Industrial managers recognise this and tend to be afraid of spending on quality. But quality also earns money. Industrial managers do not seem to be fully convinced of this fact. Unfortunately, even the existing literature on the subject does not encourage investing for higher quality. Most of the cost models about quality deal with quality improvement and the costs associated in achieving the desired level of quality, but fail to incorporate the benefits of improved quality.

In this work, an attempt has been made to develop a quality costs model which incorporates the benefits. The quality cost elements have been drawn from various standards sources such as British Standards and American Society for Quality Control publications on quality costs. The benefits from investing for quality are taken from recently published case studies and reports as well as from our own experiences. The elements of quality related activities of design department, such as design standards, training design staff and test equipment are identified. The contribution of each individual element, starting from estimation of losses due to poor design to prevention of poor design is isolated and linked dynamically so that costs and benefits are demonstrated through time.

The quality costs and benefits model was developed using the System Dynamics Modelling approach and simulated using the computer software package "Professional DYNAMO Plus". The simulated results demonstrate the extent to which prevention investment is justified by future earnings.

It is felt that the model can be a significant addition to course material for training programmes of industrial managers. It allows the user to explore the consequences of different quality management policies such as the amount of investment and the nature of investment on the profit performance and delay before profits are increased in an organisation. It is hoped that the model will serve as a useful tool in the hands of decision-makers, encouraging them to invest more in prevention activities.

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INTRODUCTION

The importance of quality costs and benefits is sometimes not recognised by industrial managers and worse, it is misunderstood. Misunderstandings determine attitudes; determined attitudes lead to sub-optimal management policy sub-optimal policy leads to company to settle for mediocre quality targets; in the end mediocre quality is the reputation of the company and affects directly the demand of the customers for its product(s).

Quality costs money. Industrial managers recognise this and tend to be afraid of spending money on achieving quality. This is because while costs are obvious enough, since accounts need to be kept of them, the benefits and savings which arise from improving quality are elusive and are never shown (Kaplan 1983), (Kaplan 1986), (Holusha 1986), (Park 1987). So, we can never know how much more we could improve the benefits and save if we spent more on quality.

The well known model (figure 1), relating quality to prevention, appraisal, and failure costs, first appeared, without any research or attributed sources, probably in Juran (1962). It has been reproduced many time since, mostly in chapter one of quality text books, but also in the British Standard on Quality Costs BS 6143 (BSI, 1981). Even if it had a factual basis, this model has several major difficulties (Bajpai and Willey, 1989). First, there is no universal measure of quality. BS 4778 (BSI, 1987) says: "Quality is the totality of features and characteristics that bear upon its ability to satisfy stated or implied need". While "totality" may sound fine in principle, it poses a conundrum. For a car, say, what is the "totality", fuel economy, reliability, safety, comfort or the drag factor and others? They are all separate components of quality which, if measured at all, have separate scales and different units. Only the customer decides "satisfy" and there is on simple, realistic index of that to plot as the axis of a graph. So much for the horizontal axis. The vertical axis of the model shows the costs of achieving a particular quality level. However, recent surveys of industry indicate that in most industries quality costs are not recorded and collected (Morrison 1984), (Abed and Dale 1987), (Kaplan 1984). Even if the components of quality costs could be unearthed, they would only refer to one quality position and we do know what the position is because we cannot measure it. This actually inhibits quality improvement. A company cannot tell whether it would reduce or increase but according to the model (figure 1), they could choose the wrong direction for change and quality costs increase!

Again the vertical axis of the model (figure 1) is variously labelled as `costs' or `unit costs'. The difference between these two is important for reasons associated with economy of scale. If a company invests seriously in a quality improvement programme, then the costs of prevention are spread over all its products. In addition, the results of improvement, as reflected in the marketplace mean increased demand. So the Unit costs of prevention are spread over a larger number of items. Yet the benefits are generated per item sold. The well-known graph does not represent that fact.

GENERAL DESCRIPTION OF THE MODEL

Several case studies and reports on quality have shown that when manufacturing organizations increase their investment on prevention-related activities they gain higher benefits in future (Blank and Solorzarno, 1978), (Brisac et al, 1971), (Chauvel and Andre, 1985), (Denton, 1988), (Issac, 1984), (Willium, 1985). The experiences of Deming (1986), Crosby (1979) and Oakland (1989) also favour higher investment in the form of so called prevention-costs to increase for future benefits.

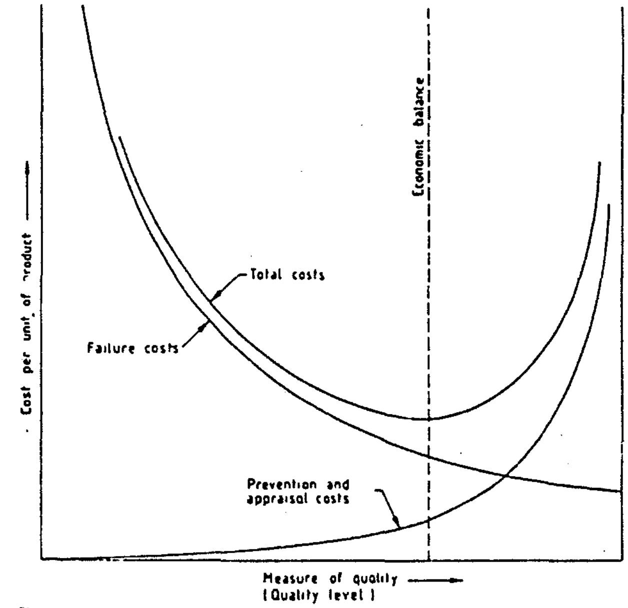


Figure 1 (After BS 6143, BSI 1981)

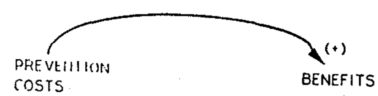


Figure 2

Figure 3

Figure 4

If higher investment in prevention produces benefits to a company that must be shown in the model. This phenomenon is shown in figure 2. The positive sign at the head of the arrow indicates that increasing prevention costs mean increasing benefits. The increase in incoming benefits will lead to an increase in cumulative benefits as shown in fig 3. However, the immediate effect of investment will the lessening of cumulative benefits (total reserve) as depicted in fig.4.

The negative sign at the head of the arrow indicates that higher investment in the form of prevention costs mean a reduction of cumulative benefits.

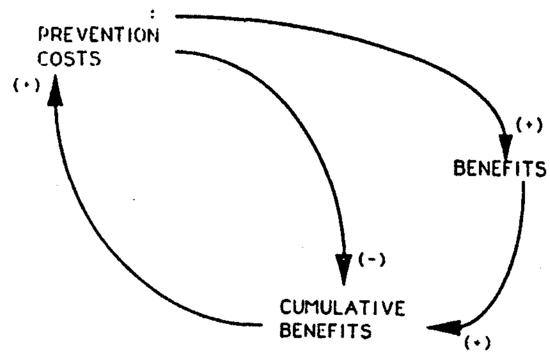


Figure 5 Causal loops diagram
showing prevention costs and benefits

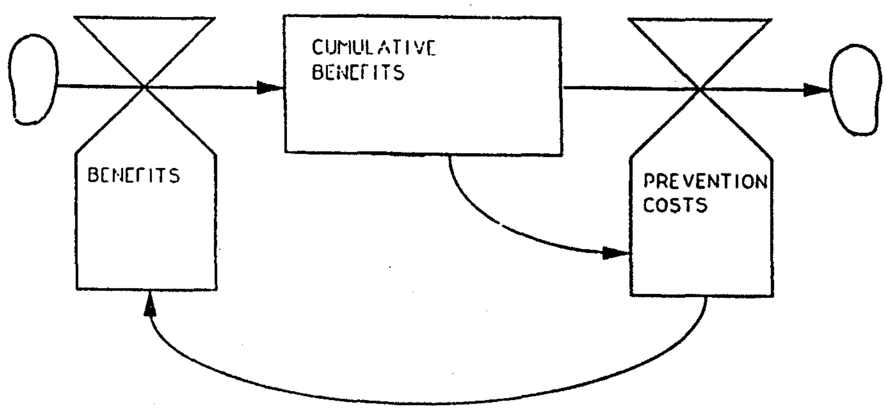


Figure 6 Flow diagram
showing prevention costs and benefits

Figure 5, which is formed by the combination of figs 2 to 4, is commonly known as "causal-loop" diagram. It contains two loops. One is a positive loop having prevention costs, benefits and cumulative benefits and the other is a negative loop between prevention costs and cumulative benefits.

These elements and logic are shown in the form of flow diagram using system Dynamics (Forrester, 1964) conception of `level' and `Rates' in fig 6. The cumulative benefit is shown as a level while prevention costs and benefits are depicted as rates. As explained above, there are two loops, a positive loop linking benefits, cumulative benefits and prevention costs and a negative loop linking prevention costs and cumulative benefits. These two loops serves together as a closed-loop feedback system. The concept developed and shown in figs 2 to 6 has been utilized throughout the building of the quality costs and benefits model for design quality. However, minor adjustments are made to suit the particular conditions.

DESIGN QUALITY

It has been stated and observed that some of the most costly problems with a product are caused by an in adequate design. Often problems in manufacture, purchasing, assembly, performance and servicing, commonly called "quality problems", have root causes in the design of the part or the assembly. So the quality of design can be evaluated from following points:

(1) The manufacture's point of view: The manufacturer is basically concerned that the component could be made from standard materials, from existing machines/machine tools with minimum special tools and uncomplicated manufacturing instructions.
Some design features adversely influence productivity such as unnecessarily tight tolerances or specifications which need special equipment for measurement but have little impact on performance.

(2) The `User's point of view: The user's view is mainly a concern for "fitness for use" or "to serve intended purpose". Durability and reliability of a product are other important concerns of the user. Apart from these he/she also expects that, in the case of failure, the product can be repaired/serviced at a reasonable cost without unreasonable delays.

In addition to the manufacturer and user, the purchase department is also affected by the design of the product particularly when there are large numbers of components to be procured from outside suppliers and assembled into the final product during the manufacturing cycle. The purchasing department is basically concerned with procuring material at reasonable costs and with reliable delivery. These aims can be achieved more readily if the product is made up from standard materials, standard components and standards hardware.

Inadequate adoption of these considerations in product design will result in more scrap, more rework and excess wastage resulting in higher manufacturing costs, higher quality costs and higher warranty, replacement, maintenance, and servicing costs. All these lose customer goodwill, which in turn leads to loss of prospective customers.

An improved design, incorporating the needs of manufacturers, purchasers and users, can be developed if the design staff is adequately trained and provided with necessary requirement, such as design standards and test equipment. Thus, for the purpose of the quality costs and benefits model, three elements have been in identified:

(1) Design standards
(2) Training design staff and
(3) Test Equipment

DESIGN STANDARDS

Design standards are sometimes not available to design and development staff. The cost of buying and using kill this bkank line appropriate design standards as very small comparey with other capital expenditure in the company but standards play a significant role in improving the quality of manufactured products and in the reducing procurement costs.

In fig. 7 the causal loops show the increasing the costs of design standards mean reduction in cumulative benefits from design standards (CBDS). In simple terms it means a debit from `design standards' account. This is represented by negative signs at the head of the arrow. The other effect of this investment is the increase in benefits which is shown by positive sign at the head of the arrow at the benefits from design standards (BDS). These incoming benefits increase the CBDS. This enables the company to invest more for the same cause which in turn enhances the benefits.

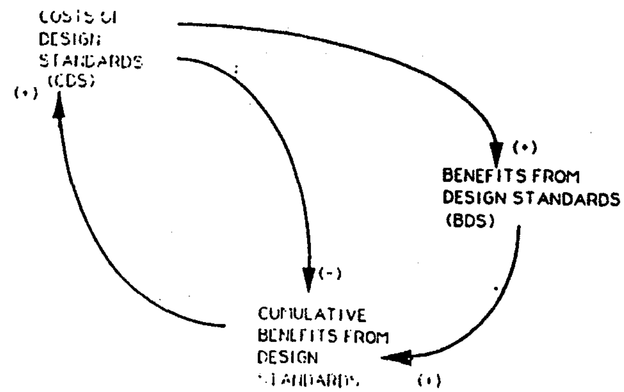


Figure 7 Causal loops for design standards

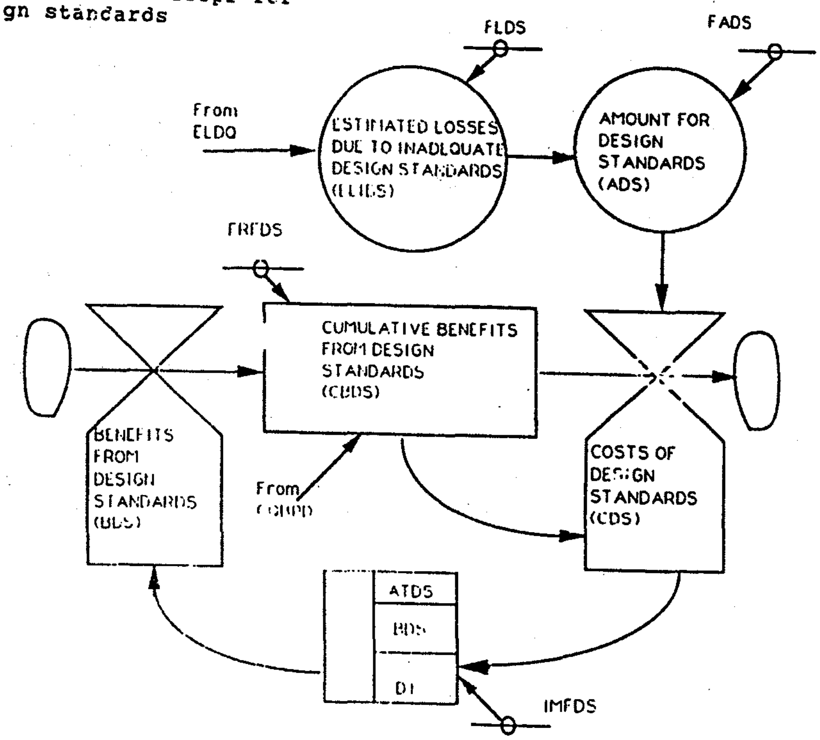


Figure 8 Flow diagram for design standards.

Figure 8 shows the flow diagram for design standards. Based on the estimated losses due to design quality (ELDQ) and with the help of factor of losses due to design standards (ELIDS), the estimation of losses due to inadequate design standards (ELIDS) is made. This is used for determination of the amount for design standards (ADS) depending upon factor for the amount for design standards (FADS), that when invested known as cost of design standards (CDS).

On the other hand, an initial amount for the procurement of design standards has been allocated, from cumulative quality benefits from prevention in design (CQBPD), depending upon the factor for design standards (FRFDS), known as cumulative benefits from design standards (CBDS).

That was all about the costs side, now coming to benefits aspect. The flow-diagram shows that all benefits from (using) design standards (BDS) come after a first order delay D1, and all the benefits are expected to emerge within a certain time span shown as averaging time for design standards

(ATDS). These benefits ought to increase, as an independent positive impact factor is incorporated in the model. Consequently the total funds for design standards goes up and so the cumulative benefits from design standards (CBDS).

TRAINING DESIGN STAFF

It has been acknowledged in the literature that sometimes components and assemblies are designed by those designers who are not adequately educated and trained for the job. Their concepts may quite out-of-date. They may be lacking in the latest know-how (and know-why!) of manufacturing techniques, materials and manufacturing processes. These personnel need up to date their knowledge through a programme of training. Training costs money. Cost will be incurred in:

- identifying training needs
- carrying out training
- keeping records of training

The costs incurred in training design staff may be considered as quality prevention costs. The benefits of training can be achieved in the form of "quality design" of products which lead to:

- Ease in manufacturing. This means saving in the form of less scrap, less rework and less wastages will appear.
- Satisfied user. This should lead to an increased demand for products.
- Ease in purchasing: As it is always convenient to buy standard component rather to arranging nonstandard parts.

Figure 9 shows the causal loops for training design staff. The figure explains that the increasing the cost of training design staff (CTDS) reduces cumulative benefits from training design staff (CBTDS). This is shown as a negative sign at the head of the arrow that links cost of training design staff to the cumulative benefits from training design staff. On the other hand, the investment for training brings benefits which are listed above. These benefits ultimately increase cumulative benefits enabling the company to invest more in training design staff. This relationship is shown with arrows with positive signs.

The figure 10 shows the flow diagram for training design staff. The diagram show that a part of losses in estimated losses due to design quality (ELDQ) which are attributed to inadequate training of design staff (ELITDS) with the help of a factor of losses due to training design staff (FLTDS). To recover the losses an allocation is made known as cumulative benefits from training design staff according to a factor known as for training design staff (FRFTDS). On the basis of ELITDS an amount for training design staff (AMITDS) to be invested for training design staff, is determined using a factor called factor for amount for training design staff (FATDS).

As training takes quite some time before a person is ready to show the impact of training that he had taken, a third order (D3) is there between investment is to be made and benefits to emerge. The figure also shows the period during which all the benefits of the training are expected to emerge (ie. averaging time for training design staff) (ATTDS) and the positive impact factor. The incoming benefits from TDS, increase cumulative benefits from training design staff.

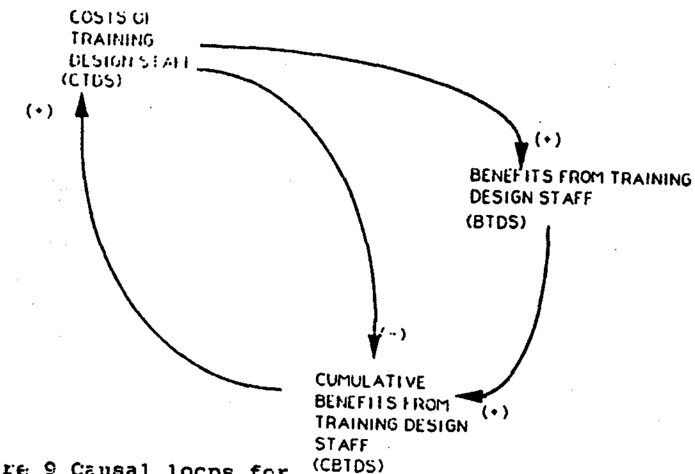


Figure 9 Causal locps for training design staff.

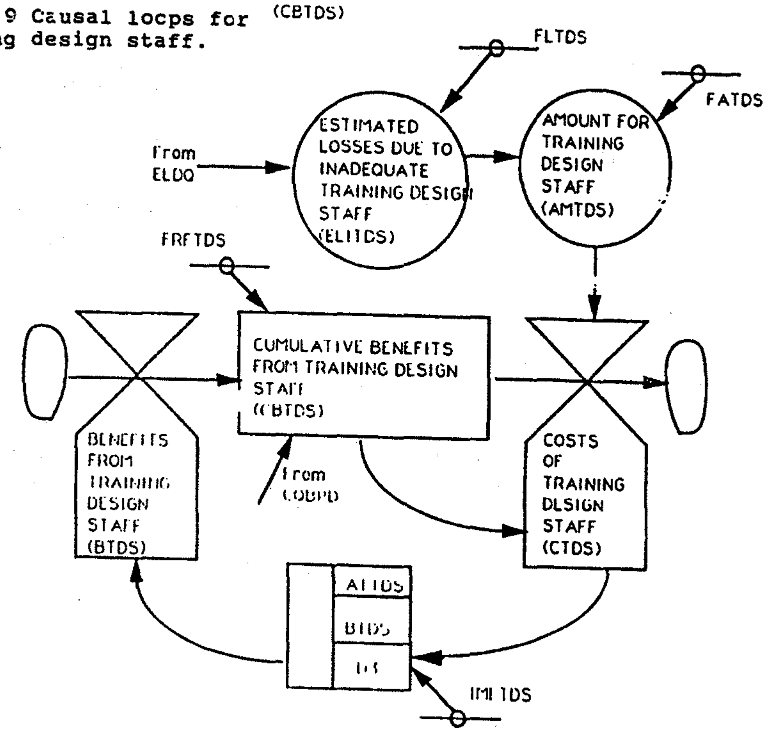


Figure 10 Flow diagram for training desigr staff.

TEST EQUIPMENT

Lack of sufficient test equipment is another cause identified for poor product quality. Sometimes prototype can not be fully tested for lack of sufficient test equipment. This causes problems in performance and increases repairs and warranty costs.

Figure 11 shows the costs and benefits relationship in the form of causal loops. It shows that the increasing the costs of test equipment (CTE) means a reduction in the cumulative benefits from test equipment (CBTE). This is shown as a negative sign at the head of the arrow that links CTE and CBTE. However, the investment for test equipment has beneficial effects which are shown as benefits from having test equipment (BTE) available in the diagram. These benefits ultimately increase CBTE, so the companies can invest more in test equipment. This concept is represented by arrows with positive signs at their heads.

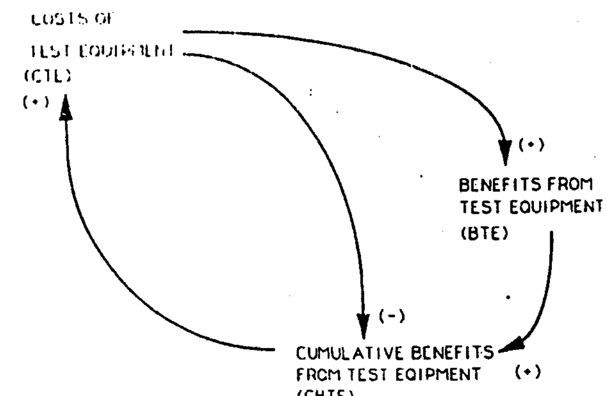


Figure 11 Causal loops for test equipment.

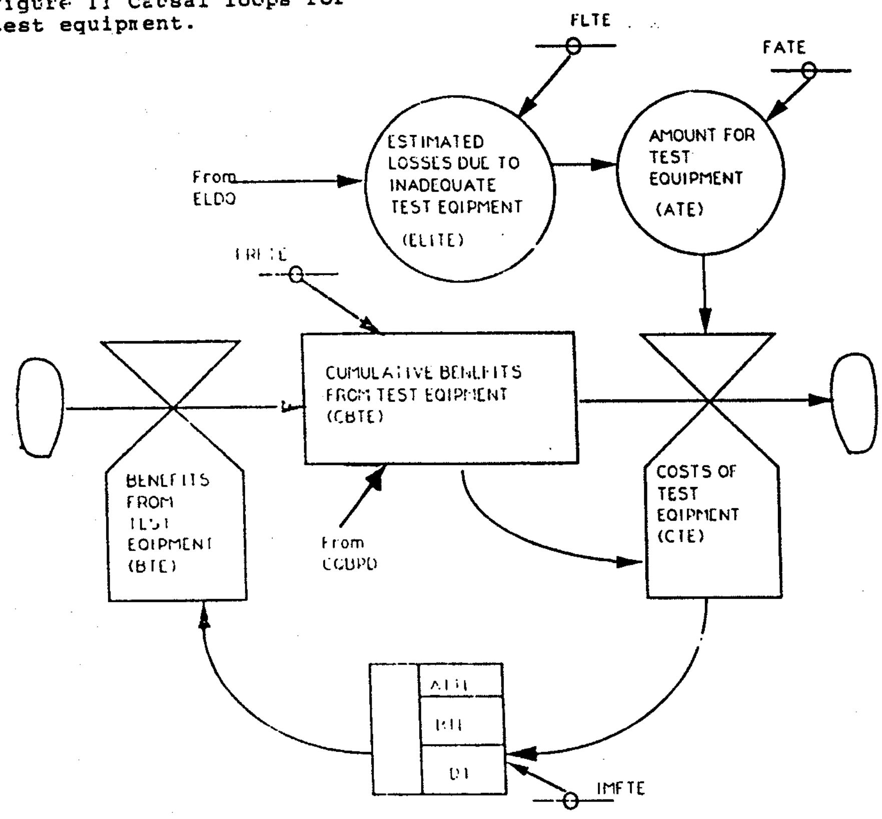
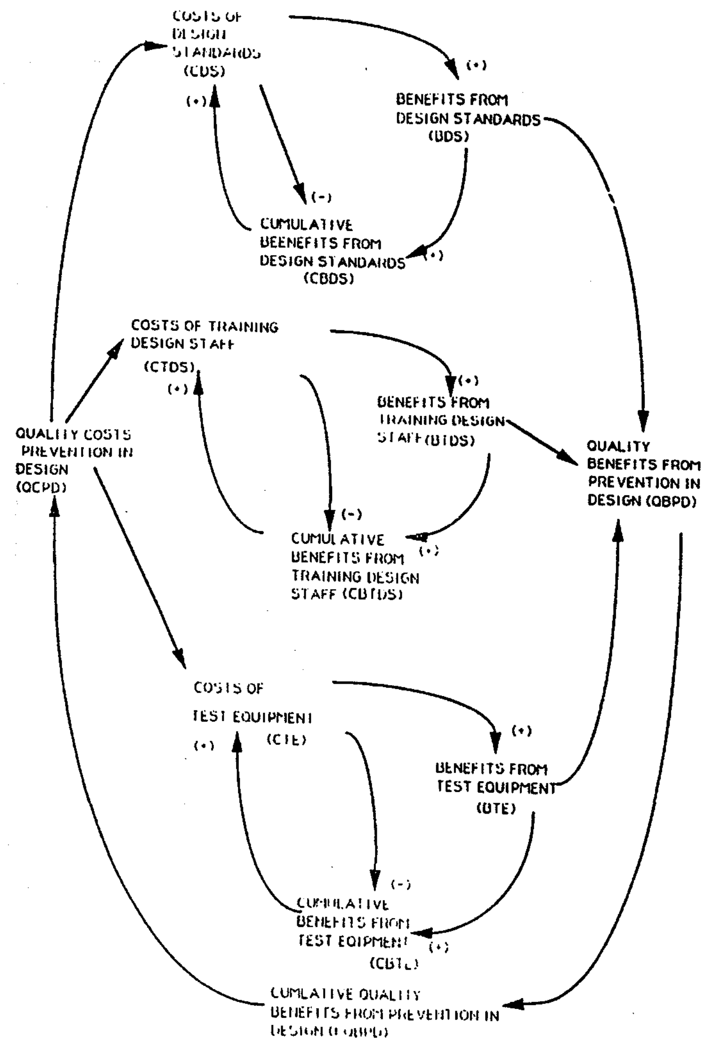


Figure 12 Flow diagram for test equipment.

The figure 12 represents flow diagram for test equipment. It shows that a part of losses in estimated losses due to design quality (ELDQ) are attributed to inadequate test equipment. The estimation of losses due to inadequate test equipment in made in accordance with the factor of losses due to test equipment (FLTE). In order to recover the losses an allocation is made called cumulative benefits from test equipment (CBTE) according to a factor for test equipment (FRFTE). On the basis of estimated losses due to inadequate test equipment an amount for test equipment (ATE), to be invested for test equipment, is worked out, using a factor for allocation for test equipment (FATE) and known as costs of test equipment (CTE).

Further, to incorporate the time delay in planning decision, finance, procurement action, installation and commissioning of the equipment a first order delay has been introduced between investment made and benefits occur. The positive impact factor ensures the benefits and averaging time, as usual shows the period during which most of the benefits will emerge. Finally, the incoming benefits will raise the cumulative benefits for equipment ie. funds for further test equipment.

DESIGN DEPARTMENT



The causal loop diagram for the design department is shown in figure 13. This is made up by combining causal loops for design standards, training design staff and test equipment. The figure shows the quality costs prevention in design is the sum of the costs of design standards, training design staff and test equipment. Similarly the quality benefits from prevention in design are the sum of the benefits arising from design standards, training design staff, and test equipment. These benefits raise the cumulative benefits ie. total budget for the design department.

In figure 14 the complete structure of design department is depicted using System Dynamics symbols. This is drawn by combining the flow diagrams for design standards, training design staff and test equipment, as shown earlier. The losses due to design quality are estimated (ELDQ), as a fraction of the losses in sales benefits (ELSB) with the help of a factor called loss factor for

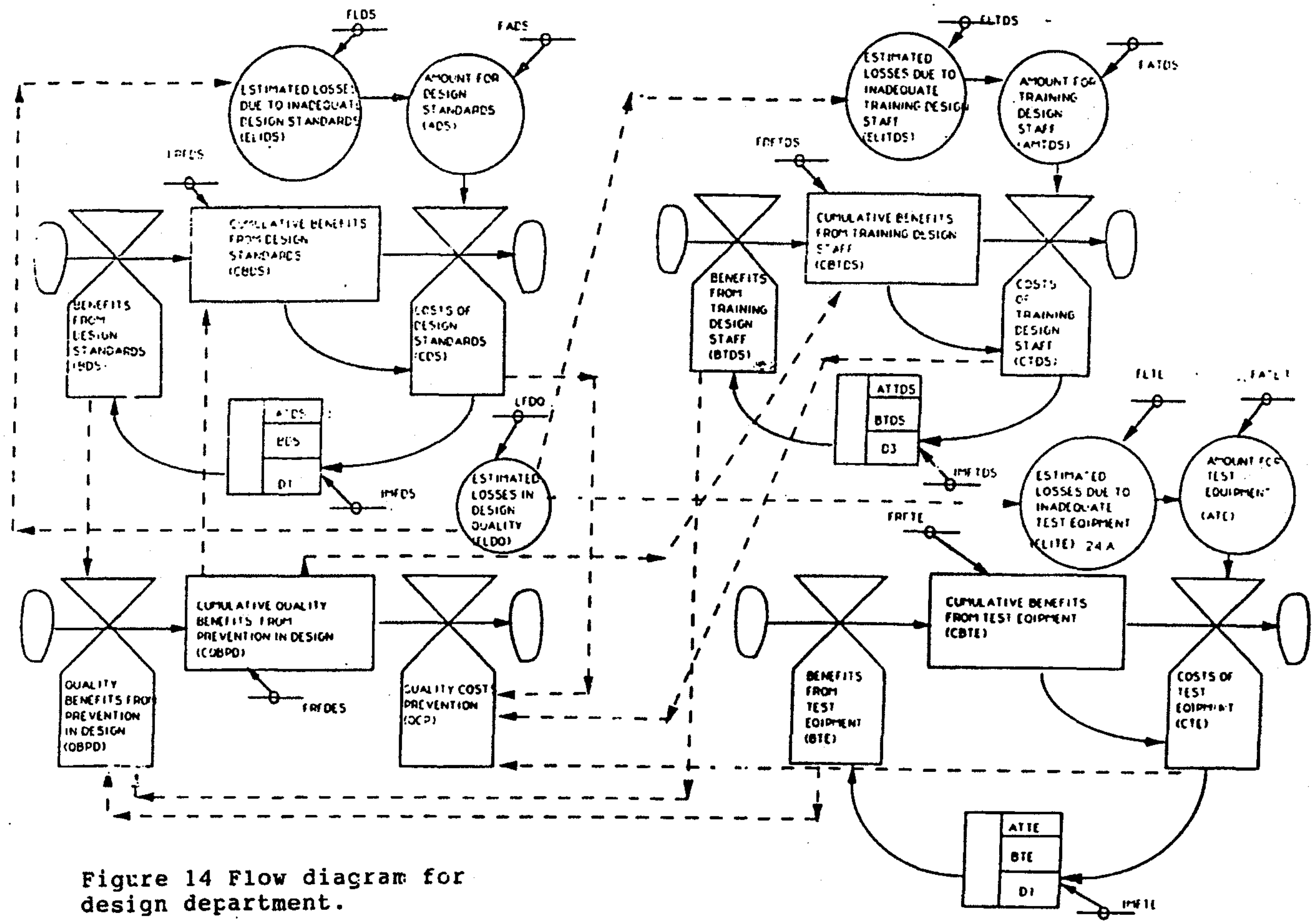


Figure 14 Flow diagram for design department.

design quality (FLDQ). These estimated losses in design quality are further attributed to individual elements within the department, ie. design standards (FLIDS) training of design staff (FLITDS), and test equipment (FLITE). At the time, an initial allocation for the improvement of design quality is made and called cumulative quality benefits from prevention in design (CQBPD). Cumulative quality benefits from prevention in design are worked out as a fraction of the cumulative quality benefits in sales (CQBS), depending upon a factor called: factor for design' (FRFDES). From the cumulative quality benefits from prevention in design berther allocation are made to individual quality elements ie. for design standards CBDS, for training design staff CBTDS, and for test equipment CBTE. Further, as explained in figure 13, the quality costs of prevention in design is the sum of the costs of design standards, training design staff and test equipment, and similarly the quality benefits of prevention is the sum of benefits from design standards, training of design staff and test equipment.

EQUATIONS OF THE MODEL

For developing equations of the model on DYNAMO (Pugh-Robert 1986) format the cost is considered as rate and shown in rate equation. For example the cost of training design staff is expressed as:

CTDS KL = PULSE (ATDS.K,DITDS,FITDS,IITDS)*(1/DT)

Where,

CTDS	:	Costs for training design staff
ATDS	:	Amount for training design staff
DITDS	:	Duration of investment for training design staff
FITDS	:	First time investment for training design staff
IITDS	:	Interval between investment for training design staff

This investment, as experience shows, result benefits that termed here as benefits from training design staff, and again expressed using rate equation.

BTDS,KL = DELAY 3 (CTDS.KL,ATDS)*IMFTDS

Where,

BTDS	:	Benefits from training design staff
CTDS	:	Costs for training design staff
ATTDS	:	Averaging time for training design staff
IMFTDS	:	Impact factor for training design staff

There benefits ultimately increase the cumulative benefits which is shown below in form of level equation:

CBTDS.K = CBTDS.J + (BTDS.JK - TDS.JK)* (1/DT)

Where,

CBTDS	:	Cumulative Benefits from training design staff
BTDS	:	Benefits from training design staff
CTDS	:	Costs of training design staff

The complete listing of the model equations is beyond the scope of this paper. But, the same is given in Bajpai (1990). The interested readers can get the model listing by writing to the author.

TEST RUN OF THE MODEL

The test run establishing the behaviour of the model under a set of conditions, that ought to be the environment under current economic and industrial setup is shown in forthcoming section. The model behaviour is displayed & discussed in subsequent section. The incorporation of benefits of improved quality' against a time scale can be seen as a major achievement in this research work.

DESIGN STANDARDS

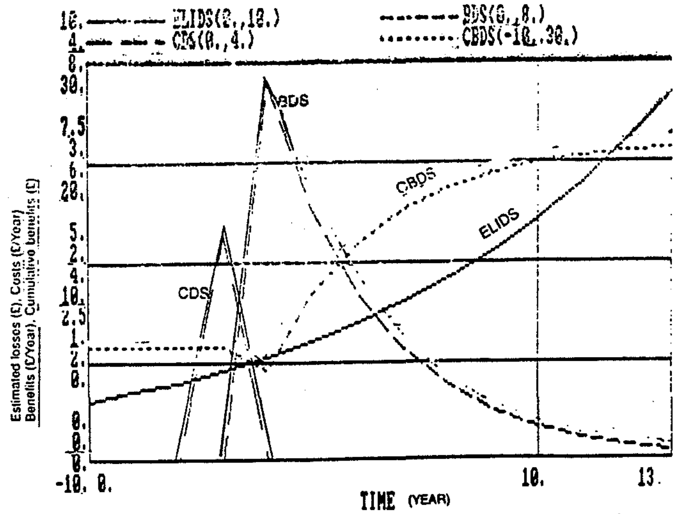


Figure 15 Test run for estimated losses due to inadequate design standards (ELIDS), benefits from design standards (BDS), and cumulative benefits from design standards (CBDS).

Fig. 15 shows the effect of investment in design standards. The time is shown along X axis while costs and benefits are along Y axis. The figure shows that estimated losses due to inadequate design standards (ELIDS) are continuesly increasing. The investment for providing adequate design standards was made after three years from the start, shown as costs of design standards, results a reduction in cumulative benefits from design standards (CBDS), appears as a depression in CBDS curve, immediate after the investment was made. The effect of investment appears after a period of one year as shown by benefits from cumulative benefits design standards (BDS). These benefits start after the lapse of one year, soon reaches to their peak values and there after gradually reduces. However the incoming benefits increasing.

TRAINING DESIGN STAFF

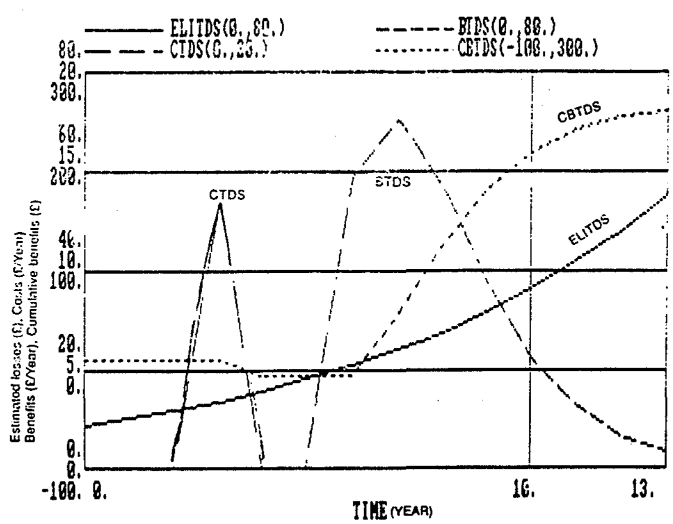


Figure 16 Test run for estimated losses due to inadequate training design staff (ELITDS), costs of training design staff (CTDS), benefits from training design staff (BTDS) and cumulative benefits from training design staff (CBTDS).

Training is a time consuming process, whether it is for top management, middle management or for perator. As explained in the previous case, the losses due to inadequate training of design staff are estimated and suitable amount is investened for the training design staff. This investment forms a substantial part of the training budget for design staff. When an investment is made from this budget, there will be decrease is it (as shown by a dip ie. CBTDS curve fig 16). The investment for training is made for one year period and the benefits of training are shown as the BTDS curve, which occur after a considerable amount of delay. The BTDS curve shows that the benefits from training started to occur after initial delay of three year period. The figure 16 shows that the benefits from training started to occur after an initial delay period of 3 years, gradually they rise to their peak and then slowly decrease as no further investment were made there after. This can be taken as a need for further training or re-training. The cumulative benefits, however, keeps on increasing. The figure also shows estimated losses due to inadequate training.

TEST EQUIPMENT

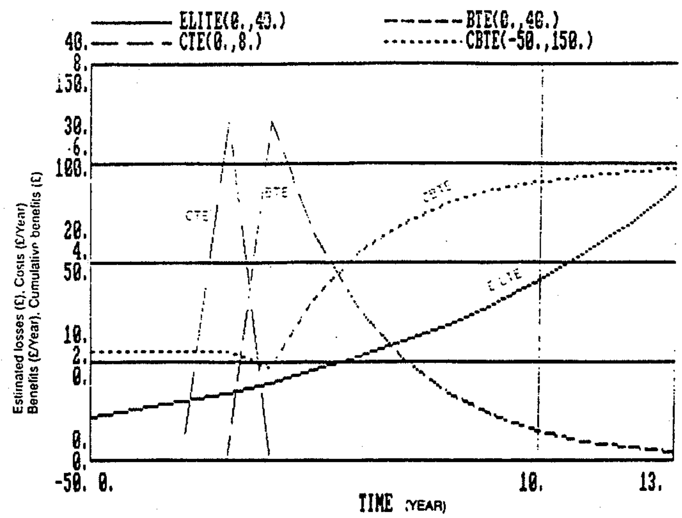


Figure 17 Test run for estimated losses due to inadequate test equipment (ELITE), costs of test equipment (CTE), benefits from test equipment (BTE). and cumulative benefits from test equipment(CBTE).

Figure 17 shows the costs and benefits curve for test equipment. The curve ELITE one word only the estimated losses due to inadeque test equipment. A one-time investment for cost of test equipment (CTE) is shown by a triangle CTE is the third year. The cumulative benefits rise as the benefits form the use of test equipment (BTE) emerge. When the equipment is new the benefits are expected to be maximum, however as the equipment ages the other costs such as maintenance, spare parts expenditure increases and hence the net benefits slowed down. So the CBTE curve starts to flatten as time passes. This may necessitate another investment in test equipment.

DESIGN DEPARTMENT

The combined effect of investment in design department is shown in the fig 18. As the investment for design standards training design staff, and test equipment are made at the same time (during the third year) all three costs curves overlap to from QCPD. The base of QCPD represents one year duration ie. duration of investment. The benefits from design standards and test equipment can be seen in fourth year in the form of a small notch in QBPD curve. The later portion on the benefit curve incorporates the benefits from training of design staff. Which starts only after sixteen year. The cumulative quality benefits from prevention remains unchanged, till investment is made in third year. However, after a short decrease in the fourth year the CQBD curve continuously rises due to incoming quality benefits of prevention in design.

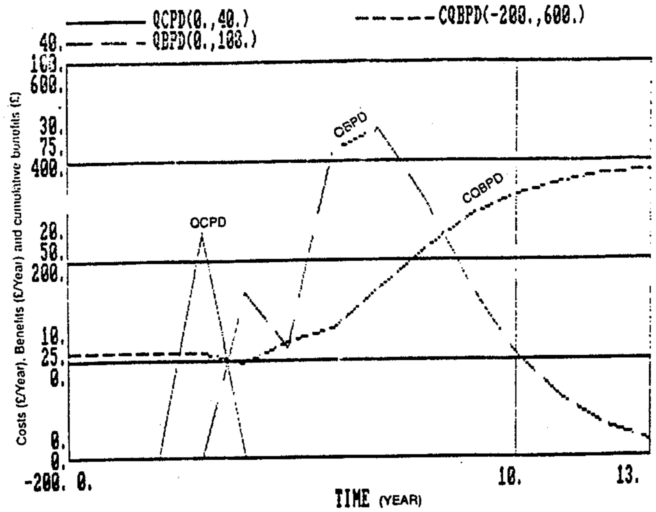


Figure 18 Test run for quality costs of prevention in Design (QCPD), quality benefits from prevention in Design (QBPD) and cumulative quality benefits from prevention in Design (CQBPD).

CONCLUSION

The work is an attempt in the direction towards development of a model which incorporates benefits of improved quality. In this, design quality-cost-elements-design standards, training design staff and test equipment have been identified and linked dynamically so that costs and benefits are demonstrated through time. The model presented here probably first of its kind in which the benefits of improved quality are incorporated against a time scale. It is felt that model can be a significant addition to course material for training programmes of industrial managers. It allows the users to explore the consequences of different quality management policies. Such as amount and nature of investment on profit performance. It is also hoped that the model will serve as a useful tool in hand of decision makers encouraging them to invest more for design standards training design staff, and test equipment, in order to improve design quality and capture the benefits.

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