Ergonomics—costs and benefits ☆

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Abstract

Ergonomics is primarily concerned with improving the performance of man or of man–machine systems. Although many applications have produced evident improvements, the terms of reference and the results are not often expressed in measures that are easily converted into financial savings. However, there is a growing demand for cost–benefit data of ergonomic improvements, and several examples in which the application of ergonomic principles has resulted in tangible benefits, are reviewed.

Cases are cited of increases of productivity resulting from equipment redesign and of savings achieved from the reduction of accidents, and from improvements in the working environment. It is concluded that there is, as yet, no large body of well-documented cases of financial savings accruing from the application of ergonomics, due in many cases to the difficulties of costing actual changes in performance in the work situation. The need for further studies is debated, and it is suggested that the use of ergonomic data in a design programme should not necessarily be based on the prediction of financial benefits.

1. Introduction

Historically, present day ergonomics evolved from wartime requirements to ensure the ability of operators to control weapon systems or interpret information from newly developed electronic displays and communication systems such as radar. The emphasis was, therefore, primarily on improving the performance of given man–machine combinations, rather than producing improvements in efficiency measured in terms of value added per man hour.

This attitude is still prevalent today, coupled in some quarters with the idea that ergonomics is some form of welfare service to be provided for the employee by improving his comfort, health or safety. Indeed, although financial savings may be shown to accrue from applying ergonomics to job or equipment redesign, they have seldom been the reasons for establishing an ergonomics service or department within an organisation. Thus the USA armed services, possibly the most extensive users of ergonomics data in the western world, require compliance with their human engineering standard, MIL STD 1472, to:

- achieve satisfactory performance by operator, control and maintenance personnel;
- reduce skill requirements and training time;
- increase the reliability of personnel-equipment combinations;
- foster design standardisation within and among systems.

In many cases these criteria are sufficient justification for the employment of ergonomics, since many data show that designing work methods, equipment and environments to suit the capacities of users greatly improves their performance, comfort and health. However, this approach, qualitative rather than quantitative, coupled with the as yet limited industrial application of ergonomics, has resulted in a paucity of data on the financial benefits of ergonomics. With the current preoccupation with production efficiency, design rationalisation and cost–benefit studies of alternative designs and processes, the subject is ill-equipped to refute allegations that financially there is no benefit to be had from ergonomics, or even to provide evidence of economic advantages to justify the inclusion of an ergonomist on a design team. Nonetheless, such questions are increasingly being asked.

Whether they should be asked is debatable, but to answer them requires evidence derived from the sort of ‘before and after’ comparison normally associated with work study techniques or more recently with value analysis programmes. Few such studies have been documented; a review in Whitfield (1962) covered the
handful of validation trials in the literature at that time, and a more recent extensive review (Slade, 1969) has added few more cases.

Not only are examples scarce, but few that have been published include economic data. This reflects the difficulty of converting the usual ergonomic criteria of human performance into costs, for example when reducing the incidence of mistakes or accidents made by a process operator to a monetary value. Not only this, but performance gains shown during comparison trials under carefully controlled conditions may be confused by other effects in actual use or by shop-floor conditions, or the criteria used during the comparison trial in a laboratory may prove unsuitable or meaningless in an industrial situation. Apart from these difficulties, the ramifications of industrial bonus systems or the results of ‘productivity bargaining’ over proposed changes in working methods can obscure potential savings when put into practice.

2. Savings from equipment redesign

Faced with such complications, it is not surprising that many ergonomic programmes do not continue beyond giving advice during the design stage. Indeed to argue that funds be allocated for a post-design evaluation of ergonomic improvements implies a lack of confidence that would dissuade some managers from employing ergonomics in the first place.

Nevertheless, examples are available. In a comparison between an old and a redesigned speed control for an industrial sewing machine (Singleton, 1960), possible differences between laboratory results and shop floor practice were accounted for by running a second comparative trial of both machines during actual workshop use. Records taken over one month’s operation of both machines showed a potential improvement in the production rate of between 10% and 15%, from what was a relatively simple change in the machine control dynamics. The increase in production was later validated on a large scale using conventional time study techniques.

Translating the improvement into economic terms proved difficult, the savings to the company depending on the bonus system finally agreed between management and operatives. Singleton estimated that by dividing the gains equally between the two interests, earnings would increase by 5% and the capital cost of the new control units, which had a life of seven years, would be recovered in about three years’ operation.

In another case (Murrell and Edwards, 1963), when investigating differences in performance between machine operatives using conventional drum scale lead-screw indicators and those using digital indicators (Gibbs, 1952), it was found that wide variations in work undertaken prevented direct comparisons of time to do the same job. By distinguishing between setting time and machine cutting time, however, comparisons were made between the performance of four operators (two young, two old) using both types of machines over a period of eight weeks. Analysis showed that the digital leadscrew indicators gave an 11% increase in machine utilisation, in terms of minutes cutting per hour of operation (Fig. 1).

From another company, Slade recently obtained comparative figures between machines with digital and with conventional drum, leadscrew indicators (Table 1, Fig. 2).

These figures were taken over several weeks routine use. The impressive reduction in operating time represents a financial saving to the company of 9 s. per hour per machine, allowing for incentive bonus.

![Fig. 1. The operator adjusts a short boring tool setting; the indicators enable the lathe to be used as a measuring instrument as well as a metal chip remover.](image-url)

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3. Accidents and mistakes

The foregoing examples clearly show savings in time resulting in savings in money. There are many cases of course, where ergonomic improvements to tasks or equipment do not result in savings in time, or increases in work rate, for example when reducing the incidence of accidents or mistakes.

In the USA there have been a number of investigations into the cost of accidents, and the West German Iron and Steel Federation has also sponsored a research programme on ‘The Direct and Indirect Costs of Accidents’ (Berckhoff, 1952). This has been summarised with an attempt to apply the results of this and some of the USA research to the British Iron and Steel Industry (Laner, 1957). However defining the exact cost of any particular accident remains extremely difficult.

Risks, and hence costs, can be greatly reduced in many cases by the use of suitable protective equipment and safety measures. A survey of the economics of an eye safety programme in a factory in the USA (Suleck, 1965) showed how a mandatory examination of the sight of all workers, with the provision of prescription safety glasses to the 35–40% who required them and plain safety glasses for the rest, cost less than the estimated amount payable under workmen’s compensation for a single eye injury.

It is not always possible to identify specific causes of accidents of course, and hence those areas in which ergonomics could be of benefit; one reason being that there are usually several contributory factors involved. For example, the number of aircraft accidents that have occurred specifically from the pilot misreading a three-pointer altimeter—a notoriously confusing instrument (see the article in the December issue on page 16)—is not known, but it seems certain that such ‘human errors’ have contributed to a considerable number of crashes.

In another case, a contributory factor in the crash of an experimental aircraft in the USA seems to have been that the pilot made an error when using a control which had been designed to operate in the opposite direction to that recommended by human factors engineers.

However, the Cornell–Guggenheim International Aviation Centre in the USA has published a report (Lederer et al., 1963) giving monetary values of many aspects of accidents and over 30 references to other economic studies of transport accidents. It includes financial statements to show that any improvement which reduces the likelihood of transport accidents is also worthwhile in monetary terms.

In a more routine application, savings in cost arising from the redesign of the cab of an electric overhead travelling crane were studied by R. G. Sell, at the British Iron and Steel Research Association. It was found that by changing the design to allow the operator to see the ‘hook’ (in this case a large magnet) and reach and operate the controls at the same time, the cost of damage to railway wagons, etc., caused by impact of the crane magnet would be reduced by at least £30 per week.

The modifications to the crane cost £270.

Even the cost of simple mistakes can be high, especially when they are widespread or occur over a long period. Over a period of more than 7 years a meter reader consistently misread the water meter—an notoriously confusing device—of a large hotel in the USA (Chapanis, 1965). Eventually a compromise settlement was agreed between the hotel and the city water department for $12,569, and even this represented a loss of some $8000 in water department revenues.

4. Environmental redesign

Despite the large number of applications of ergonomic principles in the fields of lighting, noise protection and heating and ventilation—whether by ergonomists or not—there is no greater number of documented examples of financial benefits in this area than in others. Some of the difficulties of costing improvements in production resulting from changes in...
lighting levels or other environmental factors have been discussed (Manning, 1968; Stone, 1968). A major problem is the difficulty of assigning definite costs to any particular change in operator performance following an improvement in working conditions. The well-known Hawthorne experiment in the USA demonstrated how even adverse changes in environmental and working conditions can produce an increase in performance due to the increase in operatives motivation and morale when the employers apparently express an interest in their welfare.

Nevertheless, one researcher (Robinson, 1963) has given five examples where significant improvements in output, or decreases in spoiled work, absenteeism and accidents, resulted directly from improvements in lighting. Significantly three of these were inspection tasks, or tasks having a high inspection content, where the improvement in lighting would have enhanced the differences between good and bad products. In one case, in the leather stamping department of a leather working factory in Germany, 12 consistent operatives worked for 2 years under 3761 \( \times (35 \text{ ft-candle}) \) of illumination, and for a further 2 years under 10761 \( \times (100 \text{ ft candle}) \). The average production under 10761 \( \times \) was 107.6\% of that under 3761 \( \times \) and the annual value of the extra production was 13 times the total annual cost of the revised lighting installation. Since the figures were obtained over a 2 year period, before and after changing the lighting, the ‘Hawthorne effect’ should not have confounded the comparison significantly, although some doubt must remain as with most of these examples.

In a study carefully designed to compensate for any such effects (Broadbent and Little, 1960), performance in an acoustically treated and untreated rooms of a cine film processing plant was compared over four 6-week periods, both before and after reducing the ambient noise level in one of the rooms from 99 dB to 89 dB [(above the usual zero of 0.02 mN/m \(^2\) (0.0002 dyne/sq cm)]. Although finding an increase in work rate for all rooms following the treatment, apparently due to an improvement in morale, they did find other improvements in performance related to the reduction of noise alone. Film breakages attributed to the operator error were significantly reduced (by a ratio of 1:15); shut-downs of the equipment attributed to the operator also decreased, although not by a statistically significant amount. Unfortunately, it is extremely difficult to convert these savings into monetary figures.

Further illustrations of improved performance resulting from reduced noise levels are given in a study carried out at Dresden (Hartig, 1962). One case compares two otherwise identical offices, one of which was quietened by being fitted with a “sound swallowing ceiling and wall-clothing material”, and in both of which everything they could measure was measured for a year. The results were compared and in the quiet office there was

- 19\% higher production
- 29\% less typing errors
- 52\% less errors on calculating machines
- 37\% less sick leave
- 47\% less staff changes

This paper also states that in 1960, DM 1 million were paid in compensation for occupational deafness.

Another environmental condition that seriously affects efficiency is heat, which cannot be avoided in industries such as steelmaking, forging, glassmaking, etc. In such conditions the only way of improving efficiency is by providing protection. There has been much recent development of clothing that protects against heat, some of which is described by Hellon (1961) and by Crockford (1962, 1963). The results they report of using airfed permeable clothing show that in conditions of heat such that an unprotected person has to leave within a few minutes, a man wearing such a suit can work for as much as 2 h. This work obviously has great potential for savings in labour costs where, for example, it enables the manpower required to re-line a furnace in a given time to be reduced.

5. Costs and contribution of the ergonomics team

In some applications, particularly those where ergonomists are involved in the design of a new piece of equipment from the start, it is not possible to show real or potential reductions in errors or improvements in production. Thus when validating the redesign of the EMIdec 2400 digital computer (Whitfield, 1964) it was found that the improvements to the design had not resulted in a reduction in errors, although it is possible that a comparative trial run over a longer period might have done so. Significantly, improvements were found in the operating times for some tasks on the new computer, and these were taken as indicating improvements in the relative ease of operation. However, the speed with which a particular task is performed is not an important consideration in this case, given the comparative contributions of man and machine to the data processing task.

Thus we find instances where ergonomics may improve the product—subjectively the redesigned computer was ‘better’ than the original—without any demonstrable financial advantage. Utilising ergonomics data in the design of a chair is a very basic example. Few would think of attempting a cost-benefit analysis for such an application. All that can be said is that the design is better than it might have been, — that the design is ‘right’ — and that ultimately its sales should benefit from this fact. It is a question of qualitative rather than quantitative advantages.
Given that there may be no immediate financial advantage to the user between products designed with and without ergonomic advice, the only remaining question is whether the design costs are greater or not. It is often argued by project managers that they cannot afford to employ extra staff such as ergonomists. Equally it is argued that it costs no more to design a product properly than to design it badly. This is borne out by experience during the design of the above-mentioned computer. It was found (Shackel, 1962) that as a result of preparing full sketches of panel layouts and console details, about 1 month’s work in the drawing office was saved because difficult and time-consuming decisions had already been made. The cost of all the ergonomic work, which included a study of the anthropometry of the operators’ work station, involving trials using a mock-up, was of the same order.

6. Costs of experimental work

Whilst the above argument may be accepted for routine design advice, the costs of an ergonomic study involving a research programme may, at first glance, seem formidable. With less money being freely available for research, particularly in industry, financial justification for such work is increasingly important. One stumbling block is that the results of engineering research often have wide application, whereas ergonomic research tends to relate to one particular problem or project, resulting in the occasional accusation that ergonomics presents engineers with an overwhelming mass of conflicting data.

However, in at least one case financial benefits can be claimed for such a research programme. During the design of a large materials handling plant (Shackel et al., 1967) a problem arose which could only be resolved by a 6-month ergonomics research programme. Operators were required to read an identity code printed on one face of heavy cartons moving past them on a belt conveyor. To complicate matters the carton end printed with the code could be facing in any direction when the carton was first put on the conveyor. The problem was to find a cheap and reliable means of enabling the operators to see all four vertical faces of a carton, or of turning all the cartons to face one way.

A complex simulation was set up for the experiment, including two closed-circuit TV systems for viewing a simulated conveyor, together with a ‘carousel’ of powered belt conveyors. The solution finally chosen as a result of the study was relatively cheap, and reliable (a short trial measuring physical work loads showed that a man could turn all the cartons the right way round as they passed him on the conveyor). This allowed the plant to operate at maximum throughput for all the items handled. Alternatives considered prior to the ergonomics study would have reduced the plant throughput by half when handling cartons, which constituted 30% of the total goods passed through the system. In terms of direct labour costs, therefore, the study, which cost £7000, including equipment costs, can be claimed to have made available a potential saving of £500 for every full week of operation.

In a more recent and elaborate investigation (Lewis, 1969), it was found that for some navigation tasks in helicopters flying very near the ground, the navigator using a hand-held map has generally better performance than a very sophisticated and expensive automatic navigation system. Although the important criterion in this case was accuracy of navigation, i.e. a performance measure, rather than cost-effectiveness of alternative systems, it does illustrate the contribution that a thorough study of human performance can make to the development of complex and costly systems.

7. Conclusions

In the introduction to this paper it was admitted that there is a lack of data on the costs and benefits arising from the application of ergonomics. The cases included in this review show the scope of what is available and demonstrate that financial benefits can and do accrue from the redesign of equipment and tasks using ergonomic principles. Unfortunately those included are almost the total of those available in the literature. Possibly they represent but the tip of an iceberg, the greater part of which remains hidden for understandable reasons such as company security. But it seems likely that many of the improvements resulting from ergonomic programmes have not been evaluated in financial terms if, indeed, at all. Besides the difficulties already mentioned, which may prevent benefits being expressed easily as monetary advantages, it is thought that the academic or university bias of the subject and of many ergonomists leads them, and those who hear of their results, to ignore matters of economics.

As ergonomists become more fully involved in the design of new tasks and equipment, rather than in the redesign of existing ones, there will be less opportunity to make such before and after cost comparisons. It is pointless to argue that a design could have been made more expensive, or less efficient, although there is admittedly only a shade of difference between such an argument and the example of the conveyor study mentioned above. Evaluations made within the design process should select those solutions which will lead to a reasonable compromise between all design factors, including cost and efficiency. Opportunities for making post-design evaluations of financial benefits will therefore become increasingly rare.
It is worthwhile considering whether this is important, and whether further evidence is really necessary despite the paucity of data. When matching men to machines, or machines to men, the criteria used are those of performance—information processing rate, speed of response, accuracy, tolerance to external interference, overload capacity and so on; indeed, the final specifications of many systems are written in these terms also. Should the American practice of ‘Parametric Evaluation’ (NAVWEPS O.D. 27070 1963) be adopted on a wide scale for industrial projects, the ergonomist will probably become involved in the preparation of very detailed performance specifications.

It seems unnecessary that the value to a design team of a specialist in human performance should be evaluated on a financial basis when the advice of specialists in electrical, mechanical, metallurgical or dynamic performance is accepted as natural in order to achieve a given specification. The education of designers and engineers to think of seeking the advice of an ergonomist as naturally as they would that of a specialist in an engineering discipline would do much to change current attitudes and would do away with the defensive approach implicit in talk of the financial justification of ergonomic recommendations.

The onus does not lie solely with the engineers, however. As Kraft stated (Ergonomics 1958 1, 306-6):

“I wholeheartedly support the statement made recently by an executive of a large company, that less time should be devoted to defending human engineering, and more should be spent in producing results which are understandable and so obviously worthwhile to engineers that they speak for themselves”.

References


