College Note No. 35

THE COLLEGE OF AERONAUTICS

CRANFIELD

A FRAMEWORK FOR COMPENSATING REST ALLOWANCE

by

R. M. BELBIN

NOTE NO. 35

OCTOBER, 1955

THE COLLEGE OF AERONAUTICS

CRANFIELD

A Framework for Compensating Rest Allowance*

-by-

R. M. Belbin

INTRODUCTION

A great many papers have been written on the subject of human fatigue but the complaint is often made in industry that, while many of these studies may be of scientific value, it is very difficult to see how they may assist those who are concerned with the problem in industry, in particular the time study engineers whose job it is to assess the fatigue that work involves and to apply the appropriate allowances.

The object of this paper is to consider the problem of these allowances (usually termed Compensating Rest or C.R. allowances) in the light of scientific evidence. It is not proposed to refer to previous work that bears on this field in any specific way, since a paper which did so would run to considerable length, but rather to evaluate some of the most important material and to suggest the type of framework for C.R. allowances that would appear most rational in the light of available evidence. As this paper is written primarily for those in industry, knowledge of industrial practices and terminology is assumed.

---

* The research project on Compensating Rest Allowances is being carried out at the College of Aeronautics under the auspices of the Conditional Aid scheme. This paper was written for a conference at Cambridge in April 1955 on Individual Efficiency in Industry.

C.R. allowances have been called 'the blunt edge of work measurement'. Rating no doubt competes keenly for this title but, while the problem of rating is to some extent being overcome by the growing application of predetermined time standards, no comparable advance has been made in the field of C.R. allowances. It is perhaps significant that the various systems of predetermined time standards, while claiming a high degree of exactitude with the basic units being in some instances 1/1000th of a minute, include no scheme for assessing Compensating Rest and make no recommendations as to what type of scheme should be used.

At present C.R. allowances are usually applied in one of three ways.

1. A standard C.R. allowance is given for all operations

The disadvantages of a system which does not apportion rest according to the demands of work are clear. But in addition the standard allowance tends to act as a cover for bad practices, for where allowances are given uniformly detailed study of what these allowances in fact cover is seldom made. Thus there is a tendency for such allowances to be set as sufficient to cover not only the most fatiguing operations but also those in which occur the undetected production delays of one sort and another. Such allowances, therefore, tend in most cases to become loose. In other cases where standard allowances are fixed more in accordance with the 'average' operation the allowances will prove insufficient for certain types of work.

2. C.R. allowances are given at the discretion of the time study observer

This places a heavy responsibility on human judgement. Serious inconsistencies can arise from the values awarded by different time study observers and there is no suitable means for settling differences of opinion over recommended C.R. values. When the time study engineer has little or no guide he is liable to be unduly influenced by the attitude of the operator concerned and by the vigour of the shop steward, so that inconsistencies of C.R. values often become marked between different shops. The inconsistencies which arise from this method affect job differentials, and estimation in production planning becomes more difficult.

3. C.R. allowances are built up from tables of synthetics

Attempts have been made in recent years to apply C.R. allowances from synthetics awarded for various factors.

Values are usually built up according to time study elements which afford the information in a form in which it can be most readily used by time study engineers. Such a system enables operations to be assessed on the basis of work content and avoids the tendency, which otherwise occurs, for overall assessment to be based on general and somewhat vague impressions of the job as a whole.

One of the most important features of systematic awards is that it enables greater consistency to be established. It is for this reason especially favoured by large firms.

While the systematic computation of C.R. has clear advantages over methods 1 and 2 its main disadvantage is that the values set and the criteria taken seldom come up to expectation. Nearly always values have been established empirically. This means that they prove quite useful in application to a group of operations of a similar character from which they have been derived but when systems are treated as though of general application their shortcomings tend to become manifest. This can be seen in several ways; firstly from the considerable inconsistency between different systems; secondly from the desire of large organisations employing systematic procedures to have them revised; and thirdly from the fact that the values given in these systems - and therefore the relative importance they attach to different factors - do not seem consistent with some of the findings that have been established from scientific studies of human fatigure carried out both in the laboratory and in industry.

METHOD OF ESTABLISHING A NEW SYSTEM

Criticising existing systems, however, is always far easier than building up new ones. The first step in developing a new system is to establish what it is that C.R. allowances are meant to do. The formal definition of C.R. adopted for teaching purposes in the Work Study School, Cranfield, is that it refers 'to that portion of the Work Unit awarded to an operator for the recovery from strain of working and for personal needs. Its value should be such as permits continued working at the rate of 80 Work Units per hour during normal hours without the accumulation of undue fatigue'.

It would appear from this that the objects are twofold, to relieve the operator of 'undue' fatigue and to enable a standard rate of working to be maintained.

Research at Cranfield has been conducted into both

these subjects. What is undue fatigue? And on what type of work does the operator succeed in or fail in maintaining a standard rate of working?

Let the latter question be considered first. The extent to which tendencies exist for people to take increasing rest periods or to slow up as the day progresses on various types of work can be made the subject of objective enquiry. Very detailed information is necessary and requires the use of special techniques. Two techniques are being applied.

The first is the method of ratio delay studies or snapreading, described by Williams in a previous paper, in which the investigator observes throughout the day at set or random intervals the number, and hence percentage, of occasions on which the operator is working or resting. Where the operator is not working notes are made as to cause of stoppage, that is whether it represents a voluntary rest, machine breakdown, departure to lavatory, etc. During the period under review it is possible for the output of the individual operator to be measured at given intervals and for performance to be rated.

The second method, used by the author, is the method of memo-motion study or spaced shot analysis. In this a photographic record is made of performance throughout the whole of the working day. For this type of study it is necessary to have equipment in which the number of frames taken per minute can be varied at the will of the investigator. Such a camera has been developed at the College of Aeronautics. The camera can be set to take frames automatically at intervals of from one per half second to one per twenty minutes. Further development of the apparatus has recently made it possible to run the film automatically at two speeds. Thus it can run for two minutes at two frames per second and then switch automatically to one frame per twelve seconds for twenty minutes, then back to two frames per second and so on. Such a procedure is very economical, enabling a day's performance to be recorded on two hundred feet of film. The bursts at half second intervals give a detailed measurement of performance at periods throughout the day while the more infrequently spaced shots provide a record of what is happening during the intervals.

The methods of ratio delay and memo-motion study, while serving the same end, have different advantages and disadvantages. With ratio delay there is the advantage that the observer can better interpret what is recorded, such as, for example, the cause of a stoppage. On the other hand there is the disadvantage that the presence of the observer may influence the social situation in such a way as to spoil the value of the record.

The advantage of the memo-motion camera is that it influences the social situation to a minimum. It can be secluded in a corner of the shop and after the preliminary interest has passed (it need not be operating during this time) it excites little attention. Preliminary trials have produced records of behaviour in the factory which suggest that the camera must have been quite clearly disregarded!

The disadvantage of the method of memo-motion study is that the photographic record can present problems of interpretation. This to some extent restricts the range of operations to which the technique is applicable.

Ratio delay and memo-motion while with different advantages and disadvantages will serve the same end in establishing the extent of decline in performance on various classes of operation. If these different methods succeed in producing essentially similar results the values obtained should have general application.

The second problem into which research has been conducted at Cranfield is into what is termed by those who apply C.R. allowances 'undue' or 'more than healthy' fatigue. Such fatigue appears to have no clear phsiological meaning other than in such extreme cases as the temporary paralysis of a group of muscles or the anaerobic derivation of energy with an accompanying oxygen debt. Cases of this sort seldom, if ever, occur in industry. Attempts which have been made by applied physiologists over the past thirty years to find some criterion of fatigue in the waste products resulting from metabolism, as for example lactic acid concentration in the blood or 17-Ketosteroid excretion in the urine, have not produced results of sufficient reliability to be of any practical value to industry. On the other hand measurement of certain energy transformations that take place during work have given hopeful results. These measures are of oxygen consumption and pulse rate. Thus while it is difficult to measure fatigue it is not difficult to measure energy expenditure. Moreover it is now possible to assess the calorie cost of work (that is the energy transformation involved in work) owing very largely to the amount of information that has been compiled on this subject by the Max-Planck Institut für Arbeitsphysiologie (M.P.I.) at Dortmund. This advance has important practical implications for industry for it is clear that there are limits to the amount of work that ought to be performed by industrial workers. If the calorie cost of work is high, representing, say, 2500 work Kilo-calories, it would be likely that an industrial worker would derive some of his energy from reserves (fat) so losing weight or would have to eat so much that the processes of digestion would interfere with his capacity to work or if

his level of work was maintained, as perhaps in the case of a man whose work is paced by a machine or conveyor, his work might interfere with his digestion. The maximum desirable calorie expenditure has for some time been a matter of discussion amongst applied physiologists but a figure of 2000 work kilocalories has been cited most often as the desirable upper limit.

If the calorie cost of an operation is known (and its cost may be assessed from synthetics) two alternatives present themselves, either to relate C.R. allowances to the calorie cost of work for small units of time such as for each minute of work or to award extra fatigue allowances only where the total calorie expenditure in a day's work exceeds some desirable upper limit. An illustration of the former method has been furnished by the Research Institute of Production Engineering in Norway which has developed and applied a system of C.R. allowances which effectively reduces the calorie expenditure of a job to that of 4 Kcals. per minute. The equation which forms the heart of this system requires accurate information on time taken and calorie expenditure for each of the various components of a cycle including effective delay.

The method of basing C.R. allowances on the calorie cost of work clearly represents an important advance on existing practice for certain types of operation. But it would seem that there are disadvantages in the application of this method to industrial operations in general. Firstly it is well known that human fatigue is affected as much by the way in which energy expenditure is distributed as by total calories expended. A period of very concentrated heavy work followed by a long period of inactivity may prove to cause greater strain than a long period of moderate activity interspersed with short rests although the calorie expenditure in each may be equal. The recovery of the pulse rate to its normal level following a period of concentrated heavy work is likely to be prolonged. Experiments at the Max-Planck Institut have shown that more work pulses are registered for a given amount of work performed in heavy loads than for the same amount of work performed in moderate loads. It is here that the evidence of work physiology matches that obtained from studies of industrial performance. We recall that it was Taylor who in 1890 first discovered that more work could be accomplished in loading pig iron if the load was reduced. The increase in the number of loads handled (resulting it may be inferred from the quicker recovery of the worker following each load) more than compensated for the loss in weight moved per load.

ALLOWANCES FOR HEAVY WORK

There are grounds for suggesting therefore that C.R. allowances covering heavy work should be related to two factors - the total amount of heavy work that has to be performed (i.e. total calorie expenditure) and the intensity of work during given periods. A well devised system of C.R. allowances would have the effect both of providing adequate rest allowances and of encouraging work to be spaced and designed so as to bring about the greatest economy of effort.

Fatigue in industry then for reasons mentioned above is not necessarily experienced in proportion to total calorie expenditure. The ability of the organism to regain equilibrium as indicated by the recovery of the pulse rate would appear to be a better guide for a good deal of strenuous work. However, where calorie expenditure exceeds a desirable limit and where effort is fairly well distributed throughout the cycle calorie expenditure would form a useful basis for C.R. allowances. We would regard allowances based on total calorie expenditure as being essentially limiting allowances, that is they would limit the amount of work done at the upper end of the scale but would not apply at intermediate stages where that limit was not reached. Under this scheme workers would not be expected to perform work equivalent to a calorie expenditure of more than 2000 Kcals. a day and limiting allowances would reduce work to this level where otherwise it would be exceeded. It would be equivalent to saying 'when you have done your stint of work you may go home' - a principle which interestingly enough applies to the heavy hand drawing of bricks in a good many brick-fields and one which is very popular. Such a system based on a more scientific assessment of work can be regarded as aimed primarily at protecting the health of the worker.

'Heaviness' then depends to a great extent on the continuity of heavy elements. If C.R. is given as a continuity allowance for concentrated periods of heavy work or work involving postural strain several good effects would be achieved. Firstly it would justly compensate the operator for lost time which tends to follow such periods either showing itself as rest or slowing down or more commonly as disguised rest - stopping to talk or to engage in ancillary jobs. Secondly there would be the inducement to improve the efficiency of heavy work by drawing attention to the importance of interspersing heavy work with light or with elements that provide effective rest.

The essential feature of Continuity Allowances would then be that extra fatigue allowances would be awarded where periods of concentrated heavy work occurred. They would be given irrespective of total calorie expenditure.

The extent of these allowances would depend on the degree of heaviness, the length of the heavy elements and the time intervals between them.

Continuity Allowances would not be given where the effective heavy work continuity period was exceeded by a period of Effective Rest Elements.

Effective Rest Elements would be defined as those not making high sensory demands, not requiring physical limb movements (other than occasional) or rapid operational hand movements. Effective Rest Elements would refer typically to the supervising of machines and those parts of the work cycle that are normally covered by Process Allowance.

Continuity Allowances would not be given where isolated heavy elements were followed by light elements exceeding the period of heavy work in time.

The system of Continuity Allowances is at present being worked out through experiments being conducted in the laboratory and in industry. The variables being considered for the application of a formula are the heaviness of discrete movements, lifting, pulling, etc. in various postures and the effects of frequency of such movements on the rise in the pulse count and on its recovery. In experiments which have been carried out in industry the M.P.I. Pulse Counter has been used to measure pulse rate during work. The apparatus has been modified at the College to permit the use of telemetry. Results with this apparatus have been obtained for men working on heavy jobs in Brickfields and in Steel and Engineering firms. These experiments are still proceeding and will be reported at a later date.

ALLOWANCES FOR HEAT STRESS

There are other sources of fatigue in industry which have been the subject of investigation. Of these heat stress is one which appears related to the type of strain considered above since its effects show themselves in high pulse rates. Yet on such work pulse rate is less of a limiting factor than sweat rate. The assessment of sweat rate therefore forms a useful index for comparing one operation with another. The fact that our body temperature remains relatively constant in spite of considerable variation in thermal conditions and that body cooling is effected in conditions of excessive heat primarily by the evaporation of sweat gives reliability to this index even though we realise that variations about the mean in the sweat rate of individuals may be considerable. Largely owing to the experimental studies of the Industrial Hygiene Foundation

of Pittsburg we can calculate the mean estimated sweat rate of fit workers from readings of radiation, dry bulb and wet bulb temperature and speed of air flow. The heat production from work may itself be calculated and its effect on sweat rate assessed. Thus it is possible to use an objective scale for comparing the heat stress of one operation with that of another.

How C.R. allowances should be related to this scale constitutes our next problem. The maximum sweat rate which can be maintained for various periods without the collapse of the subject has been established from experiments carried out by various research workers on unclothed and partly clothed subjects. It is clear that maximum sweat rate as yet requires correction for the effect of clothing if its application is to be considered for industry but it is hoped that in due course such corrections will be established. Where the maximum sweat rate can be assessed under given conditions, assuming the surface of the skin to be completely wet and no rise in body temperature, Dr. Belding of the Industrial Hygiene Foundation has proposed that the evaporative rate should not exceed 50 per cent of the maximum possible. Where this would be exceeded C.R. allowances would reduce the sweat rate over a period of time to this level by the introduction of rest pauses. On this basis the maximum calculated sweat rate would be associated with a 100 per cent C.R. allowance. Occasionally work requires an evaporative capacity greater than the maximum that can be maintained for long periods without a rise in body temperature. Examples of this kind have been shown to exist in the glass industry in the U.S. Haines and Hatch found for one job during the summer that the ratio of estimated sweat rate to maximum sweat rate was 2.58 to 1. Thus on the scale proposed here C.R. allowance applicable would be 416 per cent of actual working time, (2.58 - 50) x 2.

The sweat rate scale, just as the scale based on total calorie expenditure, establishes for us allowances which are of an essentially limiting character - that is their purpose is to limit the amount of work performed under extreme conditions by giving appropriate rest in the interests of health. Allowances on such a scale ought, therefore, to be related to climatic conditions and should be adjusted according to season.

Many moderately hot jobs could not make sufficient demands on sweating to qualify for heat stress allowances. For these operations C.R. would need to be worked out in accordance with Continuity Allowances. Moderately high temperatures would be taken as one of the variables contributing to high pulse rates and prolonged recovery.

There are finally two types of fatigue to be considered which unlike those considered previously cause little or no stress in human metabolism. These are sensory fatigue and mental fatigue.

SENSORY FATIGUE

Sensory fatigue is perhaps the most elusive of the fatigues. Its existence has been assumed rather than proved. On work which makes high demands on the senses, operators are usually found to have difficulty in maintaining standard performance throughout the day. It is on this type of work that short rest periods have been found in industrial experiments to give the most beneficial results.

The most common type of sensory demand in industry is visual. But other types of sensory demand are also found including demands on taste and smell. Firms employing persons making use of such senses report that performance is easily upset on jobs in which these senses are used and that a prolonged period of work is likely to impair performance.

Touch also shows marked impairment. In the worsted industry it is common for burlers (whose job it is to feel cloth for flaws), to deteriorate in their standards of work. As much of the work is continuous it is likely that habituation sets in with the more or less continuous stimulation of the touch spots of the fingers. Deterioration in performance, however, is usually ascribed to some failing in personal qualities.

The effects of visual fatigue are perhaps even more difficult to assess than of other forms of sensory fatigue, for the effects of visual fatigue are often confounded with the effects of postural strain (static fatigue) and boredom. These latter effects may be caused by the fact that work which makes high visual demands usually requires a high level of attention and concentration (factors conductive to mental fatigue) as well as the maintenance of a given posture to assist in the visual fixation of the object. One further difficulty is that visual fatigue is not measurable as such. The only indications of its presence are (a) pains in the eyes, (b) impaired performance on the task itself (which may be due to reasons other than of sensory fatigue), (c) impaired performance on some other task which is more sensitive to changes in visual performance - the extent of the impairment here varying with the nature of the task. By visual fatigue we usually imply accommodation and convergence fatigue. Conditions which produce accommodation fatigue are also likely to produce

fatigue of convergence, but we may suspect that convergence fatigue is more important in the case of very close work (and more likely to produce pains in the eyes) while accommodation fatigue will be relatively more important in the case of work which requires continual refocussing.

Under our present method therefore our aim should be to relate C.R. allowances to (a) the extent to which close vision necessitates a viewing distance of less than a given optimum (there is evidence in the literature to suggest an optimum of 33 cms.) and (b) the frequency in changes in depth of focus owing to variations in the depth of the display.

At present experiments in this field are only in an exploratory stage but the intention is in seeking suitable values to relate decrement in output over a day and time lost in voluntary stoppages to the type of visual stress involved in the work. Such a procedure should prove fruitful in the case of valve assembly operations where some initial investigations are being made. Here the various sizes of the valves assembled by hand vary from small to very small but with other conditions of the work held constant there are opportunities of judging the effects of visual stress as good as we are likely to find in industry.

MENTAL FATIGUE

Mental fatigue is recognised to be of considerable importance in industry especially in repetitive work. Assessment of it, however, is rendered very difficult owing to the fact that its existence depends to a great extent on attitude to work (morale) while individual and group differences are marked. Thus it is clear that there is little point in taking particular features of work on which to anchor allowances if these are associated with considerable mental fatigue in some instances but not in others. For example, repetitive work as such or work on which the operator is paced by a machine or conveyor which compels performance to be carried out within some rigidly fixed time may or may not be associated with fatigue. Some repetitive work is very popular and performance on it is well maintained. This occurs most typically where work requires little attention and where conversation is possible (handpolishing of bearing rings by women seated round tables affords an example). Conversation plays an important role in this field for two reasons. Firstly it makes work agreeable which would otherwise be disagreeable. Secondly it acts as a measure of the attention and concentration required by the work. Most work requires some attention

and concentration but if it is likely to be such as to make conversation difficult or impossible during work it can be regarded as imposing a level of attention and concentration which is unlikely to be maintained throughout the day without signs of impairment.

Our available knowledge of the factors contributing to mental fatigue enable us to suggest four conditions in which decrement usually occurs. Allowances would be given in ascending order for the following:

1.(a) Continuous repetitive operations (unless covered below) where the operator works alone, i.e. he is too far away from others to be able to converse with them, and where 'music while you work' is not played.

\+ C.R.

(b) Continuous repetitive operations where the work requires such partial attention and concentration as to or as would make only intermittent conversation possible.

\+ C.R.

2. Continuous repetitive operations which make continuous demands on attention such as to or as would restrict conversation during work.

++ C.R.

3. Continuous repetitive operations which make high demands on concentration such as to or as would prevent conversation during work.

+++ C.R.

4. Short cycle continuous repetitive operations which make high demands on concentration such as to or as would prevent conversation during work.

++++ C.R.

It will be observed that allowances are suggested only for continuous repetitive work. Work which is varied and work which is not continuous in the sense that the operator is not actively engaged for some period of the cycle or is engaged in a merely supervisory capacity rarely show effects of impaired performance greater than that normally encountered attributable to mental fatigue.

PERSONAL NEEDS ALLOWANCE

Included in the Compensating Rest Allowance is

the Personal Needs Allowance which is given for toilet requirements, for sneezing and coughing and for attending to matters of a personal character that are regarded as reasonable and necessary. Various systems of C.R. vary in the allowance awarded for Personal Needs. It usually ranges between 2 per cent and 8 per cent of working time. It appears, however, that systems which award a high Personal Needs Allowance award allowances for all other factors rather sparily while a low Personal Needs Allowance is often found in systems which award C.R. for a very large number of factors and conditions.

There seem good grounds for favouring a Personal Needs Allowance that is relatively high and which is expanded in such a way as to cover what may be termed normal fatigue. This avoids the necessity of computing the factor allowed for fatigue for every operation since insufficient is known about operations making moderate demands to make calculation of differences between then worthwhile. That one operation in this range is heavier than another does not necessarily mean, as might be assumed, that it is more fatiguing. But when a certain level of heaviness or stress is exceeded the evidence is sufficiently strong to justify allowances in excess of the 'normal fatigue' allowance. The allowances suggested in this paper should therefore be regarded as allowances only given where work is regarded as especially fatiguing. That is, they should be regarded as extra fatigue allowances.

CONCLUSIONS

A rational basis for C.R. allowances related to such available scientific criteria as bear on human performance has been suggested. These allowances would cover

(a) Fatigue associated with heavy work and heat stress,

(b) Sensory Fatigue,

(c) Mental fatigue.

Under (a) there would be three types of allowances. Two of these would be limiting allowances, existing in extreme cases, with the object of limiting the amount of work done to some given amount. These limiting allowances would be based on calorie expenditure (assessment of calorie expenditure being built up from synthetics presented in tables) and on sweat loss (rate of sweat loss being derived from tables indicating effects resulting from the various combinations of factors that make up heat stress). The

third allowance under (a) would be a continuity allowance given where items of heavy work and of work involving postural strain were closely grouped. This allowance is based on the index of recovery of pulse rate which is found to become more prolonged as heavy work increases in intensity. Allowances for (b) based in the case of visual fatigue on viewing distance are proposed and for (c) on the extent to which demands on attention and concentration become involved in repetitive work.

Further research on the scheme outlined is continuing with particular emphasis on the observation of rest pauses and of changes in the rate of working in various classes of work. Various modifications to the basic structure of the scheme will no doubt be necessary but it is hoped that before the research project is completed in Autumn 1956 values for the scheme and a system sufficiently simple to be practicable will have been developed.