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The ergonomics of coalface machine operators in thin seams (Leamon T, ed)

Knight AA, Murphy JW, Attfield MD



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INSTITUTE OF OCCUPATIONAL MEDICINE

THE ERGONOMICS OF COALFACE MACHINE
OPERATORS IN THIN SEAMS

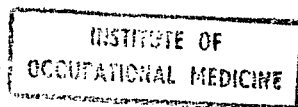
by

A A KNIGHT, J W MURPHY &

M D ATTFIELD

Edited by T.B. Leamon

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Physiology Branch
Institute of Occupational Medicine
Roxburgh Place
Edinburgh EH8 9SU

Tel: 031-667-5131

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THE ERGONOMICS OF COALFACE MACHINE OPERATORS IN THIN SEAMS

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SUMMARY

When the seam height is below 1 metre the problems of longwall machine mining increase. The work method of power loader operators is governed by the environment and face machinery. As the capacity of this equipment is increasing, there is little reason to think that the work of the machine operator is likely to be lightened in the near future. An examination was made of the work of machine operators at three separate installations. The machine operator's task, the power loader machine, the operators workspace, the noise, the lighting, the climate and the face performance were examined.

Conclusions and recommendations are drawn from these studies which have general relevance to thin seam power loader mining.

The outputs of the three installations studied were not limited by the performance of the power loader or the operator. However in the case of a Bi - Di shearer installation the machine speed varied with the operator by a factor of 10% although the operators showed no significant differences between the total output and the length of delays which they encountered. It is thought that this was due to the fact that the machine delays played a much more important part in determining output than the machine speed.

These results indicate that the factor of overwhelming importance is the length of delay times. A description of these delays and what measures may be taken is given. Once these are reduced the indication is that the next bottleneck will be the speed of the machine and more attention will be needed in the design of the machine and the support system.

Studies of the operation of the machine show that the optimum control position for power loaders is at the front of the machine for each direction of travel. The present machines do not have their controls arranged in these positions neither do individual controls conform to ergonomic standards. It is possible to introduce immediate measures to reduce the risk of accidents due to some of these poorly designed and placed controls.

Attention is drawn to the inadequacy of training both for the trainee and the instructor. Suggestions are made for the practical instruction of trainees and the development of their skill.

The operators spent 12 - 20% of their shifts travelling to and from the face. The physical work level doing this travelling on occasions exceeded the level in operating the machine. Where long distances, gradients or low height conditions are involved it is advantageous to install man-riding systems.

The study of the operator in relation to the workspace showed that the operator was forced to crawl on his hands and knees in order to control the machines. The angular construction and size of floor cross members, the position of hoses, coal and stone in the travelling track aggravated the difficulty of crawling. It is advised that priority be given to devising a system to transport the operator in a prone position along the travelling track.

The chief source of noise was the power loader. When cutting and loading the noise levels recorded were in the order of 93-98 dB(A). The operators exposure to noise during a shift depended upon the machine operating time. It is proposed that long term research should be undertaken to reduce the level of the noise of machines where exposure is unduly high. Measures are proposed which can be implemented immediately.

The lighting, while sufficient to prevent nystagmus, was not satisfactory for the operators steering task. Recommendations are made to ameliorate this condition.

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1. INTRODUCTION

A study of the task of coalface machine operators was requested by Mr G W Sanders (formerly Area Director, South Midlands). The work methods of machine operators in thin seams (those with seam heights of approximately one metre or less) are determined largely by the environment and the face machine design. It was considered that a study could lead to improvement of the working situation.

The current trends in mining technology involve the continued development of face machinery and systems. These trends include stable elimination, the mechanisation of ripping, automatic steering and increasing horsepower of power loaders. These developments are intended to increase productivity and safety. However, there is little reason to think that the machine operator will have his work lightened in the near future by these developments of machine speeds and increased working cycle. It is generally thought that factors other than the task of the machine operator limit the output in thin seams at present. However, with the continual improvement of machinery it is recognised that the output in thin seams may eventually become limited by the ability of the machine operator to carry out his task.

It was suggested that studies should be made in the South Midlands and the co-operation of Area and mine staffs was offered. Work was started in September 1971 and field investigations were completed in November 1972.

Three faces were studied. These faces were chosen to provide a range of seam heights, machinery and mines. Table No. 1 gives details of the three installations. These installations were studied by observation, measurement, discussion and interviews with machine operators.

TABLE 1 DETAILS OF THE INSTALLATIONS STUDIED

Installation	Thickness Extracted	Machine	Supports
A	0.864 m advancing	AB Conveyor Mounted Trepanner	Dowty Thin Seam 1 m/c face
B	0.990 m retreat	- do -	Wild Thin Seam 1 m/c Face
C	1.016 m Advancing	AB Bi-Di Shearer	Dowty Thin Seam 2 m/c face

This report consists of six sections:-

1. An introduction to the methods used in the investigation;
2. The machine operator and his task;
3. The design, arrangement and operation of the controls of the power loading machine;
4. The operator and his workspace;
5. The operator and his environment;
6. The operator and face performance.

The first section contains a description of how the work was done. In the other sections the results, interpretations and discussions, and the conclusions and recommendations are presented.

Following the brief from the Area Director, a number of further meetings were held to plan the study. In these discussions the 'Work Station Analysis Outline' (Shackel, 1969, p.35) shown in Table 2 was used as a base. The discussions took place at a number of different levels. Area staff, mine managers, officials, union representatives and workmen involved were informed and had the opportunity to discuss and approve the work and its possible implications before planning was finalised and the studies commenced.

TABLE 2 WORKSTATION ANALYSIS OUTLINE

A MAN			
Consideration of	age	physique	training
	size	intelligence	motivation
		experience	
Definition of operational modes, e.g. searching, monitoring, tracking, decision-taking required in situation and thus consideration of abilities and limitations of human operator for all aspects of the task.			
B MAN - MACHINE INTERACTION			
Influence, on operator and his decisions of -			
displays	-	sensory input to operator	
controls	-	motor output from operator	
panel layouts	-	display - control compatibility	
based upon study of human information - decision - action patterns and of human, equipment and task operational sequences.			
C MAN - ENVIRONMENT INTERACTION			
Influence upon behaviour and performance, of			
Physical aspects:	light, colour, noise, heat and humidity		
Psychological:	work team, command structure, pay and welfare, shift conditions, discomfort or risk.		

The headings shown in Table 2 are of a general nature and it was necessary to decide upon specific techniques in order to quantify the particular situation under consideration. It was, therefore, necessary to have further meetings of medical, physiology, method study and ergonomics staff in order to discuss what information was already available, what techniques would be required and whether the application of these techniques would be likely to be successful under the present situation. Table 3 shows the scheme that was used for this study.

TABLE 3 WORKSTATION ANALYSIS

Technique	Comments
A MAN	
A1 Interview	
A2 Anthropometry	
B MAN - MACHINE INTERACTION	
B1 Operator Position and Posture.	Movement analysis
B2 Face equipment specifications, photographs, drawings and layouts.	
C MAN-ENVIRONMENT INTERACTION	
C1 System Performance	Production Study
C2 Physical Aspects.	Heat/Ventilation. Lighting Dust Noise
C3 Psychological	Behavioural aspects of the job Job description, task analysis, accidents and absence attitudes.
D TOTAL INTERACTION	
D1 Energy expenditure	Indicates how hard the work is for operators.
D2 Heartrate	To assess stress

2. THE MACHINE OPERATOR AND HIS TASK

The machine operator and his task have been described by an elementary job description of a general nature drawn up by the Ceramics Glass and Mineral Products Industry Training Board:

this forms Appendix A and covers a Mechanical Loader Operator. This is in need of modification for the coal mining industry and a description is given at Table 4. The background and experience of the six operators was studied. A breakdown of the job into its component tasks is made. The results of system performance studies are presented. These show the length of time occupied by the machine operators in travelling to and from the face, in operating the power loader, in ancillary work and waiting due to delays.

TABLE 4 JOB DESCRIPTION

<u>Job Title:</u>	Power Loader Operator
<u>Responsible to:</u>	Face deputy
<u>Hours of work:</u>	Normal shift $7\frac{1}{4}$ hours, plus one winding time - day shifts and afternoon shifts. Five days per week. Operators may work a quarter of a shift overtime on the day shift.
<u>Promotion:</u>	Deputy Grd. II (Shotfirer).
<u>Function:</u>	Cut and load coal on the armoured face conveyor.
<u>Responsibilities:</u>	
(1)	To load as much coal as possible.
(2)	To operate the machine to avoid danger to the face team and damage to the face equipment.
(3)	To recognise faults in equipment and symptoms of electrical and mechanical breakdowns.
(4)	To steer the machine in order to preserve coal quality and to maintain good roof and face conditions.
(5)	To recognise and evaluate mining hazards.
(6)	To receive, transmit and act in accordance with the code of audible and visual signals both formal and informal.
(7)	To carry out routine inspections and testing of machines in accordance with general orders and regulations.
(8)	To read and follow line diagrams and surveyors' marks where necessary.
(9)	To assist with routine maintenance, simple running repairs and adjustments.
(10)	For the safety of any person who comes within the working area of the machine and to inform the team of hazards caused by the operation of the machine.
(11)	Observe the requirements of the Coal Mines Act and Regulations.

Duties:

(Job Requirements)

- (1) To arrive first at the coal face in order to start operations.
- (2) To observe working conditions before beginning operations.
- (3) To carry out routine inspection of the machine to ensure it is in working order.
- (4) Before starting the machine, to give warning and make certain there is no one near dangerous parts of the machine.
- (5) To turn on dust suppression equipment before beginning to cut and to turn this off when cutting is stopped. When the armoured face conveyor is running, to cut as much coal as possible, keeping the grade right. To stop the power loader when the conveyor is stopped.
- (6) To identify faulty running of the machine and rectify this within his capabilities or report the irregularities or defects.
- (7) Where the machine or haulage chain can cause an accident, warn the team.
- (8) Where there are poor roof conditions, to manoeuvre the machine to catch bad ground.
- (9) To isolate the power supply and ensure machinery is out of gear and left safely at the end of the shift.

2.1 The background and experience of operators

The three mines studied draw most of their workers from traditional mining areas. It was not surprising, therefore, that five out of the six operators were sons of miners. Three of them had brothers working underground at the time of the study. Table 5 shows the previous experience of the machine operators, as taken from colliery training records.

TABLE 5 PREVIOUS EXPERIENCE OF MACHINE OPERATORS

Operator	1	2	3	4	5	6
No. of Years Underground	26	19	21	29	19	16
No. of machines certified to operate	5	2	3	4	1	2
Total no. of days spent in training for these machines	35	5	27	17	10	5
No. of years since first receiving certificate for present machine	3	2	1	1	4	4

There appear to be two types of situation in machine training, firstly, where a man has been working on a face for some years and is trained for the first time to use a power loader, and secondly, where an experienced operator is trained to use a machine which is new and unfamiliar. Both cases require the development of new skills by the operator.

These skills are of the same nature as other types of industrial skills, as described by Seymour (1966), where skill is defined as the ability to perceive fine variations in the requirements of the task and the ability to distinguish and provide the responses which are appropriate to these requirements at any given moment. The results of the time studies and interviews show the usual characteristics of 'skilled' performance in this case -

- (1) That an untrained worker will not be able to carry out critical operations in the task, e.g. keeping the machine on the armoured face conveyor or keeping the grade correct.
- (2) That the skill becomes unconscious with practice, so that the skilled man cannot describe his behaviour.
- (3) The initial stage of learning, the general sequence of activities and how controls operate, followed by learning the exact sequence of operating the controls to use at each stage, is rapid. This is probably completed in a week or two.
- (4) Perceptual ability takes longer to develop. Both research literature and operators' replies suggest a period longer than a few weeks is required. The operator is then able to select the right signal (cues) from the appropriate sources which need attention, and to check the results of control actions and machine behaviour by the most reliable and speedy means. Operators often describe this as 'knowing the feel of the machine'. This is a specific improvement which arises from the ability of the operator to select more and more frequently the optimum, or near optimum responses from a repertoire of possible responses. The operator becomes more confident and machine driving becomes easier.

It can be seen from Table 5 that each has a considerable amount of underground experience but some operators have much more experience in operating the power loader. Indeed, when the study commenced at the mine where operators 1 and 2 are employed, operators 3 and 4 were being trained. Therefore, during the interviews one had the view points of not only those undergoing training but also those responsible for the practical training of power loader operators.

2.2 Selection and training for Machine Operators

Older men, following two or three years on the face so that they knew the job apart from the actual driving of the machine said they were asked to take on the job. They were a success and had been kept on ever since. Some younger men said that it had been their ambition to become machine drivers.

The requirements before men are allowed to operate coal-getting machinery consists of three parts. There is a period of basic training and improvership for coal face work. Secondly, there is training in operating the machine of the type on which he is to be employed. Finally, the manager must be satisfied that he is competent to operate or assist in operating the machine. Further details of these legal requirements are given in Appendix B. The actual training given conformed to these legal requirements.

All machine operators were of the opinion that training for machine operation is needed, and although the reasons which they advanced varied, they included:

- (1) Without training it would be impossible to operate the machine.
- (2) Knowledge is required of what the controls do and practice is required.
- (3) There is a formula for successful driving that operators develop.
- (4) The loader may come off the armoured conveyor if the operator is inexperienced.
- (5) It takes time to learn the correct reactions.
- (6) After the operator learns the purposes of each control he needs to learn the dynamics of the controls.

TABLE 6 LENGTH OF TIME IN TRAINING FOR THE STUDIED MACHINE
(taken from colliery training records)

Operator	1	2	3	4	5	6
Days	-	-	2	2	10	-

2.3 Task Analysis

From the background and the training of operators so far described, it is evident that the man chosen as machine operator normally has a considerable experience of face work and a sense of responsibility. In describing the specific task of machine driving, it must be emphasised that the machine operator is a member of the face team.

Therefore, while he is responsible for the power loader machine, his work is not restricted to controlling the machine. There are a variety of situations when it is necessary for the operator to carry out other tasks. Some of these tasks may be of short duration carried out at his own instigation in order to enhance production and safety. Other tasks may be of longer duration when the face deputy may ask him to assist where there are breakdowns or delays and extra help is required. It is, therefore, not possible to say, without production studies what tasks the machine operator performs.

In presenting the results, a broad description of the jobs at the three installations is made. Then further detailed examination is made of the tasks making up these jobs.

The classifications of machine operators' working time are:

- 2.3.1 Travelling Time
- 2.3.2 Machine Running Time
- 2.3.3. Machine Ancillary Time
- 2.3.4. Operational Delay Time
- 2.3.5. Lost Time at the Face
- 2.3.6. Lost Time Outbye

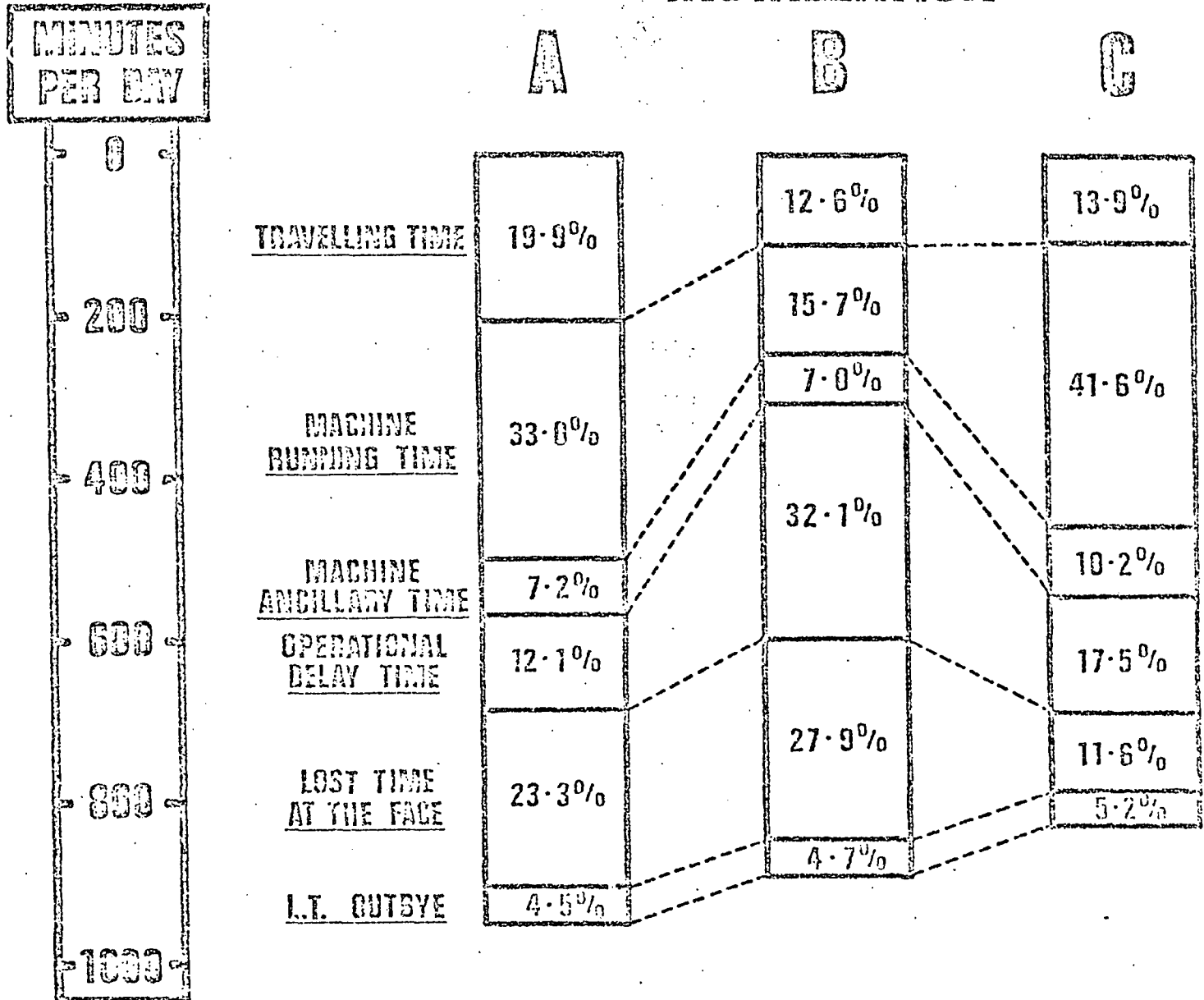
Figure 1 shows the average percentages of time for these classifications. The definitions and method of arriving at these are discussed in the following sections but it is necessary to draw attention to the fact that 'minutes per day' in Figure 1 refers to the total of the two shift times. It is thus the sum of the time spent by the morning operator and the afternoon operator and as the shifts overlap it is not a chronological time period.

The proportion of time engaged in the six main occupations varies from installation to installation. It can be seen that travelling time varies between 12 - 20%, machine running time 16 - 42% machine ancillary time 7 - 10%, operational delays 12 - 32%, lost time on the face 12 - 28% and lost time outbye 4 - 5% of the total shift time. These occupations are now examined in further detail, drawing attention to critical considerations and making recommendations.

2.3.1 Travelling Time (12 - 20%)

In Figure 1 the travelling time shown is the duration of time between the operator's arrival at the pit bottom and the arrival at the machine beginning the shift, together with the duration between departure from the machine and the arrival at the pit bottom in ending the shift. Each percentage quoted includes the times for four journeys: the morning shift, in and out, plus the afternoon shift in and out.

INSTALLATION



**AVERAGE TIME PER DAY FOR
SIX MAIN OCCUPATIONS**

FIGURE 1.

The importance of travelling time as a factor acting to reduce the time available for work is widely recognised. Therefore, a more detailed examination of this time has been undertaken. This is shown in Table 7. The table shows the results of time, distance and energy considerations of making one of the journeys described above. The table is divided into three sections. The first describes the total time and total distance travelled. The second section describes that part of the journey walked and the third, that part travelled on a manrider where this is available. Mine A had a rope haulage, Mine B no manrider and Mine C a diesel locomotive.

TABLE 7 SHOWING RESULTS OF TIME, DISTANCE AND ENERGY CONSIDERATIONS OF MAKING ONE JOURNEY TO WORK

	A	B	C
Total distance - m	2997	1797	2569
Total time - min	48.37	28.41	28.36
(wait for man rider)	(7.26)		
Walking distance - m	1911.1	1797	1472
Walking time - min	28.98	28.41	23.54
Walking total energy used K Cal	147.50	111.60	107.00
Walking rate of using energy K Cal/ min (Watts)	5.1* (355.6)	3.9* (271.9)	4.5* (313.8)
Riding distance - m	1086	-	1097
Riding time - min	12.13	-	5.32
Riding total energy used K Cal	19.41	-	8.51
Riding rate of using energy K Cal/ min (Watts)	1.6* (111.6)	-	1.6* (111.6)

*A man should be able to work at an average rate of about 350 Watts (5 K Cal/min) without developing fatigue.

The results show the importance of providing man-riding for as much of the travelling distance as possible. This would increase the time available at the face and reduce the rate of energy used in getting to the face. The importance of providing a fast travelling manrider is also illustrated.

Subsequent results show that the level of energy expenditure in travelling was higher than that of working on the coal face. A reduction of the expenditure in travelling would reduce the shift energy expenditure.

2.3.2 Machine Running Time (16 - 42%)

The purpose of this section is to build up a broad picture of the task of machine running while details of

individual controls and control arrangements are dealt with in the following Part 3 entitled 'The power loader machine'. Running the machine really means controlling the machine. Figure 12 shows an operator controlling one of these machines. An essential part of the job is crawling with the machine, and figures Nos. 10 and 11 illustrate operators crawling with their machines.

Figure 5 shows the following main aspects in machine cutting:-

- 2.3.2.1 Monitoring the conveyor
- 2.3.2.2 Monitoring the Power loader
- 2.3.2.3 Steering procedure
- 2.3.2.4 Stall procedure
- 2.3.2.5 Monitoring roof supports

An examination of each of these aspects gives the following results:-

2.3.2.1 Monitoring the conveyor

The monitoring of the conveyor is a continuous occupation while the machine is cutting and loading. When the conveyor stops, the machine is taken out of gear, the power switched off and the dust suppression water turned off. Similarly, when the conveyor starts the reverse procedure takes place. This stopping and starting procedure is triggered off by the operator seeing or hearing the conveyor chain stop or start. With thinner seams vision becomes more restricted and it becomes difficult for the operator to see the conveyor chain. In these cases the operators try to listen for the continual tap - tap of the chain and switch off the power loader when this stops. However, on many occasions the operator does not see or hear the conveyor stop and relies on other team members waving their cap lamps in order to attract his attention. It is, therefore, recommended that measures to reduce the noise of power loader machines be investigated to alleviate this problem and assist with the general noise problem as discussed later.

This task has a low skill content, can be monotonous and requires extra vigilance where it is difficult for the operator to move. It is feasible to consider a remote control system which has a manual override at the machine and this should be investigated.

There is an important safety consideration in the monitoring of the conveyor and the consequent stop and start procedure. This includes avoiding the danger of workmen being struck by the picks of the machine on starting, particularly at road ends and in stables. All drivers had been issued with warning whistles to be used before they started the machine.

Ergonomically, it is considered that Klaxons are more desirable than whistles, provided that they are reliable. It is therefore recommended that on the operation of a starting handle there should be an audible warning, a pre-start delay, and the sprays should be turned on automatically.

2.3.2.2 Monitoring the power loader

When the machine is cutting and loading the operator is monitoring its progress along the face. This is mainly by the sound of the motor, but also by observing the forward movement of the machine and observing the slackness or tension of the haulage chain. The purpose of this type of monitoring is two fold. Firstly, to ensure that the machine is travelling as fast as possible. Secondly, to listen for possible causes which will slow the machine or stall it. For example, one can hear -

- (a) when the speed is excessive and the machine begins to stall;
- (b) when the conveyor has been snaked over too close to the face:
- (c) when lumps of stone are wedged against the machine.

Thus the sound of the motor is the most important source of information in monitoring the progress of the power loader.

2.3.2.3 Steering Procedure

The steering determines the horizon at which the seam is cut. If monitoring the progress of the machine through the face is considered important, the steering procedure is crucial. On the faces which were studied, incorrect steering could lead to the machine cutting into the roof and causing poor roof conditions. It could lead to cutting into the floor and producing too much dirt, or to the machine coming off the armoured face conveyor and causing long delays.

A previous study was undertaken by the Institute of Occupational Medicine (Mallan 1972). In this it was reported that operators expressed differing opinions as to the ideal position for an operator to take in relation to the machine. It is also known that differing seams and strata conditions influence steering procedures. Therefore, during the study these procedures were closely examined. The steering procedures used by each operator were examined and it was concluded that steering is a visual task and operators use a number of cues in order to decide when to change and how much change to make with the steering controls. The cues most commonly used are:-

The mix of dirt and coal in the trepanner head;
The level of the armoured face conveyor;
The position of bands of dirt;
The nature of the roof;
The level of the machine;
Chalk marks on the coalface;
Stone at Floor level.

In the thicker of the seams it was possible for the operator to lean over the haulage, motor and gearbox cases to see ahead of his machine but this was an undesirable position. He could also look forward at the level of the conveyor or over the machine to the trepanner head or drum. In the thinner seam conditions this was not possible and in order to see these the operator had to position himself in front of the machine for each direction of travel. This leads to recommendations that in thin seams it is necessary for the operator to travel in front of the machine; therefore, the machine should be designed with these frequently used controls located at each end. Men should be trained to take up these positions and supervisors on the face should realise the importance of this for the control of the machine.

2.3.2.4 Stall Procedure

A sensory motor task analysis was made of the stall procedures used at installation C and this is shown in Appendix C. Examination of these procedures with engineering staff leads to the conclusion that operators used trial and error to get the machine started after a stall. Observation of the machine's reactions to the controls was of greater importance to the machine operators than the machine sounds. It is recommended that the sequence of checks could be improved to find the causes of the stalls and to eliminate them. Instruction during training, describing what is happening inside the machine and an explanation of what is happening during stalling, would also assist operators.

2.3.2.5 Monitoring roof supports

In thinner seams monitoring roof supports becomes an important part of the task, while it may be of little concern in thicker seams. It is critical where water pipes lie on top of the body of the machine. However, even where this is not the case it is important, for if an operator can see a low roof support in front of the machine he can raise it before the machine reaches that point and thereby prevent a machine delay. Again, the same conclusions

TASK OF MACHINE OPERATOR

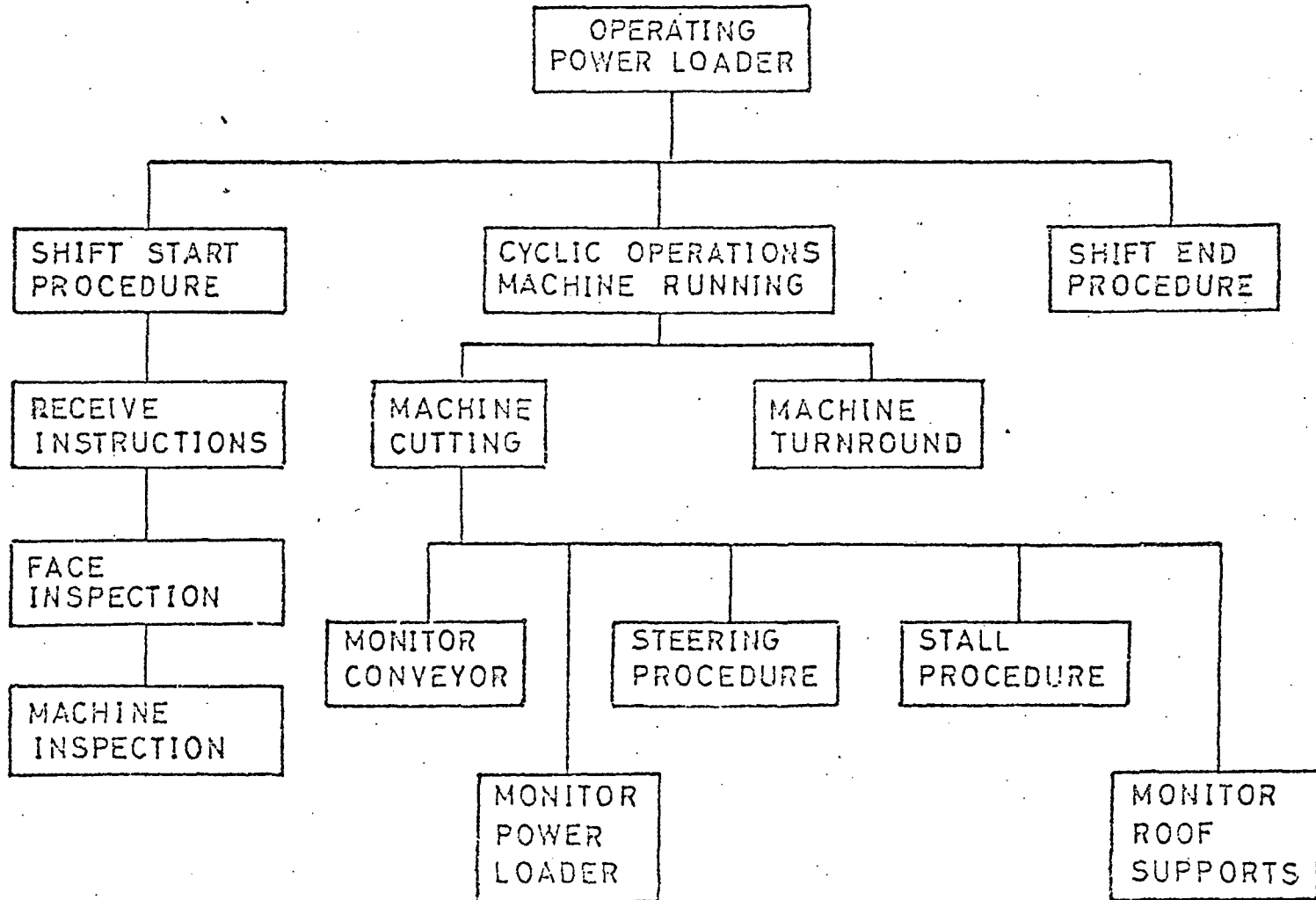


FIGURE 2

MACHINE TURNROUND

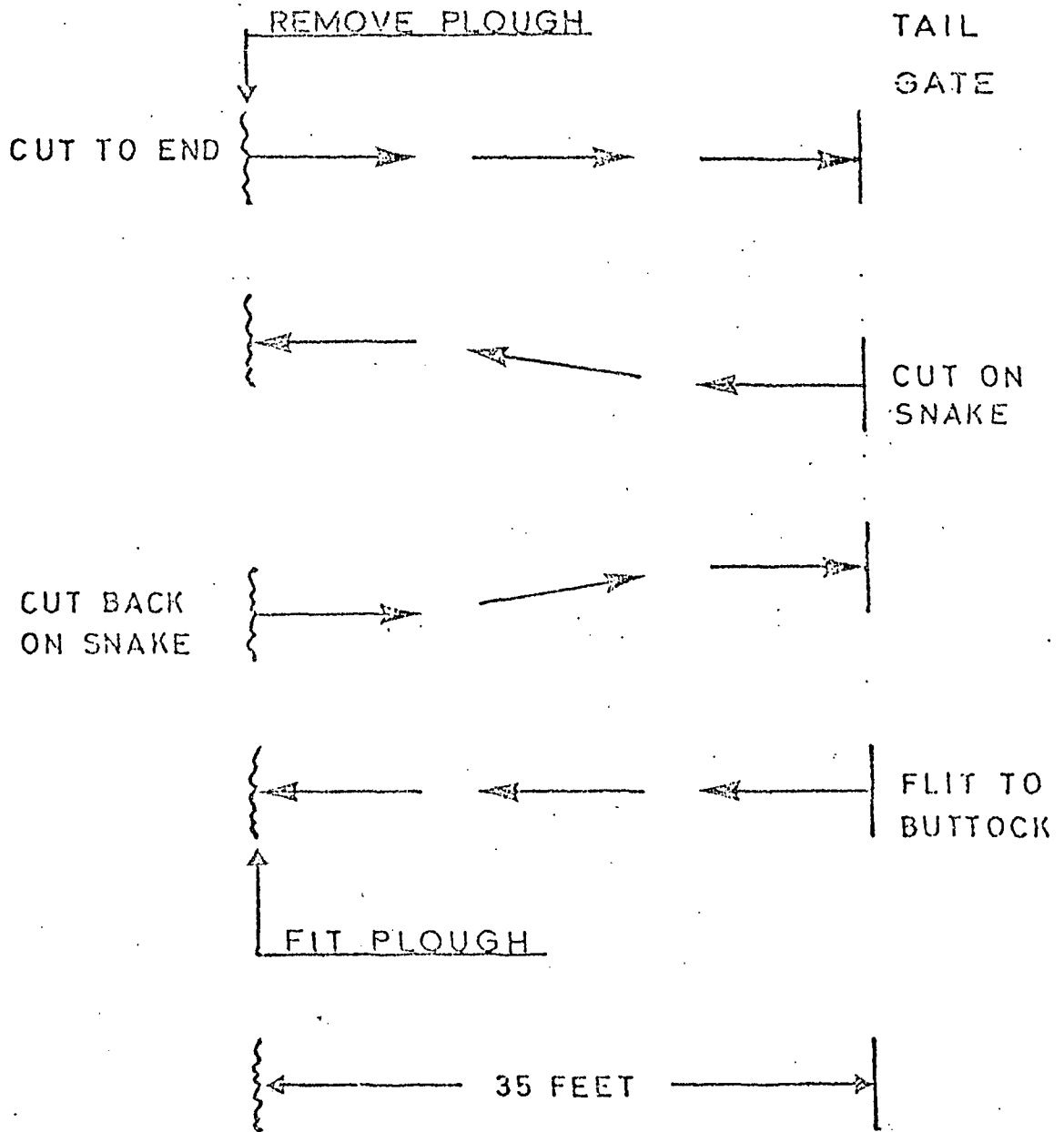


FIGURE 3.

ANCILLARY WORK CYCLIC PART

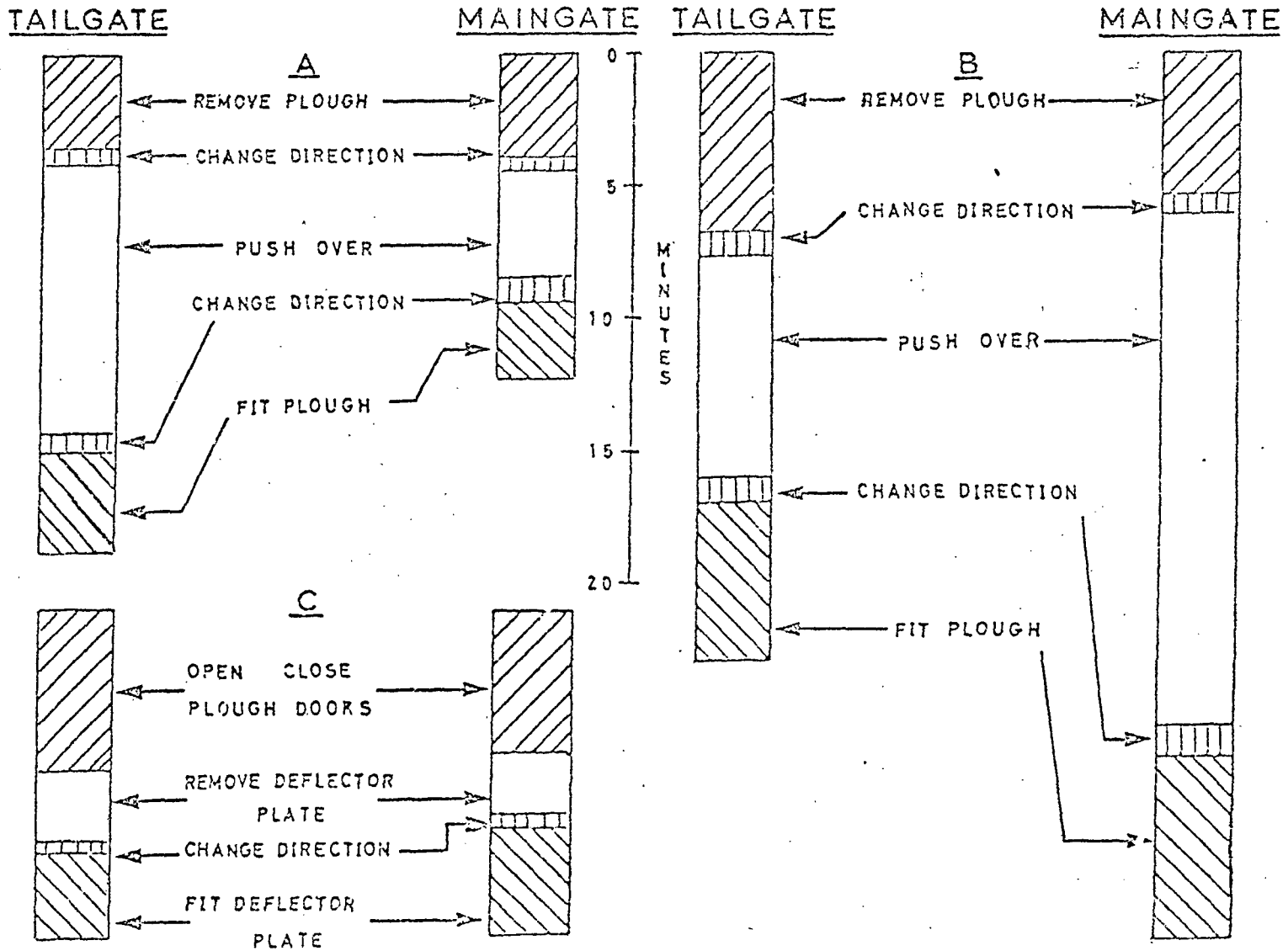


FIGURE 4

apply as were discussed when considering the steering, that it is necessary for the operator to travel at the front of the machine for each direction of travel and the machine design and training should take this into account.

2.3.3

MACHINE ANCILLARY TIME (7 - 10%)

The definition of machine ancillary time used in this report is 'the service or other work related to a process which it is not appropriate to classify as productive'. There are two types of ancillary work, the cyclic and the non-cyclic. The cyclic part consists of the work dependent on the machine cycle, e.g. the work at the turn-round, and the non-cyclic part is made up of shift start procedures, shift end procedures (as shown in Figure 2) and other service work. This other service work may occur at any time of the day or shift unrelated to the machine cycle, e.g. checking and changing picks. Figure 3 shows that ancillary work is one of the main occupations and the time spent on this is the second lowest of all main occupations. The average time for ancillary work per day can be seen in Table 8.

TABLE 8 SHOWING THE AVERAGE TIME TAKEN BY ANCILLARY WORK PER DAY

Installation	A		B		C	
	Minutes Per Day	Percentage of total time	Minutes Per Day	Percentage of total time	Minutes Per Day	Percentage of total time
Cyclic	53.70		52.4		61.7	
Non-Cyclic	14.5		10.1		23.1	
TOTAL	68.2	7.2	62.5	7.0	84.8	10.2

By examination of Figure No. 1 page 8 and this table it can be seen that as the percentage of machine running time increases, so also the time taken by cyclic and non-cyclic ancillary work increases. This is as one would predict and leads to the conclusion that on all faces more attention is required to the organisation and management of ancillary work.

2.3.3.1

Cyclic Ancillary Work

The work done by the operator during the machine turn-round is the only cyclic ancillary work performed at these installations. Figure 4 illustrates the type of machine turn-round that was used at all installations with one exception. The exception was installation C where in the tailgate a second shearer was used to cut a buttock. Figure 3 shows the ancillary work necessary to achieve these turn-rounds. Each block diagram represents the average time for one turn-round in the

gate and is the means of all measurements taken during the 4 weeks of study. (The average time for a turn-round varies between 12 and 33 minutes.) The operation which accounts for the differences between installations is the 'push over'. It is concluded that this difference is due to three factors, work in preheads and stables delaying pushover, roof conditions at face ends and work organisation. It is not possible to place an order of importance on these factors as conditions varied widely between the installations.

There is another aspect of the work during the machine turn-round which concerned a number of machine operators. This is the work involving the plough and deflector plates shown in Figure 3. Firstly, as the seam becomes thinner, operators find more difficulty in clambering over the conveyor side plates and chain to get on the face side and then to return afterwards. Sometimes they are carrying heavy weights and bars. Secondly, this routine requires the driver to move into a place of potential danger. It is, therefore, suggested that an hydraulic mechanism might be used to alter the plough or deflector plate at each end of the face. It is recommended that face supervision should regularly monitor the time taken by 'push over' as this is the most critical part of the machine turn-round and a feasibility design study should be made for an hydraulic mechanism to alter the plough or deflector plate at each end of the face, the purpose being to get rid of the danger for the operators in going to the face side during the turn-round. The NCB have recognised this by issuing specific instructions.

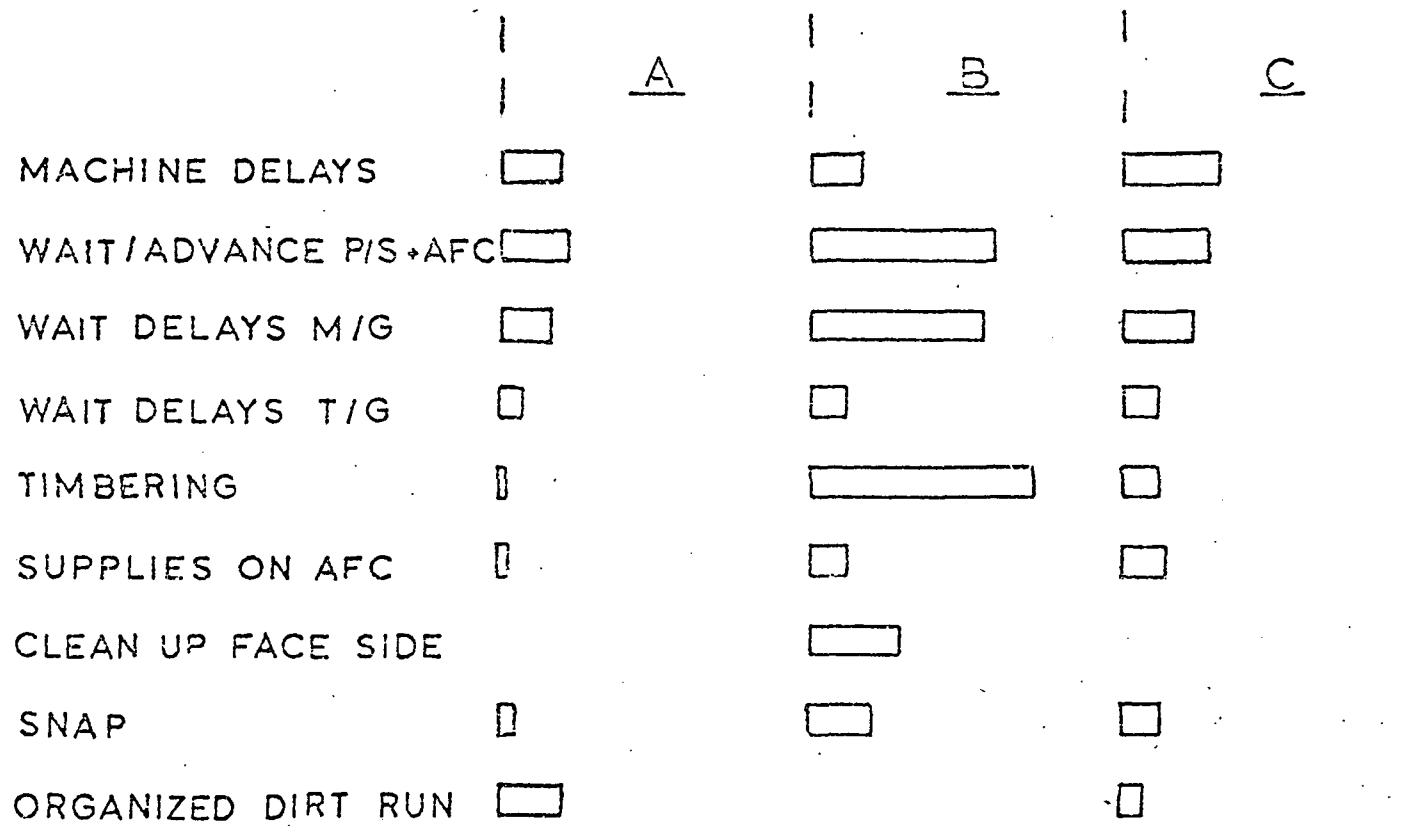
2.3.3.2 Non-Cyclic Ancillary Work

As is shown in Table 8, page 13 the non-cyclic part forms a small proportion of all ancillary work. It is made up of two types - one which occurs regularly and is illustrated in Figure 2 by the first and last columns of the machine operator's task. These are the shift start and shift end procedures, e.g. machine preparation. The second type is work of the kind described in section 2.3 as being work which is of short or long duration to attain production or increased safety, e.g. timbering up a tail gate fall. As this work forms such a small proportion of the daily work of the studied machine operators recommendations are not made on this part of the work.

2.3.4 OPERATIONAL DELAY TIME (12 - 32%)

An operational delay is a delay in the sequence of events affecting the machine cycle of operations. Figure 5 shows a breakdown of the operational delays per day. Some combination of the causes of operational delays has been made in order to assist in the presentation of the results. For example, the first item 'machine delays' includes: start the machine,

OPERATIONAL DELAYS



0 ——— 50 ——— 100
 MINUTES

FIGURE 5

machine stall, adjust cutting horizon and crawl to machine. Wait/advance PS and AFC refer to waiting to advance the powered supports and armoured face conveyor and awaiting snakers and powered support men. Wait delays main gate (M/G) include wait M/G preparation, wait M/G firing and lumps at gear head.

An examination of Figure 5 shows that delays were higher in installation B. This was due to bad conditions on this face due to falling roof stone. Several of the delays, such as timbering (the placing of split bars over roof beams of the powered supports) wait/advance PS, AFC and clean up face side, were related to these poor face conditions. On this particular face the factor limiting performance was the chocking. The chockers could not keep up with the machine due to the roof conditions. This was not the case in installations A and C, where the operators claimed that operational delays did not limit performance. It is considered that the chocks used on installation B (see Table 1 page 1) are not particularly suitable for a rough face because any debris that falls in the travelling track cannot be shed into the waste. It is pulled forward each time because of the design of the pipes and chock legs.

2.3.5 LOST TIME AT THE FACE (12 - 28%)

The lost time at the face is the time duration when the machine cannot be operated because of delays not connected with the machine cycle of operations. On average this duration varies between 100 and 250 minutes per day in these installations. The causes of this lost time have been classified into nine headings; the machine, the armoured face conveyor (AFC), geological, mechanical, electrical, supports, organisation and unknown. The last category contains lost time at the face for which it was not possible to find the cause.

TABLE 9 AVERAGE LOST TIME AT THE FACE MINUTES/DAY

Installation	A	B	C
Machine	9.0	17.6	0.6
AFC	3.5	17.8	0.6
Geological	51.6	0.0	0.9
Mechanical	62.6	42.5	23.3
Electrical	20.6	21.8	17.0
Supports	4.8	2.2	0.6
Organisation	58.5	127.1	28.5
Unknown	10.2	19.4	25.1
TOTAL	220.8	247.4	96.6
% of Operator's Total Time	23.3	27.9	11.6

Table 9 shows the average lost time at the face for each installation classified by these causes. It can be seen that the largest delay in the table is 127.1 minutes for organisational causes in installation B. the main causes of this delay were:-

- waiting for timber in the district;
- machine off the conveyor;
- twisted haulage chain;
- waiting for fitter;
- machine cable fast and machine cable burst;
- waiting for tail gate work;
- waiting for machine driver at start of shift when he is absent;
- Motor cable burst at main gate.

Further examination of table 9 shows that installation A has three delays classified of over 50 minutes duration per day. These are 'geological', 'organisational' and 'mechanical'.

As these delays are extensive they have been examined in further detail. Again, as in the previous case, they did not occur every shift, but when they occurred the delay was often for an hour or more and

this averaged over the total study period gives the delay per day. Under the heading 'geological' the following reasons were given for delays:-

Timber fall area;

Machine fast in low area;

Burst hoses on the machine;

and in the case of the organisational delays:-

Fitter repairs burst oil pipe;

Setting road head girders M/G;

Push over T/G;

AFC flight out;

Haulage chain fast in the channel.

Further training may assist in these cases and also the design of the machine so that oil pipes are not exposed to damage.

2.3.6 LOST TIME OUTBYE (4 - 5%)

The time duration in which the machine cannot be operated due to gate or trunk conveyor or further outbye stoppages is known as 'lost time outbye'. The machine operator during this time is usually waiting by his machine to start as soon as the conveyor begins to move. Although this time is the smallest of the seven main occupations which have been described, it is often the most annoying to the machine operator. Often they get into a rhythm of working and then have to stop due to these outbye delays. It is sometimes difficult to determine the causes of these delays when one is on the face. However, table 10 shows a breakdown by time of the outbye delays per day into conveyor delays, other reasons and unknown. The results of the table are the average of the 4 weeks' studies. During individual studies for several consecutive shifts no delays would be recorded and then a 5 minute to one hour delay occurred to give these representative results.

TABLE 10 AVERAGE LOST TIME OUTBYE THE FACE MINUTES/DAY

Installation	A	B	C
Conveyor delays	19.8	28.0	24.1
Other reasons	18.3	3.8	10.1
Unknown	4.2	9.5	8.9
TOTAL	42.3	41.3	43.1
% of Operator's total time	4.5	4.7	5.2

As far as could be discovered, the conveyor delays were almost entirely due to the main gate conveyor. The faults included:-

- blocked chute;
- belt slip;
- bad alignment;
- repair rip;
- belt overturned;
- belt broken;
- motor cutting out;
- signal fault;
- putting rollers in.

The other reasons for lost time outbye of the face recorded in the table differed between installations. At installation A two reasons were recorded; 'bunker full' and 'dirt run from development'. The delay at installation B was due to a full bunker and at C due to the pit bottom being blocked, and to a coal preparation plant delay.

2.4 The Machine Operator's Physical Work Load

Having individually examined the six main tasks of machine operators, the task is now considered as a whole. The question of how hard an operator works is closely followed by two more questions - does he become fatigued and would increased machine performance result from the design of work: rest periods for the operator. These are critical questions but are not as directly related as they first appear. This section does not deal with the muscular load of individual hand controls (this is discussed in section 3 - the power loader machine). It is concerned with the overall body work load.

A physical load is imposed whenever there is an expenditure of energy in the manual execution of a task. The rate of energy expenditure can be measured in work units (watts) or heat units (K calories per minute). In this section the units used are watts with the heat units (K calories per minute) quoted in brackets. One watt = 0.0144 K calories per minute. The energy that is required to do any task is provided by oxidation of foodstuffs with the oxygen that is breathed. A measurement of oxygen uptake (or consumption) by the body is thus an indirect but accurate method of measuring the exact amount of energy expended in a task.

The equipment used for determining oxygen consumed has been used extensively and is well proven in the laboratory and in mines. The unit used for these

measurements was the Max Planck respirometer (see Figure 6.) It consists of a small dry gas meter weighing 3 Kg which can be worn either on the back like a haversack or on the chest like rescue breathing apparatus. The operator doing his ordinary work, breathes out through an expiratory valve, and the expired air is passed through the meter, which measures the volume. It contains a device which diverts a fraction of the expired air into a small rubber bag. This sample is subsequently analysed to determine the percentage of oxygen in the expired air. Details of the technique may be found in the paper by Humphreys, Lind and Sweetland (1962) entitled 'The Energy Expenditure of Miners at Work'.

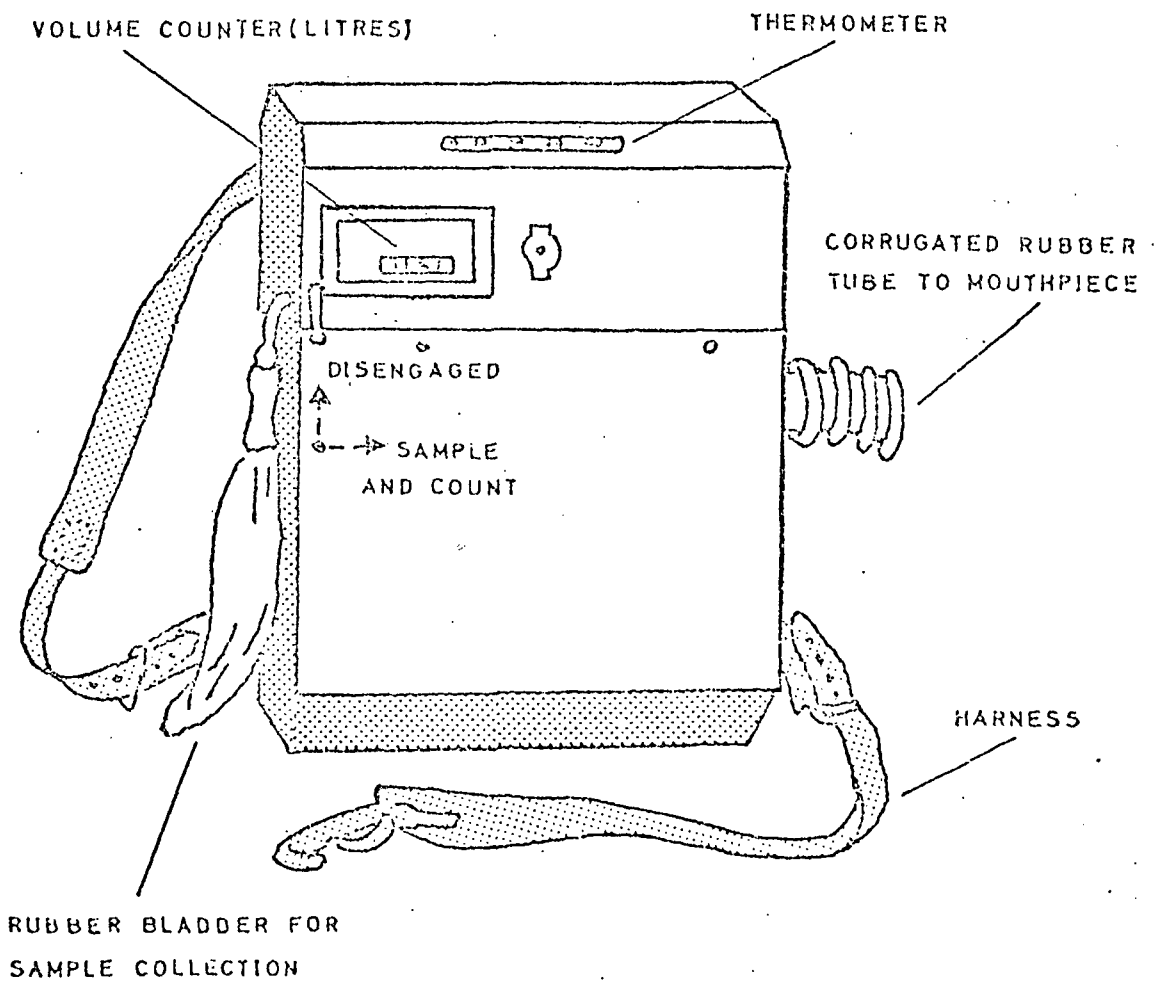
A system of grading of the physical effort required in industrial work (Christensen, E.H., 1964) is shown in the table. This shows the grades for men and has proved sensible and helpful to industrialists. The terms light, moderate and hard are used to describe work which falls within the ranges set out in the table.

CLASSIFICATION OF WORK

Grade of Work	Rate of Energy Expenditure		Heart Rate
	Watts	K. Cals. per min.	Beats per min.
Very Light	175	(2.5)	75
Light	175-350	(2.5 - 5.0)	75-100
Moderate	350-525	(5.0 - 7.5)	100-125
Hard	525-700	(7.5 - 10.0)	125-150
Very Hard	700-875	(10.0 - 12.5)	150-175
Extremely Hard	875	(12.5)	175

The amount of energy expended at work varies greatly if the work is sedentary with minimal body movement, the energy output is only a little more than would be needed at rest; this is still true even if the mental effort results in a feeling of physical tiredness. At rest about 70W (1 K cal. per min.) is needed to do the internal work of the body and for movements of the heart and respiratory muscles. On the other hand, workers in heavy industries often expend an average of 350 watts (5 K cal. per min i.e. 2,400 K cal. during an eight hour shift).

Table 11 shows the average energy expenditure of machine operators as measured at the three installations. It can be seen by comparison of this table with the above table that the work of operating the machine is light to moderate. However, when the whole shift is considered, especially when delays are short, the work is shown to



THE MAX PLANCK RESPIROMETER

FIGURE 6.

be heavier. It is concluded that the work of the machine drivers in the thin seam installations studied was not unduly heavy.

TABLE 11 ENERGY EXPENDITURE OF MACHINE OPERATORS

Installation	A	B	C
Average rate of energy expenditure when operating power loader, watts.	305 (4.38 K. cal. per min.)	328 (4.71 K. cal. per min.)	285 (4.1 K. cal. per min.)
Calculated average energy expenditure per shift during 4 weeks			
1. morning shift	246	249	254
2. afternoon shift	250	253	248
Energy expenditure on shift when delays were shortest.	283	313	277
Energy expenditure on shift when delays were longest	161	118	211

The reasons for this are three fold. They are related to the machine, the installation and the face delays. Firstly, the speed that the machine is capable of cutting determines the speed of movement of the machine operator, and hence the operator's energy expenditure in operating the machine. Secondly, in the very small space available for operator movement it may not be possible to exert high levels of energy expenditure. These limitations of space are further examined in section 4 of this report. Thirdly, the delays when the operator is waiting by his machine reduce the energy expenditure for the shift's work. It is concluded that, with the present machine speeds and pattern of delays, the physical work load is not of sufficient severity as to require further rest periods or rotation of machine operators on a half shift basis to compensate for purely physical work.

2.4.1 Heart Rate Measurement

Heart rates recorded during the performance of work depend on a variety of factors. These include: individual physical fitness, the physical and mental demands of the work, and the environmental stress. The meaning of heart rate as a measure of strain has been documented by Christensen (1964) in relation to the energy expended on the task. This is shown on page 19.

The heart rate of a man can be used to rate the relative physical demands of a particular job. Evidence suggests that few men show average rates (including rest periods) in excess of 110-120 beats per minute during day-to-day employment. A more usual average for active men is 90-100 beats per minute. The highest rates of 180-190 beats per minute can only be sustained for a few minutes; 120-130 beats per minute for perhaps one hour, and 145-150 beats per minute for about ten minutes. Hot conditions will cause the heart rate to rise above that for the same physical work load in colder conditions and thus reduce the work period.

Heart rate can be recorded by palpation at the wrist or other convenient site. This requires practice and involves some inconvenience to the operator. More sophisticated techniques are available based on monitoring the electrical activity which accompanies the heart beat. Such information may be recorded on small personal instruments or by telemetry.

Within the mining industry at the time of this exercise, suitable equipment for monitoring cardiac electrical activity was not available for underground use. It was, therefore, necessary to use the palpation method. It was important not to interfere with the operator during machine running or ancillary activities and, therefore, pulse measurements were taken during machine stoppages. The average time between measurements was of the order of ten minutes. Notes were taken of the previous activity before the measurement and the time of the measurement from the beginning of the shift. A typical set of results is shown in Figure 7.

The average heart rate during the shift is 85 beats per minute, based on the sampled points. There are six peaks to note on the figure. The two major peaks are at the beginning and end of the shift when walking into work and outbye. A measured peak heart rate of 140 beats per minute was observed during that walk. Three of the peaks result from crawling along the face for 20 to 50 metres and shovelling mineral to clear the face conveyor. The fourth notable peak followed plough removal at a face end. This is a heavy activity of too short a duration for measurement by energy expenditure methods. However, the heart rate measurement indicates that mechanical methods of plough handling should be investigated to reduce this regular heavy loading and also to decrease the need for work on the face side.

In general, the results show that, with few exceptions, work on the face is light to moderately heavy, confirming the results shown by energy expenditure methods. Walking in and outbye is heavier physical work particularly when walking to the rise.

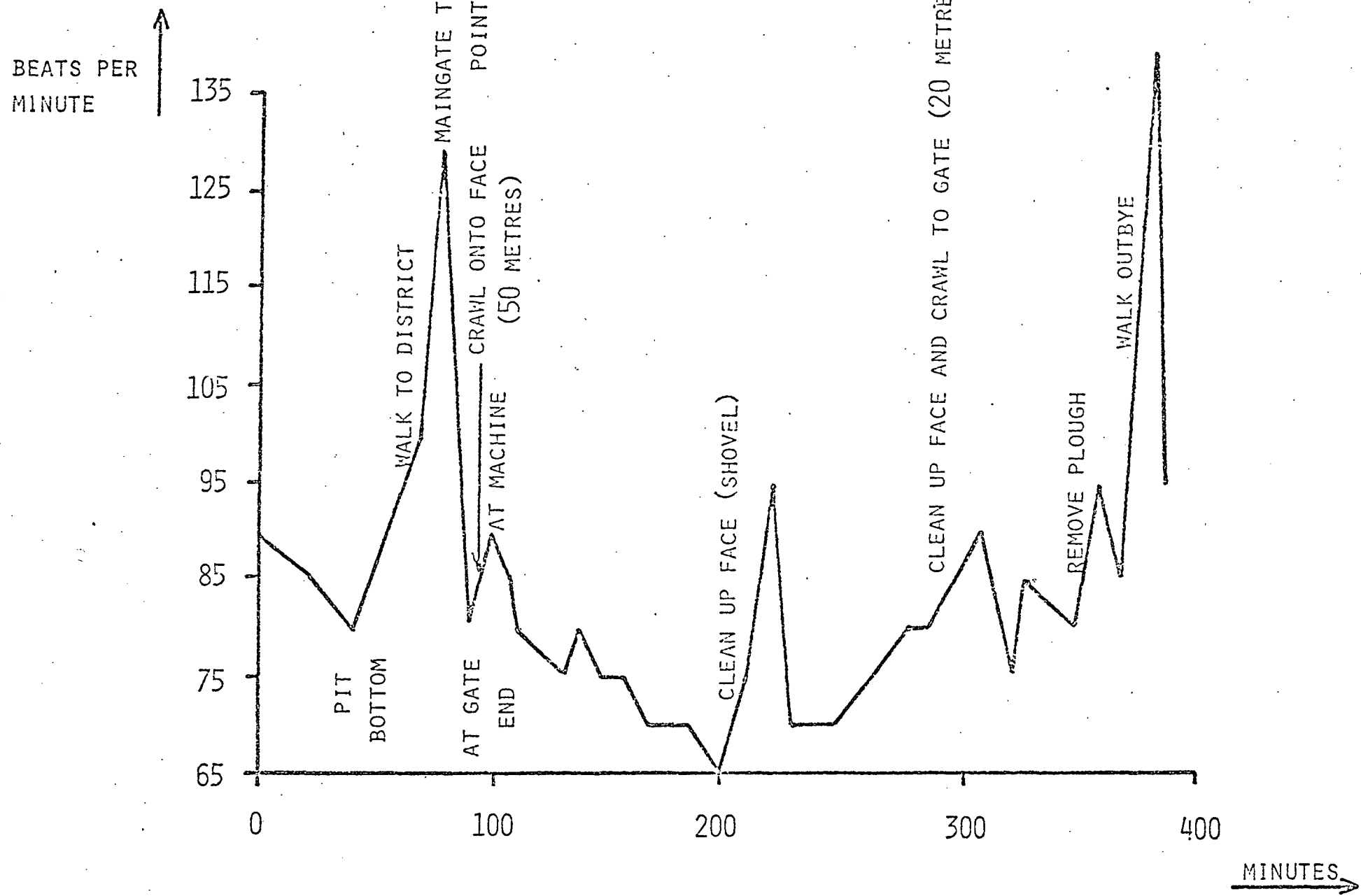


FIGURE 7. AN EXAMPLE OF FULL SHIFT HEART RATE RECORDINGS.

The shortcoming of this technique is that it does not show accurately the minute to minute variations of heart rate more closely allied to the complete work cycle. As an extension of this aspect of the study, a project is now in hand to measure heart rate during work at the coalface, using an intrinsically safe portable tape recorder to monitor the electrical cardiac activity. In this way it is hoped to discover which aspects of coalface working are liable to cause stress.

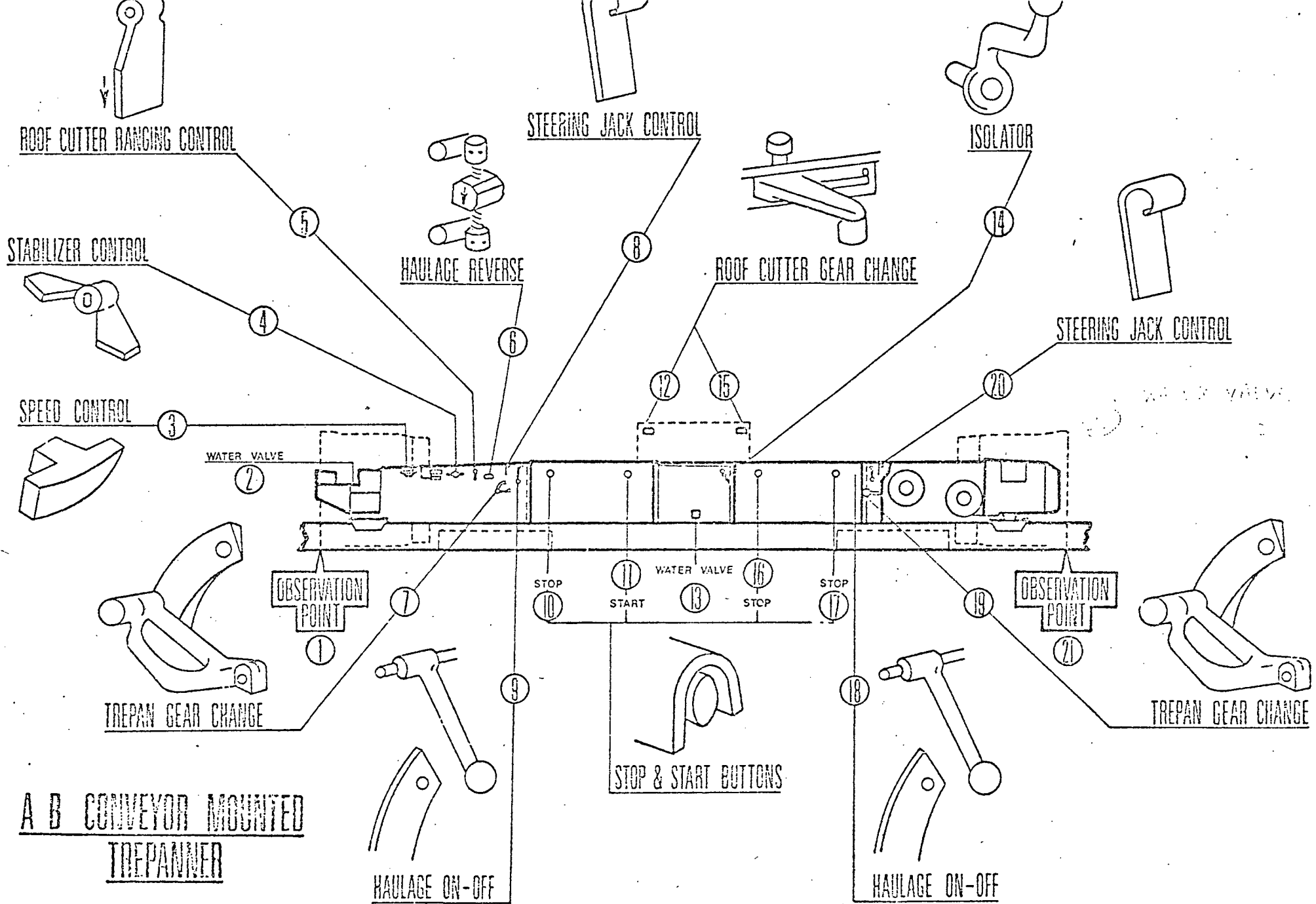
3. THE DESIGN, ARRANGEMENT AND OPERATION OF THE CONTROLS OF THE POWER LOADING MACHINE

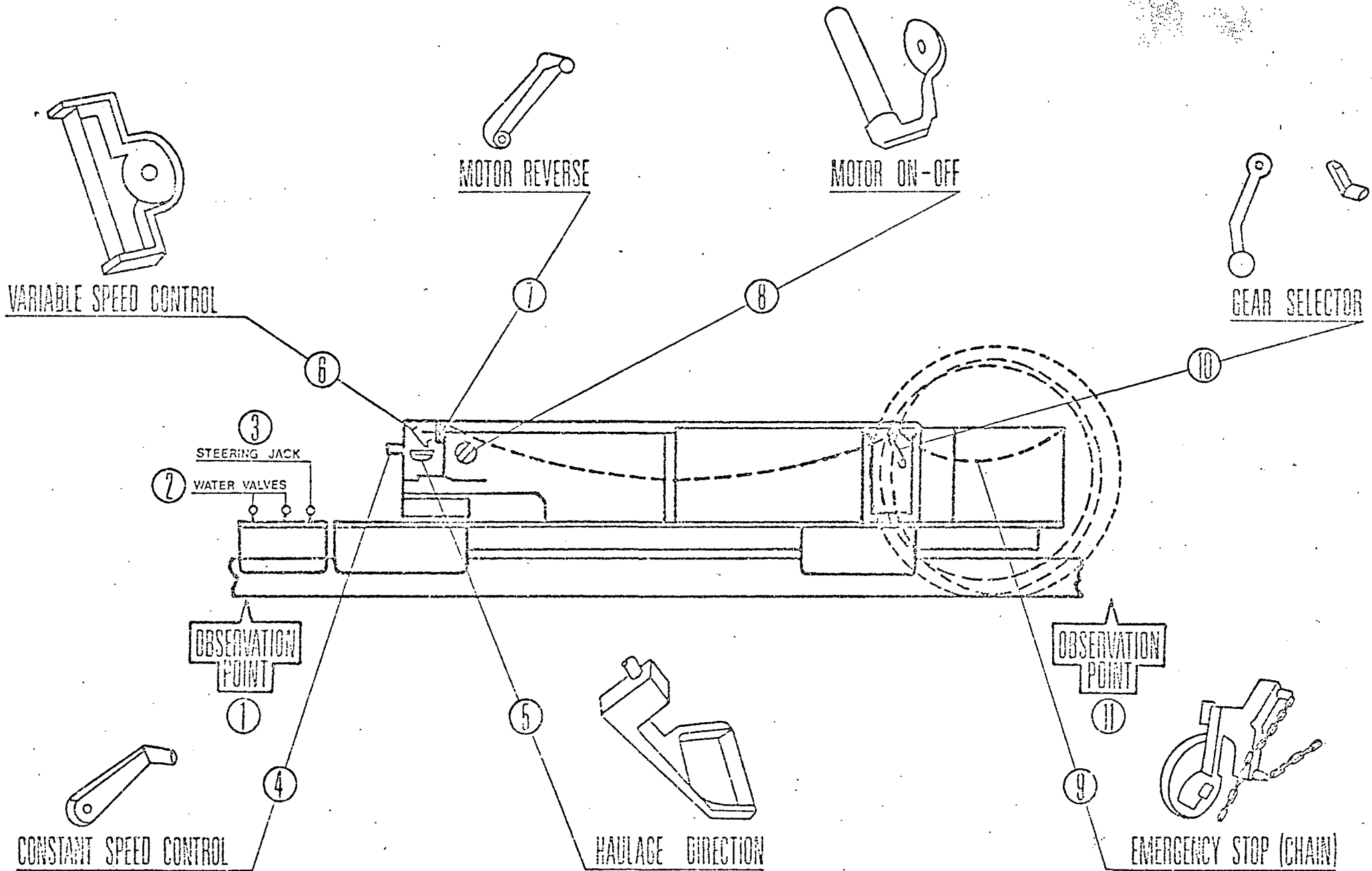
Two types of power loader were studied - the AB Conveyor Mounted Trepanner and the AB Bi-Di Shearer. This section describes the human factor considerations in the control of these machines. The machines have existed in their present forms for about ten years. The controls have therefore evolved without the benefit of the recent trend of increasing the importance of the operator as a design consideration. General layout sketches, figures 8 and 9, show the positions of the main controls. The task of the machine operator has been described in section 2. This section continues by re-examining the job and relating how it is achieved in practice. Section 2.3.2 'Maching Running Time' was concerned with the operator tasks. In this section the controls are related to these tasks. Table 12 shows the frequency of use of the controls in relation to the individual tasks. These frequencies varied from shift to shift but the figures listed give a guide to the order of magnitude. The section concludes by surveying the existing arrangements of controls.

TABLE 12 SHOWING THE NUMBER OF MACHINE ADJUSTMENTS RELATED TO THE TASKS OF OPERATORS DURING A STUDIED SHIFT

	Installation		
	A	B	C
Starting Procedure at beginning of shift	1	1	1
Monitoring (Stop Power Loader Conveyor (Start Power Loader	23 23	32 32	29 29
Monitoring (Speed Changes Power Loader	1	15	15
Steering (Stabilizer Procedure (Jacks	13 4	67 8	- 8
Monitoring (Stop Power Loader Roof Supports (Start Power Loader	2 2	8 8	5 5
Stabling Procedure	1	2	2
End of Shift Procedure	1	1	1

FIGURE 8





A B M-01 SHEARER

In operating the machine, the driver crawls alongside the machine in the travelling track (see Figures 10 and 11). When he needs to make a control change he turns to the machine, puts his arm between the line of roof supports to reach the control and makes the control adjustment (Figure 12). If the adjustment cannot be achieved rapidly, due to the advance of the machine, he must take his arm from between the supports and re-insert his arm in the next bay. Alternatively, the machine may be stopped or slowed down. It is obvious that the faster the machine speed the more difficult become control adjustments while the machine is moving.

3.1 Starting and end of shift procedures

At the start of the shift, when the operator arrives at the face, there is the safety inspection of the work place, which includes the machine cable and the machine. On the afternoon shift there is usually the direct take-over of controls by one operator from the other. In practice, this is not always achieved, but whenever it is possible this appears to be a worthwhile, safe and efficient practice. In the case of the morning shift, the exact machine start procedure which follows the inspection varied. This variation depended on how the machine was left by the previous operational shift or by the maintenance operations.

Two examples of start procedures used during the study are described with the exact positions and illustrations of the controls shown in Figures 8 and 9.

For the Conveyor Mounted Trepanner:-

- (a) Check isolator (14) is in the 'off' position;
- (b) Check picks in trepan wheel and roof cutter;
- (c) Put roof cutter into gear (12) or (15) on the face side;
- (d) Push isolator (14) into 'on' position;
- (e) Start warning given;
- (f) Check/push start button (11);
- (g) Press stop button (10);
- (h) Turn water valve 'on' (13);
- (i) Press start button (11);
- (j) Put haulage in reverse (6);
- (k) Push down haulage control (9) to start hauling.

For the Bi-Di Shearer:-

- (a) Check power (8) turn 'on', 'off' and 'on';
- (b) Check haulage (5) 'on' and turn 'off';

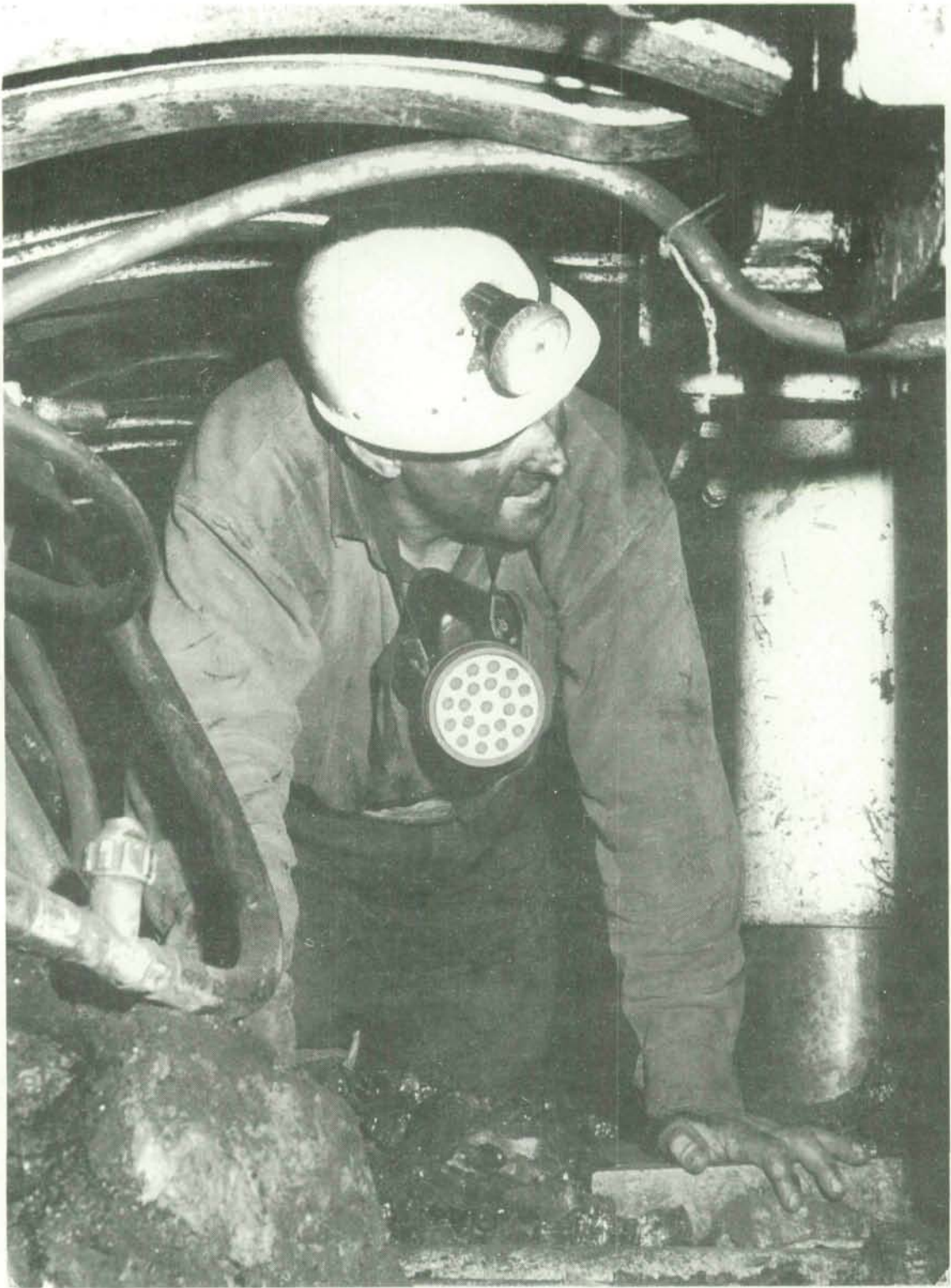


FIGURE 10 OPERATING POSITION ON A CMT WITH WILD THIN SEAM SUPPORTS

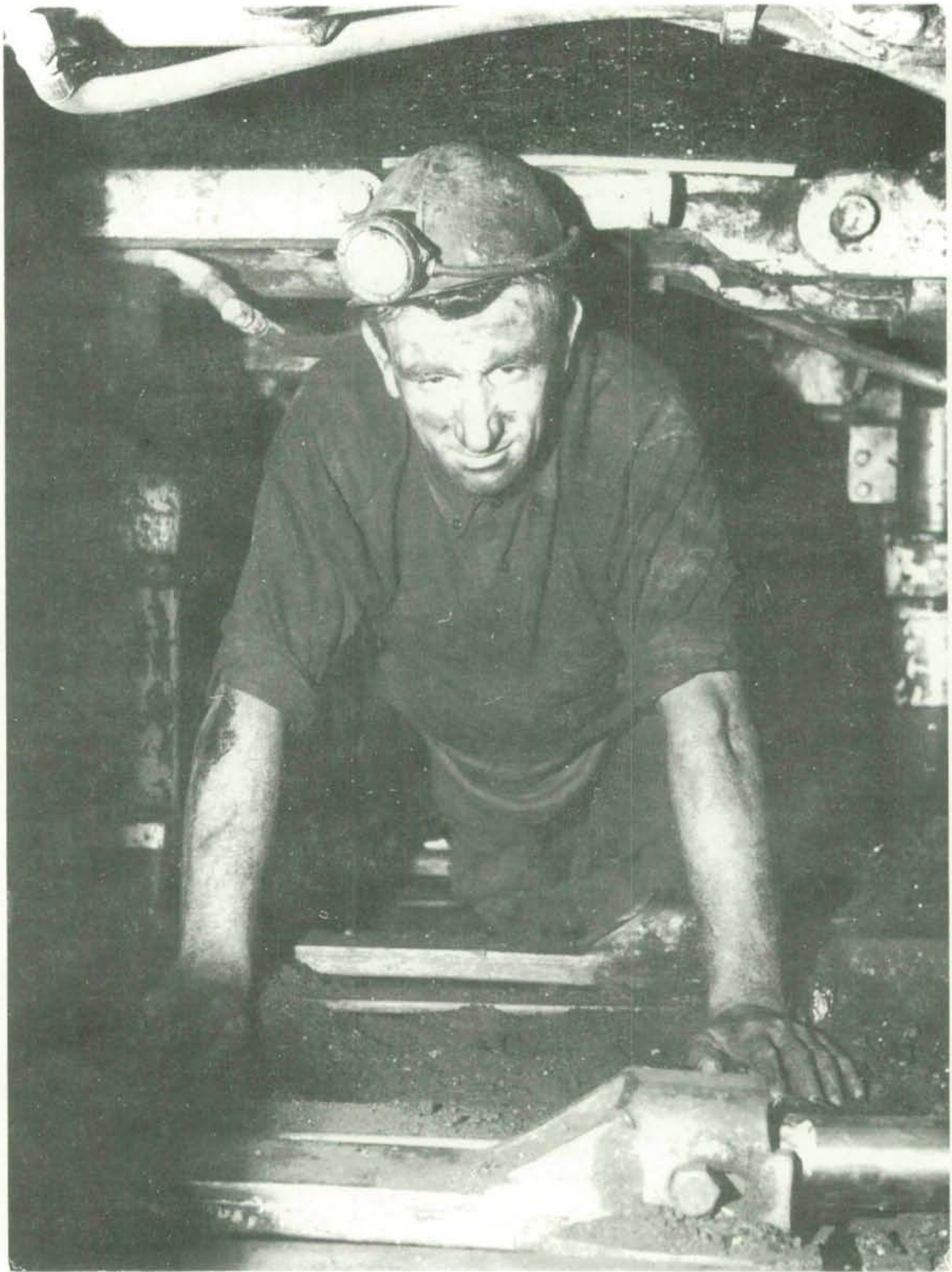


FIGURE 11 OPERATING POSITION ON A CMT IN DOWTY THIN SEAM SUPPORTS

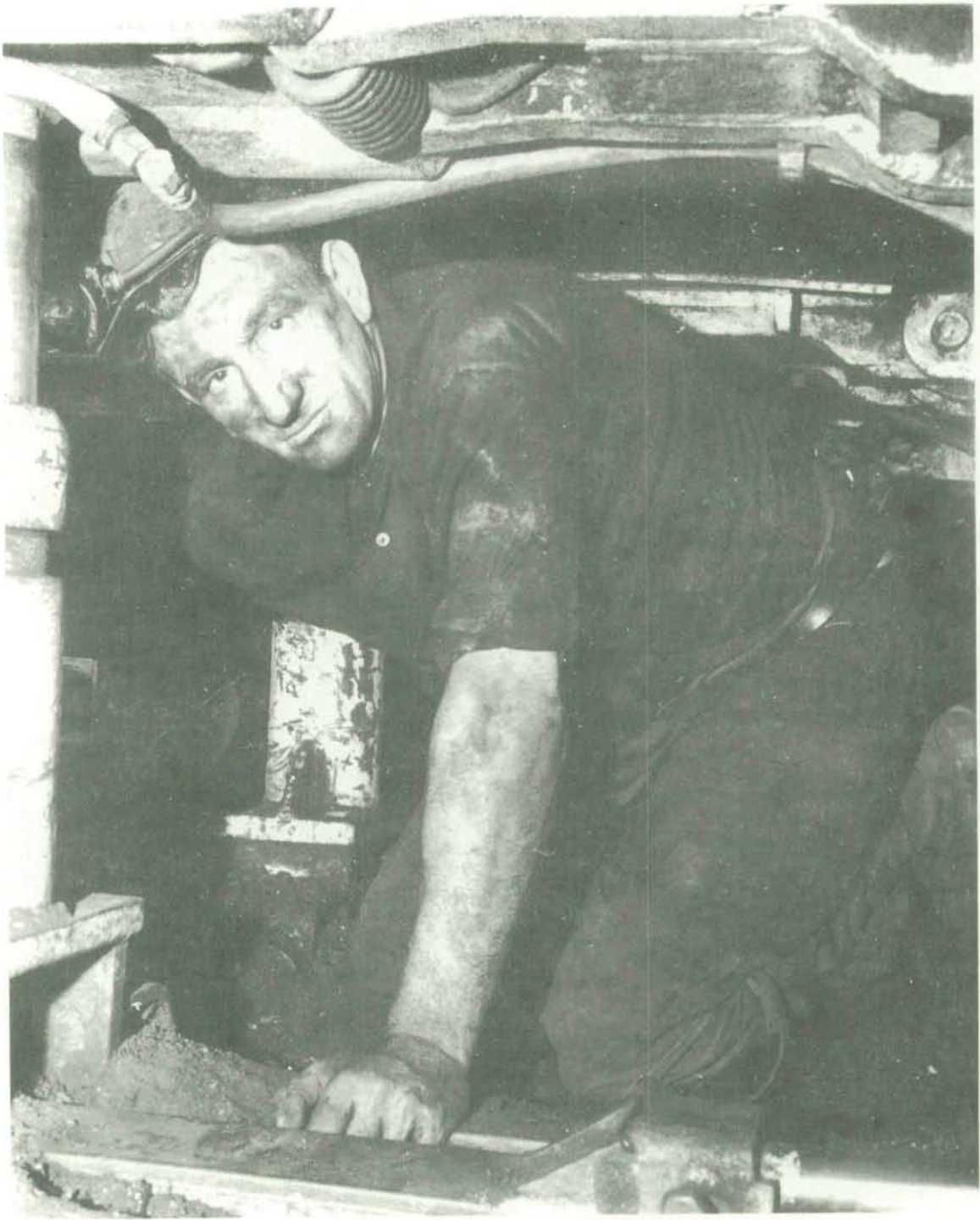


FIGURE 12 AN OPERATOR CONTROLLING A MACHINE

- (c) Check tilt steering jack (3) power (8) 'off';
- (d) Check gear selector out of gear (10);
- (e) Examine picks, changing and tightening where necessary;
- (f) Start warning given;
- (g) Power (8) 'on', power 'off', operator engages cutting drum gear (10) as motor comes to rest;
- (h) Speed control (6), 3 turns anti clockwise;
- (i) Power 'on' (8);
- (j) Haulage 'on' (5);
- (k) Water valve 'on' (2).

The machine was usually sited by the main gate or tail gate while these operations were undertaken at the beginning of the day shift. These start procedures were normally quite brief. Section 2.3.3 has drawn attention to the relatively small proportion of time taken by operations of this type. It was only when the checks during the procedure revealed a fault or that an adjustment was required, that there was difficulty reported.

Generally, during the start procedures the same controls were used as those employed while operating the machines in the course of the rest of the shift. It has previously been mentioned that the start procedure depended on how the machine was left. The importance of leaving the machine out of gear while the machine was left unattended was stressed by all operators.

In the case of the conveyor mounted trepanner, it was not possible to put all mechanisms individually out of gear at the end of the afternoon shift. The gear selectors for the two bottom discs and the roof cutter gear change (12, 15), for example, were situated between the coal face and the machine. The normal procedure was, therefore, always to disengage the isolator (14). In order to ensure that the machine was not accidentally activated or operated by unauthorised personnel, the isolator handle could be removed. At one installation it had been suggested that each operator and fitter should have an isolator handle and that they should carry it about with them. However, due to the size and shape of the handle, this had proved impractical and the normal system was to take the isolator handle and put it in the pommel cover at the end of the afternoon shift. Measurements of the force required to operate the isolator using a spring balance showed a resistance of 25.4 Kg (56 pounds). The maximum resistance which is recommended for intermittently used controls of this type is 9 Kg (20 pounds). It is concluded that at present the method of isolation of conveyor mounted trepanners and the force required to operate the isolator handle are not satisfactory and in new designs need to be modified.

In the case of the shearer, the disengagement of gears at the end of the afternoon shift was more simple than that of the trepanner. The gear selection was accomplished by means of two levers (10), an 89 mm (3½ inch) long gear change lever, which rotated through 70 degrees, and a small 50 mm (2 inch) crank which rotated through 160 degrees to act as a safety lock. These controls were considered satisfactory by operators for operation and prevention of accidental activation, although there was no means of immobilizing the machine against operation of the machine by unauthorised personnel.

3.2 Monitoring the Conveyor

The operator's part in the monitoring of the conveyor has been described in section 2.2. In the case of the conveyor mounted trepanner, the machine starting and stopping sequences used were (see Figure 8):-

<u>conveyor stops</u>	<u>conveyor starts</u>
Haulage on/off control (9, 18) operated	Start button (11) pressed
Stop button (10, 16 or 17) pressed	Water valve (13) turned on
Water valve (13) turned off	Haulage on/off control (9, 18) operated

All operators were of the opinion that dual controls would make the work considerably easier (see section 2.3.2.3). This was because one of the difficult parts of the work was the crawling and turning in the travelling track. In the case of the conveyor monitoring, operators were satisfied with the number and the position of the stop buttons and the haulage on/off controls. It was suggested that there should be dual water spray controls - one at each end of the machine.

As far as the design of individual controls was concerned, a number of comments were made. Operators at one installation were dissatisfied with the haulage on/off control (9, 18). This control was of a dual type. It was in the form of a lever 114 mm (4½ inch) long with a ball of diameter 44.5 mm (1¾ inch). The measured operating resistance was 10.9 Kg (24 pounds). It was fitted in a recess between the gear box and motor (see Figure 8). There is very limited access for the hand. Anthropometric data suggests that the space is insufficient and this is confirmed by an operator comment. The space around the lever was less than 44.5 mm (1¾ inch) at some points. At another installation the lever had been bent to enable 50 mm (2 inch) clearance. However, it was not possible to operate the control while wearing gloves unless the thumb and first finger were cut out of the glove. Operators also reported that on some occasions, during bad roof conditions, falls have operated the control both starting and stopping the machine. It was observed that one operator did not

use the auxiliary haulage on/off control. When questioned why, he said that a connecting rod with the main haulage on/off control did not provide a satisfactory engagement of gears. From these observations it appears that the individual controls were not very satisfactory both from comparison with human factor recommendations and operators' opinions.

In the case of the Bi-Di shearer when monitoring the conveyor the starting and stopping sequences used were:- (see Figure 9).

<u>conveyor stops</u>	<u>conveyor starts</u>
Turn haulage direction control (5) horizontal	switch on motor (8)
Switch off motor (3)	Turn haulage direction control (5)
Turn off water valve (2)	Turn on water valve (2)

In regard to the sequence of these operations, the stop sequence is satisfactory but the start sequence is dangerous. It is dangerous because the operator has to reach over the machine with his hand, arm and, on occasions, his head in order to operate the water control. When the conveyor and power loader are both moving there is always the possibility of the machine rising due to lumps of stone, coal or materials travelling under the machine. Should this occur when the operator is reaching, a serious accident could occur.

This sequence of starting was observed many times during the study and when operators were asked why this sequence was used it was said that as the water valves were furthest away they were operated last. It has been suggested (Sections 2.3, 2.1) that sprays could be operated automatically but if this is not possible the water spray valve should be re-positioned. The new position should be near the travelling track and the motor on-off switch (8).

The position and shapes of individual controls can be seen in figure 9. The motor on-off switch (8) consisted of a handle 25.4 mm (1 inch) diameter and 69.8 mm (2 $\frac{3}{4}$ inch) long. In order to switch on, the handle was rotated anti-clockwise through 145 degrees. The 'on' and 'off' positions were marked in raised cast letters 8 mm (5/16 inch) in height. The clearance between the control and the machine was not sufficient. At some points the clearance was only 19 mm ($\frac{3}{4}$ inch). The expected direction of movement was incorrect and the rotation of 145 degrees was too large, being beyond the limit of wrist rotation. The maximum acceptable angle for rotation is 120 degrees. There was an increase in resistance mid-way through the switching off due to the built-in safety device which allowed off-load contacts to open before on-load. The present design of the control does not achieve rapid and smooth operation. The haulage direction control (5) served two purposes. It controlled the on-off of the haulage and the direction of the haulage. The handgrip was 100 mm (4 inches) wide

and it had a total rotation of 60-75 degrees. The handle was horizontal in the 'off' position and the control had a positive stop to prevent the machine from changing direction of haulage quickly. This stop was negotiated by a push or pull according to the position of the handle. The water sprays were operated by wheel valves mounted on an extended underframe.

3.3 Monitoring the Power Loader

In the case of the trepanner, the haulage speed control (3) enabled the speed of the machine to be varied from zero to 3 metres/min (10 ft/min). The control was in the form of a T - shaped handle, 95 mm ($3\frac{3}{4}$ inch) long, mounted in a recess in the gear case. Twelve complete clock-wise turns were required to increase the speed from zero to the maximum speed. T-handles are not normally recommended for controls which need such a large number of revolutions.

There were two speed controls for the Bi-Di shearer, the variable speed control (6) and the constant speed control (4). The variable speed control (6) had a handle 89 mm ($3\frac{1}{2}$ inch) wide and an 19 mm ($\frac{3}{4}$ inch) hand grip. It rotated on a spindle with $13\frac{1}{2}$ turns from zero to maximum speed. The control was very similar in shape to that of the haulage direction control (5). These two controls (5) and (6) were closely situated. Again, the large number of turns required also makes the variable speed control (6) very awkward to use. The constant speed control (4) had 'on' or 'off' position with no intermediate positions. It took the form of a 44 mm ($1\frac{3}{4}$ inch) handle mounted on a crank of length 89 mm ($3\frac{1}{2}$ inch). The crank turned through 150 degrees. It was necessary to lean over the face conveyor to operate this control. It, therefore, constituted a danger to the operator similar to that of the water spray controls described earlier.

3.4 Steering Procedure

In the case of the trepanner, steering is achieved by the use of the stabilizer control (4) and the steering jack controls (8 and 20). Operators reported that they found the stabilizers more sensitive for the control of steering than the jacks. Table 12 shows the number of machine adjustments during a typical shift and indicates that the stabilizers were used more often than the jacks. However, the stabilizers did have to work in conjunction with the jacks. The operation of the stabilizer raised and lowered the face side to stabilize the machine. The operator's control consisted of a large wing nut, 76 mm (3 inch) width mounted on the left hand gear box. The steering jack controls (8 and 20) raised and lowered the goaf side of the machine. Two of these controls were fitted in the recesses between the electric motor and the gear boxes. They consisted of bar knobs as shown in the illustration (Figure 8) which rotated through 110 degrees with a neutral central position. The space in these recesses was very limited and when under pressure the controls were stiff and there was difficulty in finding neutral. The stereotype between movements for both of these controls and the mechanisms which they control are very poor.

The steering of the Bi-Di shearer was not very effective. The reason for this was that, although the jack was on the face side and had a stroke in the order of 76 mm (3 inch), on this installation, due to fragmentation from the face, it was not possible to push the machine against the face side. Therefore, the actual lift on the jacks was in the order of 50 mm (2 inch). In these thin seams the operators considered that a ranging drum would be greater benefit than the use of such jacks.

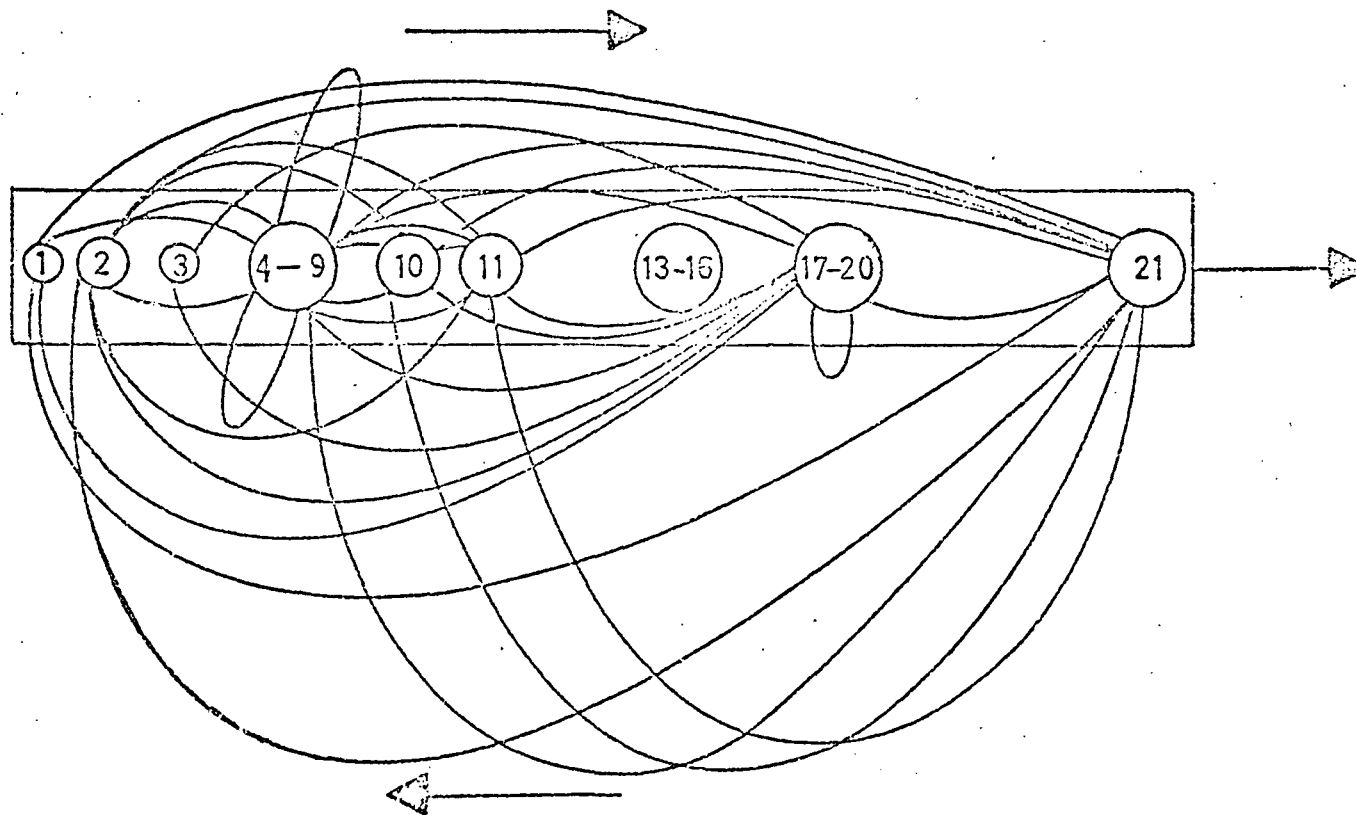
The steering procedures described by the operators are summarized in Appendix 3.

3.5 The arrangement of controls

The conveyor mounted trepanners studied had 19 separate controls as shown in Figure 8. Table 13 shows a list of these controls with the respective distances from the left hand end of the machine, and frequencies of use. (Minor frequencies have been omitted where safety considerations have been taken into account.) Figures 13 and 14 illustrate the typical movement patterns found during the cutting of one web. Figure 13 shows the movements between controls when the machine was cutting main to tail, and Figure 14 shows the movements when the machine was cutting tail to main. The lines represent the movement pattern and not the number of movements. An examination of operator movements showed that as the machine traversed the face (length approximately 180m) some 50 percent more operator movement was required when the machine traversed the face in one direction than in the other. This arose, principally, because the operators discovered that they could steer the machine better with the stabilizer (controlled from only one end of the machine) than by using the jack controls originally placed on both ends. Also there are a number of other controls which are not duplicated and require such movement. The water valve control is one of these which may be used more frequently than others. It is concluded that the use of a remote control device which could be operated from the travelling track at a position in advance of the machine, or duplication of controls at each end would reduce the movement required at present.

The seam conditions of the installation where the Bi-Di shearer was used allowed operators to look over the top of the machine and forward along the conveyor. Therefore, less movement around the machine was necessary. (See figures 15 and 16). The main controls were placed at one end of the machine in a confined space. The control positions and the frequency of their use are shown in Table 14. Operators reported that one problem with this layout was that when falls occurred and happened at the control end it was not possible to reach the controls. The fall had to be cleared and the controls cleaned out before the machine could be operated again. Again, it is recommended that remote control be used or dual controls mounted along the goaf side of the machine would improve arrangements.

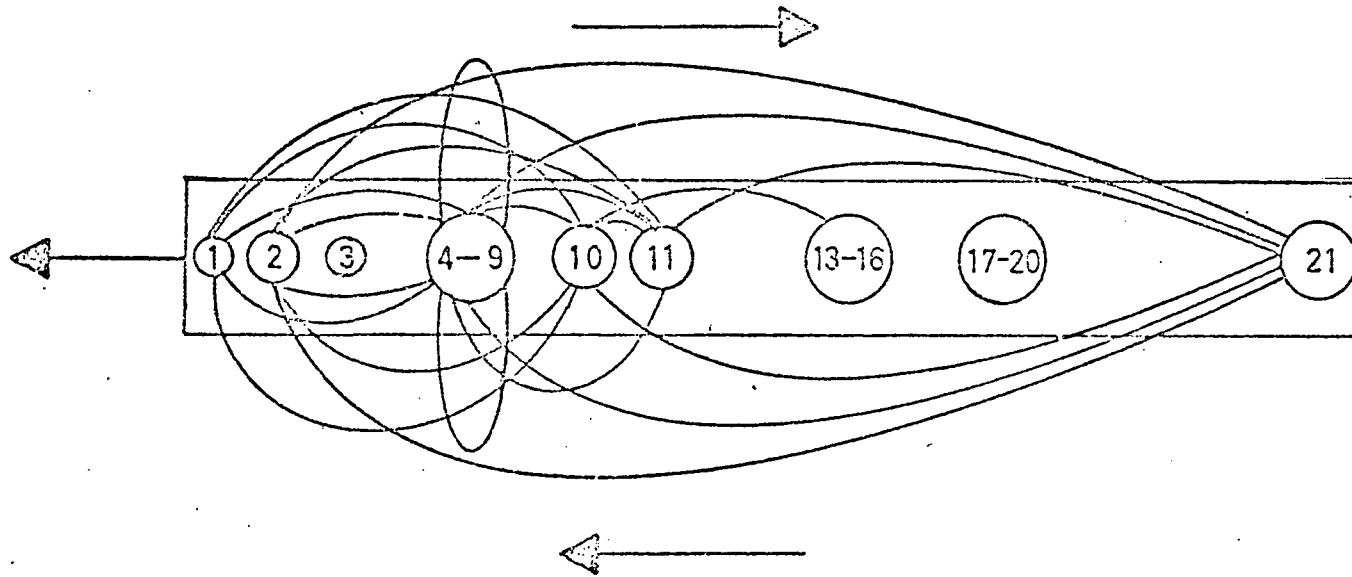
OPERATOR MOVEMENT



TREPANNER CUTTING MAIN TO TAIL

FIGURE 13

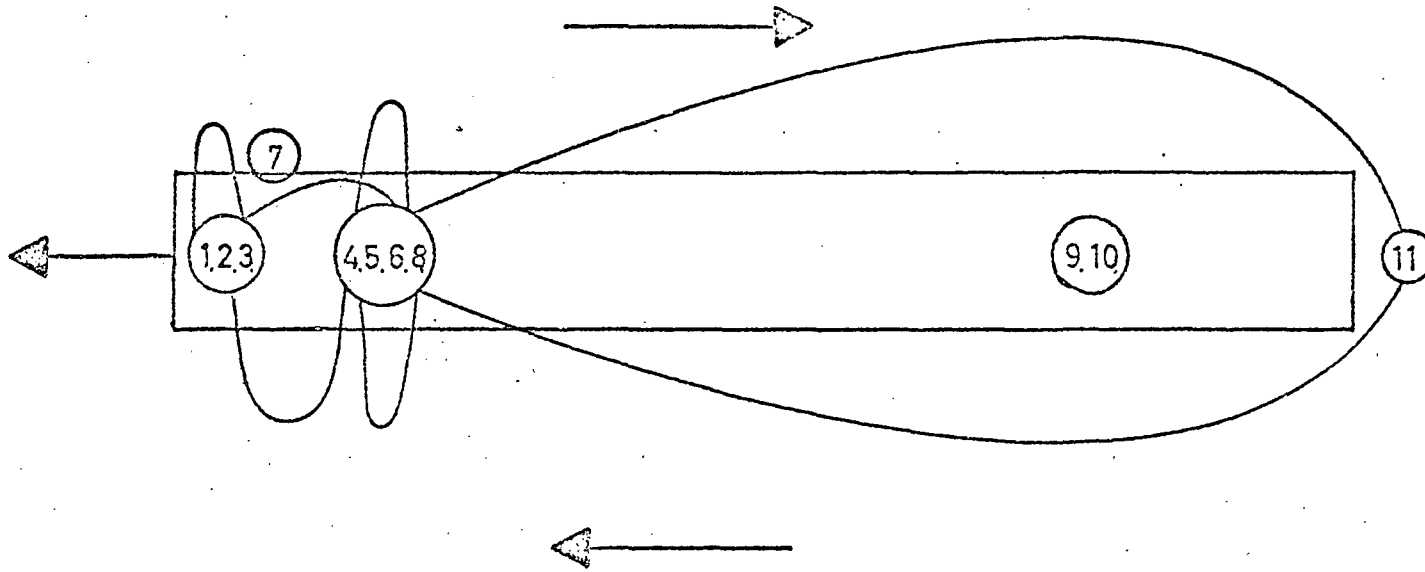
OPERATOR MOVEMENT



TREPANNER CUTTING TAIL TO MAIN

FIGURE 14

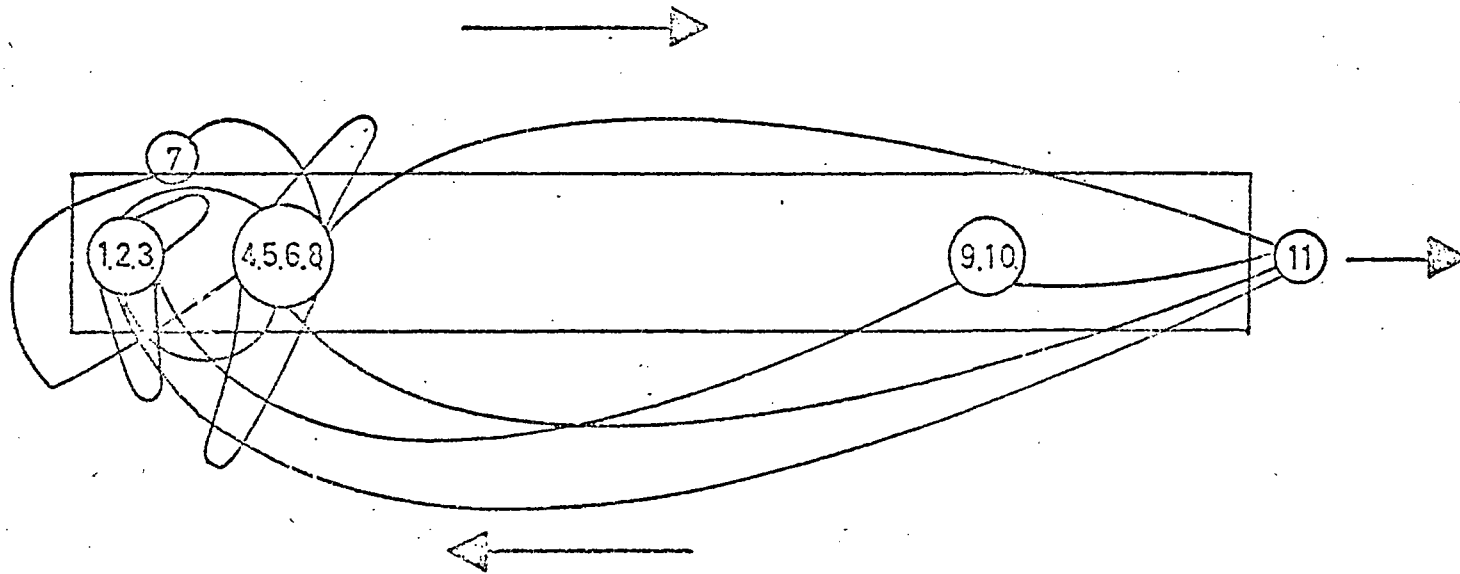
OPERATOR MOVEMENT



Bi-Di SHEARER CUTTING MAIN TO TAIL

FIGURE 15

OPERATOR MOVEMENT



Bi-Di SHEARER CUTTING TAIL TO MAIN

FIGURE 16

The conclusions and recommendations regarding the controls of the conveyor mounted trepanner have been examined by NCB engineers and accepted as being practical and worthy of drawing to the manufacturer's attention on future models.

TABLE 13 LIST OF CONTROL POSITIONS FOR THE CONVEYOR MOUNTED TREPANNER, TOGETHER WITH FREQUENCY OF USE OF THESE CONTROLS

	Distance from LH end of machine m	Frequency %	
		Installation	Installation
		A	B
1. Observation at Main control position (1)	0.0	7.8	2.3
2. Water Valve (2)	0.23	5.6	14.9
3. Speed control (3)	0.52		5.3
4. Stabilizer control (4)	0.82	14.2	23.8
5. Roof cutter ranging control (5)	0.94	1.5	
6. Haulage reverse (6)	0.99	1.9	2.0
7. Trepan gear change (7)	1.07	-	-
8. Steering jacks (8)	1.14	4.9	2.0
9. Haulage on-off (9)	1.17	26.1	29.3
10. Stop (10)	1.52	11.6	9.6
11. Start (11)	1.88	17.2	7.9
12. Water valve (13)	2.34		
13. Isolator handle (14)	2.49		
14. Stop (16)	2.54		
15. Stop (17)	3.15	3.3	
16. Haulage on-off (18)	3.20		
17. Trepan gear disengagement (19)	3.20		
18. Steering jacks (20)	3.20		
19. Observation at auxiliary control position (21)	3.82	4.5	2.0

numbers in parentheses refer to Figure 8

TABLE 14 LIST OF CONTROL POSITIONS FOR THE BI-DI SHEARER, TOGETHER WITH FREQUENCY OF USE OF THESE CONTROLS

	Distance from LH end of Shearer m	% Frequency
		Installation C
1. Observation at Main Control position (1)	0.0	5.9
2. Water Valve (2)	0.0	3.1
3. Steering Jacks (3)	0.0	4.3
4. Constant speed control (4)	0.45	0.9
5. Haulage direction and on-off control (5)	0.64	42.5
6. Haulage variable speed control (6)	0.64	7.8
7. Motor reverse (7)	0.80	3.3
8. Motor on-off control (8)	0.95	30.2
9. Emergency stop (chain) (9)	0.95- 3.82	0.2
10. Gear selector (10)	4.00	0.2
11. Observation at auxiliary control position (11)	4.00	1.6

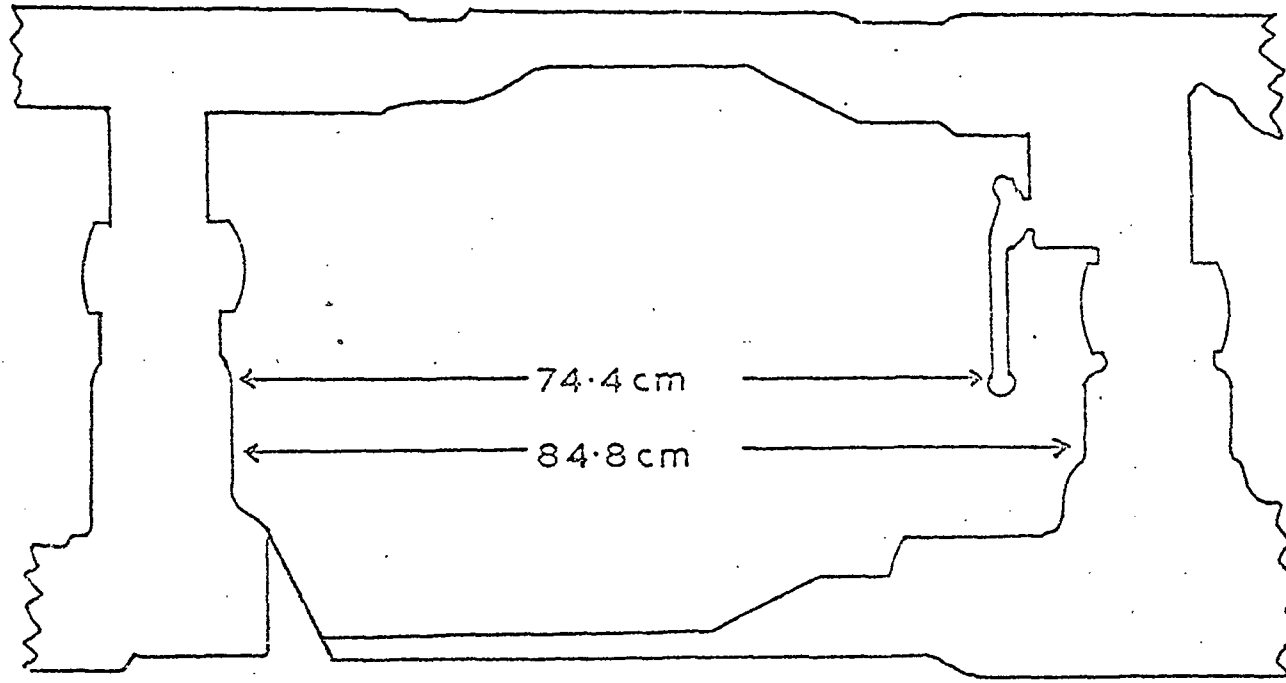
Numbers in parentheses refer to Figure 12

4. THE OPERATOR AND HIS WORKSPACE

Figures 17 and 18 show the workspace in the travel-ways. A short study was made for the purpose of investigating the effects of restricted workspace and clothing on posture of machine operators and to make recommendations, where possible, to apply to the working situation. Measurements were taken to determine the influence of two working heights simulating the range of height of travelling tracks of 76 cm and 56 cm on the body size parameters of operators. The effects of clothing and equipment were taken into account. The lack of space and inadequate lighting for photography made the measurement of the operators' posture an impossible task underground. Therefore, a simulation of the heights and widths typical of a thin seam coal face was employed. For this purpose a rig was constructed to duplicate the coal face dimensions and to provide an unobstructed view of the machine operator. (Dixon 1972)

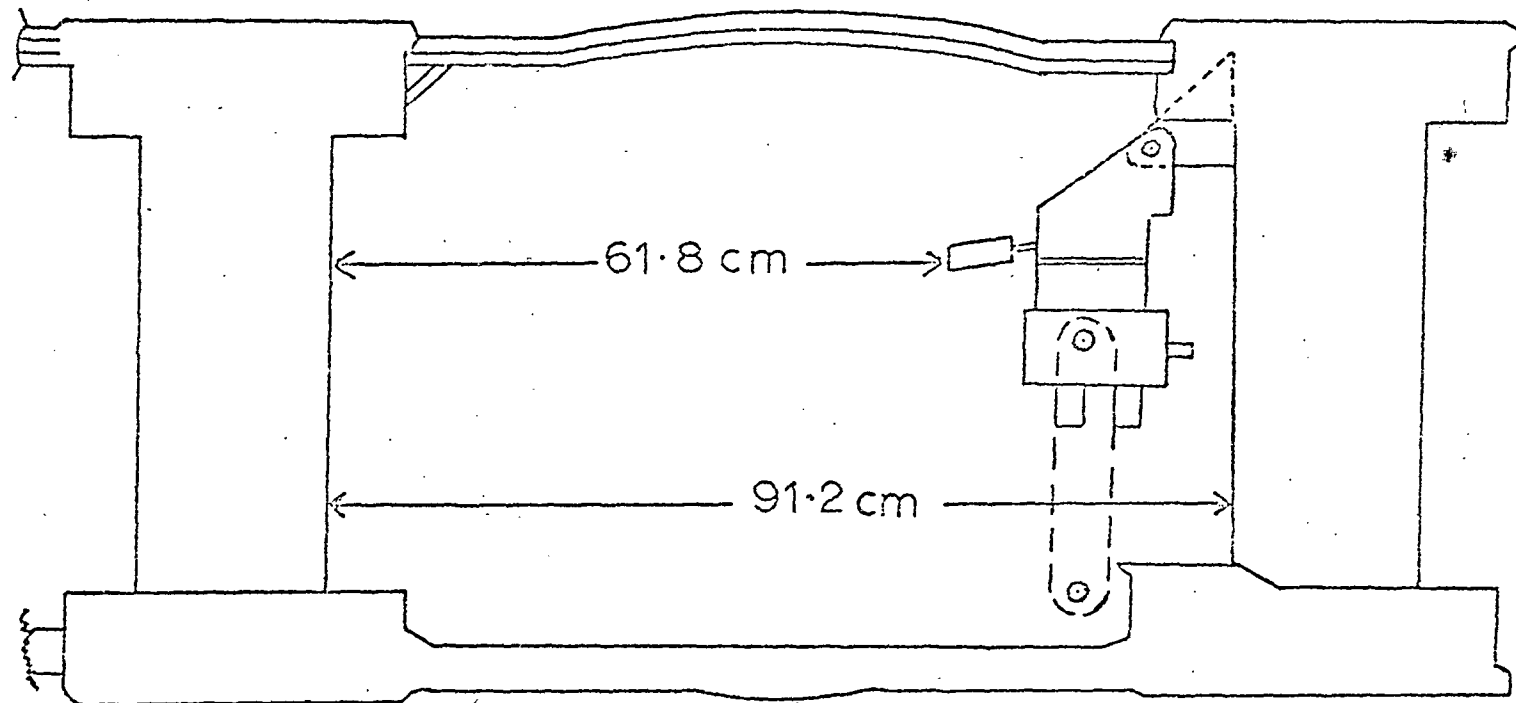
A photogrammetric method was used. Subjects were asked to take up the positions in the rig that they normally used in crawling through the coalface. Vertical and horizontal scales were placed by the rig and photographs were taken. The rig

FIGURE 17



TRAVEL-WAY BETWEEN DOWTY THIN SEAM SUPPORTS

FIGURE 18



TRAVEL-WAY BETWEEN WILD THIN SEAM SUPPORTS

was mounted on a turntable and rotation of the rig provided three views, a left lateral, an anterior and a posterior. From these photographs taken, both at roof height of 76 cm and 56 cm, it was possible to scale measure the body sizes both when clothed for mining conditions and when unclothed.

The original intention was to use actual machine operators for the study. Unfortunately these men were not available at the time and eight mine rescue workers were used instead. All these men were originally face workers and were in regular training for working in the heights used in the study. The data are summarised in Figures 19 and 20. The dimensions are described in Figures 19 and 20 and the data contained in Appendix D.

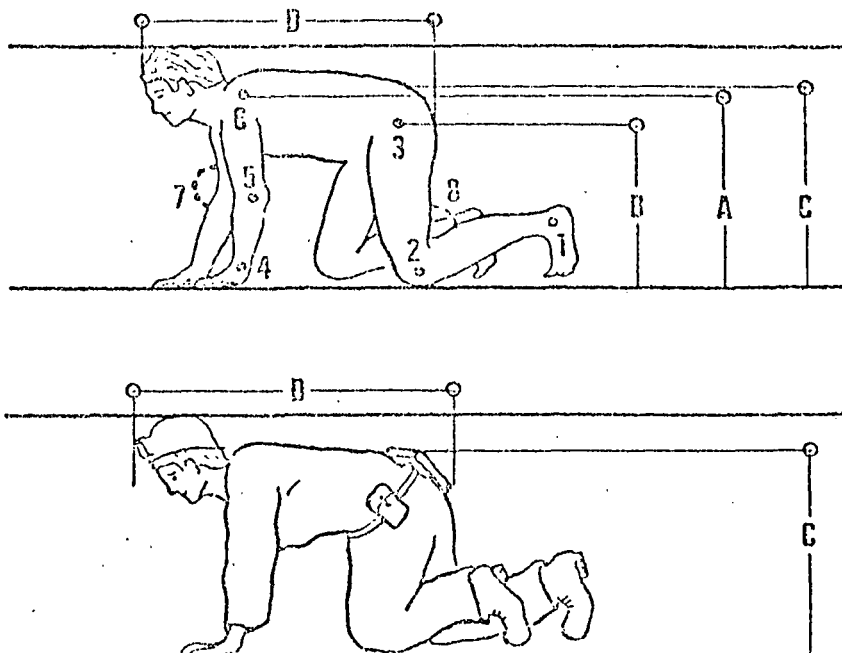
The question arises whether the sample of subjects used in this study is representative of the general mining population and in particular of machine operators. When the means and standard deviations from the study were compared with those found by earlier studies (Ward, 1965) there was no indication of a difference between the two groups. The ideal spatial arrangements of supports should accommodate all men, however, a compromise on 95 percent of the users is normal.

From the analysis of these results it was observed that the maximum width of men under both roof conditions was the elbow width. As a result of this observation, the contribution made by the clothed elbow width must be discussed in connection with the ability of the machine operator to move in the travel way.

With a travel way roof height of 76 cm the 95th percentile for the clothed elbow width was 63.5 cm. The minimum width of the Dowty support was 84.8 cm giving adequate clearance. The attachment of the hydraulic operating lever causes an intrusion into this space, giving an effective clearance of 74.4 cm which is still sufficient at the 76 cm roof height. However, for a roof height of 56 cm, there will be a marginal problem for large crawling operators, suggesting that attempts to increase this clearance would be an advantage and that certainly no future designs should be accepted if this clearance would be reduced as a result of the modification.

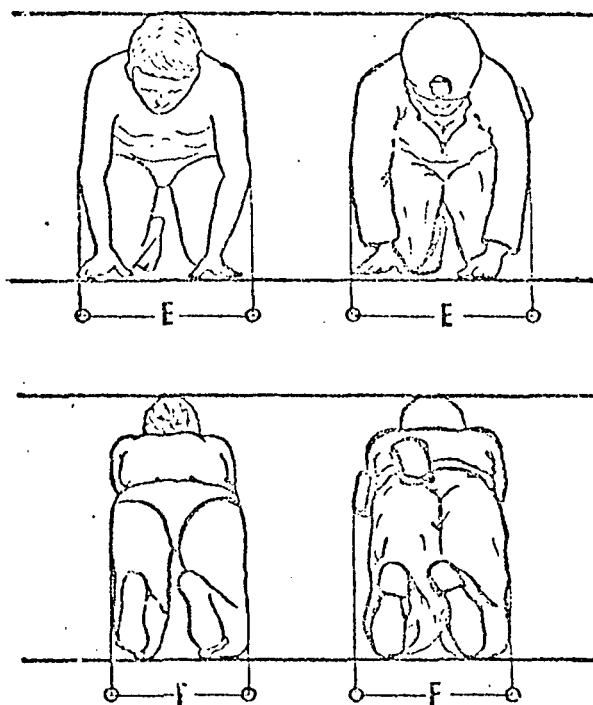
Although the Wild support gives a basic clearance of 91.2 cm, the filter attachments reduce this to 61.8 cm, which creates significant problems for operators traversing the face.

One problem which is a major concern in the movement of the operator is the ability of the operator to turn in such confined conditions present in the travel way. Here the minimum dimension between the face side support leg and the hydraulic operating level of the Dowty support leads to restrictions on turning. To demonstrate the difficulties, clothed stem lengths are used and the 95th percentile values are 105.44 cm and 109.52 cm for roof heights of 76 cm and 56 cm respectively. Comparing these with the Dowty support width of 74.4 cm it can be envisaged that considerable back bending and tucking of the head will be necessary for the operator to turn in the travel way. With a roof height of 76 cm this procedure may be possible, but



MEASUREMENT	DESCRIPTION
1-2.	LATERAL MALLEOLUS - KNEE JOINT SPACE
2-3.	KNEE JOINT SPACE - GREATER TROCHANTER
4-5.	SYLOID PROCESS - OLECRANON PROCESS
5-6.	OLECRANON PROCESS - ACROMION PROCESS
7.	LINK ANGLE BETWEEN UPPER & LOWER ARM
8.	LINK ANGLE BETWEEN UPPER & LOWER LEG
A.	ACROMION HEIGHT
B.	THE GREATER TROCHANTER
C.	BUTTOCK HEIGHT (CLOTHED & UNCLOTHED)
D.	STEM LENGTH (CLOTHED & UNCLOTHED)

FIGURE 19



ELBOW WIDTH (CLOTHED & UNCLOTHED)
 WIDTH ACROSS GREATER TROCHANTER (CLOTHED & UNCLOTHED)

FIGURE 20

at the lower roof height (56 cm) there may be insufficient space to allow for the elevation of the back. Therefore, in this situation turning is only possible in the spaces between adjacent support legs.

The effect of roof height on posture can be seen by examination of Appendix D, table D4 showing the arm and leg link angles. In the case of the 56 cm roof height most operators had to bend their arms in order to crawl. At the 56 cm height, the buttocks under the unclothed conditions utilize almost all of the available height. The addition of clothing and battery causes men to crouch lower. This difference between the clothed and unclothed buttock height is produced mainly by the positioning of the lamp battery over the buttock region. In thinner seams smaller types of lamp battery (such as the zinc air cell construction batteries) could be provided.

The foregoing results have been obtained from photographic studies taken from stationary subjects simulating working in thin seams. No account was taken of the collection of debris, such as pieces of coal and roof which contaminate the travel way, and, undoubtedly, some of the dimensions taken, especially heights, would change with movement of the subject. Both of these considerations make the problem of movement on the face more acute. Therefore, a motion film study of movement along the travel way would provide a useful supplement to the information gained by photogrammetry.

Operators who were working on installations with Dowty five leg supports had a very favourable opinion of this support. Those working with Wild thin seam powered supports complained that the rams, pipes and debris on the floor made travelling through the face very difficult.

It is possible with existing types of supports to take greater consideration for the operators hands and legs. A level and smooth floor to the travelling track is desirable. The present designs of floor members, rams and pipes severely impede movement. Adequate width is needed for crawling. The width required becomes greater with lower travelling track heights.

TABLE 15

<u>For crawling on hands and knees</u>	<u>For prone crawling</u>
<u>Optimum</u>	<u>Minimum</u>
Height 81 cm (32 inches)	Height 43 cm (17 inches)
Width 63.5 cm (25 inches)	Width 101.6 cm (40 inches)

A more radical approach to the workplace design is based on three unsatisfactory aspects of the workplace. Firstly, that wherever miners have to kneel in confined spaces the development of bent knee in some is unavoidable (Williamson, 1972). Secondly, the onerous nature of crawling for operators, and thirdly with faster machine speeds the situation becomes more acute. It is therefore recommended that a system should be designed to transport the operator in a prone position along the travelling track.

5. THE OPERATOR AND HIS ENVIRONMENT

The noise, lighting and climatic conditions in relation to the task of the operator in the three installations studied are the subject of this section.

5.1 Noise

With the aid of the Scientific Control Department, spot noise level readings were taken at the three installations. The readings were taken with the aid of a 'Dawe' intrinsically safe sound level meter with an octave band filter. This sound level meter was of industrial grade, complying with B.S. 3489: 1962 and amendment PD 4825. In the measurements taken the sound level meter was held in the hand with the microphone at the same height as the operator's ear and at the normal positions that operators chose to control the machines. The results of the noise levels at the installations A, B and C are shown below. It is considered that these spot measurements were taken during sample periods which were typical of the operator's working day.

The presence of background noise at the place of measurement can affect the measured results. If, for instance, it is required to measure the noise produced by a particular piece of machinery in a mine, the noise produced by other machinery might more or less 'mask' that which is to be measured. In such cases either the machine being investigated has to be moved to a quieter place or the other machinery producing the background noise has to be shut down. If the noise level measured when the machine being investigated is shut off is more than 10 dB lower than the noise level measured with the machine operating, no correction of the measured result due to background noise is necessary.

TABLE 16

Installation	Sound Level dB (A)		
	A	B	C
Power loader cutting normally	95	98	93
Conveyor running full (power loader switched off)	70	76	74
Conveyor running empty (power loader switched off)	90	88	84

It can be seen that in every case the noise with the conveyor running full differed by more than 19 dB from that when the power loader was cutting normally. Similarly, examination of the difference between the noise levels in individual octave bands shows difference greater than 10dB. Therefore, the chief source of noise for the machine operator was the power loader and it was not necessary to make a correction for the background noise.

The noise is of a mixed type with a large contribution from the lower frequencies. It is believed that the levels recorded give a general indication of the noise situation in thin seams.

In the design of power loaders little consideration has been taken of noise. Therefore, little is known of the intensity of noise produced by the various operating parts of the machine and how these vary with wear in the machine parts. The sources which are likely to contribute to the total noise produced by the power loader include items such as striking of the coal by picks, vibration of the drum, the gear drives, bearings, the electric motor, structure borne vibration and moving chains. Detailed measurements of noise and vibration would be necessary to find the relative contribution of these noise sources and further investigation and design work would be necessary to reduce the noise of the components contributing most to the total noise of the machine. This is likely to be a difficult and lengthy procedure and only worthwhile if it is desired to make major modification to the machine.

The intensity of noise of conveyors, while lower in magnitude than power loaders, was very variable. The conveyors were not of the bottom covered type. While this study was not directly concerned with the noise from gearheads or stage loaders, those measurements taken when the machine was near the Main Gate usually showed higher readings than those taken in the middle of the face. On the face length itself the noise level was considerably higher when the conveyor was running empty than when it was loaded with coal. The noise level was influenced by bends in the conveyor and local changes in gradient. Most noise appeared to be caused by impact and friction between the conveyor chain and the race. Another source of noise on some occasions was impacts between the power loader haulage chain and flight bars. While these sources of noise from the conveyor can affect other workers on the face, the conveyor noise is of less importance to machine operators.

5.1.1 Operator exposure to noise

There are two major factors in considering the exposure to noise in a task:

- (1) the intensity of the noise; and
- (2) the length of time of exposure.

The Department of Employment have suggested that when these two factors are taken into consideration an

equivalent continuous sound level of 90 dB (A) for 8 hours should be the limiting level. (Dept. of Employment, 1972).

In the present case, it has already been shown that the noise level when the machine was operating was above 90 dB (A). There, it is necessary to determine the actual cutting time and the time for other operations having a noise level of above 85 dB (A). (Periods of exposure to noise at less than 85 dB (A) do not affect the equivalent continuous sound level). Detailed time studies were made at the three installations. The average times for exposure to the noise levels above 85 dB (A) were recorded and are shown in Table 17. This table shows the calculated equivalent continuous levels for each shift of the installations. It can be seen that for two shifts the limit of 90 dB (A) equivalent continuous level was exceeded. The noise exposure limit was not exceeded during the afternoon shifts.

As a result of this study it is concluded that the precise noise exposure of operators is difficult to measure. Some reasons for this statement are:-

- (1) The operator moves continuously during the shift, both about the machine and the coal face;
- (2) The noise emitted by power loaders varies. (Values of between 93 and 98 dB (A) were recorded);
- (3) The machine operating time varied between installations and varied on each installation from week to week.

In view of these difficulties it is recommended that noise exposure should be controlled rather than efforts to measure whether particular installations exceed the prescribed 90 dB (A) equivalent continuous sound limit. This control can be achieved from knowledge of the noise level of the particular power loader and using the method suggested by the Department of Employment code of practice to predict the period of time which the operator should be allowed to operate the machine. Then arranging for job rotation so that the machine operators change to quieter situations within this predicted period of time.

In conclusion longer term measures to reduce the noise at source have been discussed. In the shorter term it is recommended that the restriction of exposure by job rotation and the use of light-weight ear protectors be investigated.

5.1.2 Communication

During interviews, machine operators were asked about face communication by telephone, by word of mouth and also if they could hear signals and noises relevant to their work. Interviews revealed that operators could not hear

TABLE 17:

The Equivalent Continuous Sound Level per Shift
for the three installations, Ignoring periods of
exposure at less than 85 dB (A)

Operation	Measured noise level dB (A)	Total Exposure per shift hrs.	Adjustment to measured level for continuous exposure. dB (A)	Adjusted level to nearest dB(A)	Fractional Exposure
<u>Installation A</u>					
(Morning shift)					
Cutting	95	3.2	- 3.6	91	1.3
Ancillary Ops.	90	0.7	- 9.0	81	0
Equivalent continuous level = 91 dB (A)					
(Afternoon shift)					
Cutting	95	2.0	- 6.0	89	0.8
Ancillary Ops.	90	0.5	-12.0	78	0
Equivalent continuous level = 89 dB (A)					
<u>Installation B</u>					
(Morning shift)					
Cutting	98	1.3	- 7.3	91	1.3
Ancillary Ops.	90	0.6	- 9.0	81	0
Equivalent continuous level = 91 dB (A)					
(Afternoon shift)					
Cutting	98	1.0	- 9.0	89	0.8
Ancillary Ops.	90	0.5	-12.0	78	0
Equivalent continuous level = 89 dB (A)					
<u>Installation C</u>					
(Morning shift)					
Cutting	93	3.2	- 3.6	89	0.8
Ancillary Ops.	90	0.8	- 9.0	81	
Equivalent continuous level = 89 dB (A)					
(Afternoon shift)					
Cutting	93	2.6	- 4.3	89	0.8
Ancillary Ops.	90	0.5	-12.0	78	
Equivalent continuous level = 89 dB (A)					

people speaking on the face intercom, and for important messages, stopped the A.F.C. and the machine to hear. In order to communicate between members of the team lamp signals are used and the operator often depends on others in the team to signal to him when the conveyor stops.

The evidence shows that on some occasions machine operators do have communication difficulties. There is a method of predicting the intelligibility of face-to-face speech. This method is to calculate the speech-interference level (S.I.L.) (Morgan et al. 1963). This measure is calculated from the octave band frequency analysis and enables the voice level to be specified that is necessary for a given background noise and distance between talker and listener. These calculations have been carried out for these installations and give the following range of results.

TABLE 18 CALCULATED MAXIMUM DISTANCE BETWEEN TALKER AND LISTENER AT WHICH 75% OF WORDS ARE CORRECTLY RECEIVED

Power Loader cutting	Varies between shouting at 0.5 ft and very loud speech at 1.0 ft
Conveyor running empty	Shouting at 2 ft
Conveyor running full	Continuous communication possible in work area between limits of:- Shouting - 12 ft Normal speech - 2 ft

5.2 Lighting and Visual Tasks

Following an introduction to some problems of lighting on coal faces, the method of measuring illumination in this study is described and the results presented. There is then a short discussion of the results, making conclusions and recommendations.

The problems associated with lighting in mines have been described by Roberts (1955), Halldane (1970) and Bell (1972). The standards which have been adopted in the lighting of mines are different to those used in other fields. The basis upon which mine lighting has been designed is as follows:-

While it is accepted unquestioningly that mine lighting should permit work to proceed safely and efficiently it is not possible to define this in quantitative terms other than the minimum luminance level of about 0.20 candelas per square meter (Cd/m^2) at the centre of the visual field. This is determined by the necessity to permit detail vision. When illumination is lower than this value, the result is a restless search over a much wider area of the retina. This is thought to cause some forms of nystagmus. The use of the electric cap lamp has virtually eliminated nystagmus amongst coal face workers. Nevertheless, mine illumination levels are low (Walton, 1974). Lighting must also enable men to see their visual task accurately, quickly and without unnecessary effort. Good lighting contributes to the pleasant and comfortable appearance of an environment.

For many years it has been common place for mains lighting to be installed at many important locations and with the introduction of fluorescent lamps it has been possible to improve further the standard of illumination. However, the most important place in the mine, the coal face is still only illuminated in a small number of cases by mains-fed lighting units. This is due largely to problems of safety and maintenance. In the case of thin seams, because of the limited space and the nature of the postures which must be adopted by operators, the situation becomes even more difficult. The special difficulties include:-

- (a) Generally, the sources of light which produce illumination are not intended to be looked on directly and it is even preferable that they be placed as peripherally as possible in the visual field to avoid glare. It is only light reflected or scattered by the surfaces of objects in the visual field which assists in a visual task. One of the most suitable peripheral positions in relation to the human eye is above the head. It is obviously not possible to use this position in thin seams.
- (b) The size of the lighting fitting is an important factor. In thin seam faces there is not room to put a flame-proof fitting on the roof supports in a position where it will provide the correct distribution of illumination and at the same time allow free passage between roof supports. Manufacturers are now experimenting with small intrinsically safe luminaires which are more economical in space requirements.
- (c) The maintenance of forward vision whilst travelling along the face presents a problem. For with low roof heights a posture has to be adopted whereby the normal line of vision is directed towards the ground. In this situation the maintenance of forward vision can be achieved by either upward rotation of the eyes, excessive bending of the neck, tilting of the head to one side or some combination of these postures.

With these difficulties it is understandable that minimum values of illumination or maximum values of glare for machine operation on the coal face are not stated in legislative or advisory national documents (e.g. Mines & Quarries Act, 1954 or Institute of Illuminating Engineering Society Code, 1973). When handfilling was widely practiced the Reid report laid down a recommended minimum of 4 lux at the coal face. At a distance of 1.32 metres (4 feet) a cap lamp with a non-specular reflector will generally provide a light distribution of higher than this recommended minimum over a circle of 1.83 metres (6 feet) in diameter. This illumination was sufficient for the miner working on a hand-filled face where there was background illumination provided by the cap-lamps of other miners, or by general illumination from mains face lighting. It has been suggested (Bell & Neill, 1968) that where machine mining is carried out, longer range vision is more important and that a machine operator may need to fixate at a distance of many feet in perhaps a dusty atmosphere. These authors, suggested that this can only be achieved using a cap-lamp with a specular reflector if no other means of lighting is available and that, due to the effective light distribution being severely reduced, safety may be jeopardised by the lack of adequate peripheral vision. They, therefore, considered that it was necessary for general background illumination to be provided to produce adequate lighting. It was further recommended that the minimum level of illumination on the whole coal face to allow safe and efficient operation be 10 lux. This is provided by a general system of mains lighting, and to perform specific tasks a higher level of illumination is required and a level of 40 lux is recommended as a minimum. These recommended values are low compared to those recommended for surface work, factories, offices and homes in the Institute of Illuminating Engineers Code of Practice 1973. For example:

TABLE 19

Situation	Lux
In General Building Areas - Corridors	100
Coal Preparation Plants - Working areas	300
Machine and Fitting Shops - Rough bench work	300
Homes - Living room	50
Homes - Kitchen	300

5.2.1 Method

All three installations relied on the operators' use of cap lamps for illumination with no mains lighting. The cap lamps were of a lead-acid type with a power of about 4 watts. The reflector surfaces in the lamps issued to the machine operators were of the 'specular' type, which gives little surround illumination but concentrates the majority of the light in a high

intensity beam. Details of the lamp's construction and the distribution of illumination may be found in Bell & Neill (1968). In this study, measurements of the illumination of the work-places were taken using a Megatron Light Meter Type D15. The measurements were taken at a time approximately half-way through the day shift. The operator was asked to look at various points in the normal manner when controlling the machine so that the cap lamp was located in the correct position. Then the level of illumination of those points was measured. The machine was not operating at the time of measurement so the effect of dust produced in lowering the illumination was not taken into account.

Each measurement was taken on three occasions and an average taken to give a more representative value.

5.2.2 Results

The illumination measurements' results are shown in Table 16. At each installation the illumination shown was the average of the three readings. The individual reading did not vary by more than 10% from the average value shown in the table. The luminance was calculated using the formula:

$$L = RE \pi$$

where L = luminance (Cd/m^2)

R = reflectivity (value of 0.05 for coal surface.

Value of 0.25 for conveyor).

E = normal illumination (lux).

TABLE 20 RESULTS OF ILLUMINATION MEASUREMENTS

Installation	A		B		C	
	Illumination (Lux)	Luminance (Cd/m ²)	Illumination (Lux)	Luminance (Cd/m ²)	Illumination (Lux)	Luminance (Cd/m ²)
<u>Position of Measurement</u>						
The roof at the trepanner head or shearer drum.	135	6.75	100	5	150	7.5
The conveyor 5 metres forward of the power loader.	10	2.5	15	3.75	15	3.75
The conveyor 20 metres forward of the power loader.	1.2	0.3	1.3	0.33	1.6	0.4
0.5 metres to the side of the operator 90 degrees to line of sight	0.20	-	0.20	-	0.20	-

Operators reported that improved lighting would enable them to see longer distances and reduce the amount of crawling. Special mention was made of the gate ends when some operators crawl the last 20 yards ahead of the machine to make sure the pans are level. One operator was concerned that if powerful spotlights were used they could dazzle other men working on the face.

5.2.3 Discussion

The values of illumination found confirm the views of research workers in this field which were discussed earlier in this section. The operators replies to questions show their concern for lighting and indicate difficulty in seeing long distances, but as none had, in fact, worked on faces with improved lighting their view that improved lighting would improve the job must not be taken as conclusive. In order to find the answer to this question, it would be necessary to enquire from operators working on faces with improved lighting.

There are four aspects of illumination which have relevance to the lighting and visual tasks of machine operators. These are short range tasks, long range tasks, background illumination and glare.

5.2.3.1 Short Range Tasks

We take for this purpose the definition of short range tasks as a visual task which must be within about 2 metres of the operator's eyes. This will include more than the area within reach of the operator. If he is lying down or crawling it will include his feet and extend a little further according to his posture and size. In relation to the machine, the short range visual length is less than half of the length of the machine. Vision of the coal face and the drum or trepanner head are within this range when the operator is positioned opposite them in the travelling track. The first row of results in Table 20 confirms that the luminance was sufficient for detail vision and the higher illumination level recommended for specific tasks on the coal face by Bell & Neill of 40 Lux is also exceeded.

However, there are other factors which these values do not take into account. In section 2.3.2.3 it was mentioned that steering the machine was a visual task and that a number of cues were used to decide when to change and by how much to change the steering controls. These cues included a visual examination of the coal and dirt in the trepanner head, the position of bands of dirt or stone. In these tasks brightness discrimination is used as the recommended value of 40 lux does not allow colour discrimination. Improved illumination for this task could result in both cleaner coal and improved face conditions. The exact amount of illumination necessary and the manner in which it is provided would need further investigation.

5.2.3.2 Long Range Tasks

Again, the definition of long range is fairly arbitrary. The supposition is made that these tasks are further than 2 metres from the operator and can be in any position of the visual field within 50° of the fovea. Long range tasks include looking forward to the level of the A.F.C. and other tasks as mentioned by the operators in the results section. Long range vision is required not only for the performance of steering but also for the safety of personnel. In table 16 the readings taken at 5 and 20 metres forward of the machine on the conveyor are examples of this type of task. The luminance level is sufficient for detail vision at 5 metres but not sufficient at 20 metres, also the level recommended to perform specific tasks was not attained at either position. It is, therefore, recommended that measures should be taken to examine the requirements of these long range tasks in terms of:-

- (1) Further research to determine illumination requirements to steer the machine, and to see equipment and personnel during the task of machine operating;
- (2) An examination of the conspicuity of machinery, equipment and personnel to provide improved visibility.

5.2.3.3 Background Illumination

The measurements of illumination at right angles to the line of sight shown in Table 20 illustrate the point made by Bell and discussed earlier that the cap lamp with a specular reflector (where no other means of lighting is available) does not provide an adequate distribution of light for peripheral vision. It is recommended that mains face lighting be adopted which is suitable for providing satisfactory illumination which is not only safe but can be maintained and is designed in conjunction with the roof support system.

5.2.3.4 Glare

For all uniform light distributions it is correct to state that any increase in light above a certain level improves visibility. If the visual field is composed of a non-uniform luminance distribution the statement is not correct. In fact, it is possible to decrease visibility by the increase of illumination and this increase of illumination can be termed 'glare'. This subject has been studied in detail both for cap lamps (Neill, 1959) and for mains lighting (Saunders, 1969). Again, as with other problems on coal faces, glare is a factor which becomes more acute in thin seams. It is recommended that careful application of the known principles of illumination engineering to a system of general lighting to be used in conjunction with portable lighting by cap lamps will be necessary to minimise the detrimental effects of glare.

5.3 Climate

The environmental conditions which govern the thermal exchanges of the body are the air temperature, air velocity, radiant temperature and water vapour pressure (Crockford, 1973). It was necessary to check the climatic conditions for operators at these three installations. Conditions on coal faces, where high temperatures are encountered, have been examined in detail by Lind (1964) and others. However, it was not anticipated that there would be problems of high temperatures at these installations because the coal seams were not at great depth and the ventilation was provided by efficient systems.

Conditions at the other extreme; the cold environment have been described in detail by Burton & Edholme (1955) and Morgan et al (1963). It has been reported that the air temperatures at production coal faces rise during the week and fall over the weekend when no coal is being extracted. It was, therefore, necessary to take this factor into account.

The measurements were taken by the Ventilation Department of the South Midlands Area.

5.3.1 Method

At each installation three measuring points were selected. These points were 10 metres from the main gate, at mid-face, and 10 metres from the tail gate. During a normal production week, measurements were taken at these points during Monday morning shift, Wednesday morning shift and Friday afternoon shift. All measurements were taken in the machine operator's position with the one exception of the barometric pressure, which was measured on the surface and used to calculate the value at the level of the installation. At each measuring point the air velocity, the dry bulb, wet bulb and globe temperature were recorded.

5.3.2 Results

The detailed results are shown in Appendix E together with the results of analyses of variances performed on the dry bulb and wet bulb temperatures. These analyses show that in the cases of these installations the dry bulb temperatures did not vary from day to day but the wet bulb temperatures did vary with the day of measurement. The temperature rose gradually through the week although the rise was small. The analyses also show that the temperature conditions were uniform at the three measuring points and Table 21 shows a summary of the results, together with the calculated relative humidity.

TABLE 21 SUMMARY OF RESULTS OF VENTILATION MEASUREMENTS

Installation		Temperature Reading °C			Air Velocity M/S	Relative Humidity %
		Dry Bulb	Wet Bulb	Globe		
A	Monday	21.3	20.2	21.3	0.76	90
	Wednesday	21.5	20.2	21.5	0.76	86
	Friday	21.5	20.4	21.5	0.81	91
B	Monday	18.3	17.9	18.3	1.37	95
	Wednesday	18.9	18.3	18.9	1.17	95
	Friday	19.4	19.0	19.4	1.41	95
C	Monday	21.2	19.5	21.2	0.58	86
	Wednesday	21.3	19.7	21.3	0.64	86
	Friday	21.0	19.8	21.0	0.63	90

Operators recognized that in their environment it was necessary to wear extra clothing when they were inactive. Pullovers were usually carried for these occasions.

5.3.3 Discussion

The globe thermometer readings recorded were not different from the dry bulb readings. Therefore, the operator was not exposed to radiant heat of a measurable quantity. The dry bulb temperatures range from 18.3 to 21.7 degrees centigrade. These are within the comfort zone of 16-24°C suggested by Crockford (1973). Within the comfort zone it is possible to work over a range of metabolic rates without undue thermal strain occurring. The temperature depends on the clothing worn and the metabolic rate, but for temperatures within this comfort zone subjects do not need excessive or special protective clothing for climatic reasons.

The exact clothing requirements in terms of the insulation required can be calculated by the method suggested by Burton and Edholme (1955). These calculations have been made. As already stated, the insulation required in an environment depends on the activity. Broadly speaking, the activities of the operators oscillated between controlling the machine at a moderately hard work level during machine cutting (200 cal/m²/hr.) to sitting quietly when there are delays (50 cal/m²/hr). The insulation required for comfort, therefore, varies between 2.2 Clo and 0.6 Clo. To give a guide to these values approximately 1 Clo of insulation is given by wearing light overalls and cotton underwear and 2 Clo by the wearing of woollen underclothes, overalls and jacket. The operators confirmed that extra clothing was required when extensive delays occurred.

6. THE OPERATOR AND FACE PERFORMANCE

It is the operator who starts the machine, changes the speed and stops the machine. The man controlling the machine, therefore, ultimately determines the performance of the machine in the working conditions. However, the total production, the rate of production and the delays may, in fact, be determined by geological, mechanical, electrical, system or operator limitations. Measurements of machine performance were made at each installation for a four week period. In section 2.3 the work of the machine operator was classified into 6 main types. The average time occupied in these categories of work was shown in Figure 1. This section examines this work further and is concerned with the distances cut, the delays and machine speeds, in relation to individual operators.

The primary object was to discover if there was a decrement in performance during the shift due to the continual effort required to crawl when controlling the machine. Other objectives were to discover if there were consistent differences in the performances of operators and to summarize the operators' opinions of their tasks. Two aspects of the latter were of particular interest. The first was their views of what could be done to improve their job, and the second was their opinion of what factors limited machine performance.

6.1 Method

The examination of the effect of fatigue on face performance was tackled in two ways. The first approach was to divide each shift into two time periods and compare the performance in each half. The second was to obtain measures of the work done after certain fixed increments of work had been completed.

It has been suggested that production could be increased if the machine operator was changed halfway through the shift. The first method of analysis was designed specifically to answer this problem. Each shift was split into two parts - the first continued from the start of the shift for three hours - the second from then to the end of the shift. This division of the shift was thought to be close to that which might be adopted in practice. From the fifteen minute period observations, total values of distance cut, cutting time, delay time and length of time period were obtained for each time period. These were used to calculate the following variables:-

- (a) % of time spent cutting;
- (b) % of time delayed;
- (c) cutting speed.

The object of the analysis was to compare these values for the two time periods to see if any decrement in performance occurred over the shift. The analysis was undertaken separately for the three installations. In addition the effects of the different operators, shifts and days were investigated.

The second approach was based on work completed rather than time elapsed since it was felt that production should depend more on energy expended rather than time. Improvements in organisation and the design of machines should cause the operators to work harder and so the relationship between work and performance was of direct relevance. Accordingly, only those shift were investigated where a substantial amount of work had been completed. This was defined as 1,500 feet of coal cut, or greater, and this was achieved on 24 shifts. Values of variables (a), (b) and (c) were investigated for each of the intervals during which 500 feet of coal was cut. There were four intervals covering 0 - 500, 500 - 1,000, 1,000 - 1,500 and 1,500 + feet at every shift.

6.2 Results

The details of the results and a discussion of their implications is given in Appendix F. The outcome from both methods of analysis showed no evidence of a decrement in performance over the shift. Results from the first approach to the problem at the third installation showed that production was higher during the second time period compared to the first (% cutting time 46.7 compared to 38.5, $p < 1\%$). The results from this pit also showed a

substantial difference in cutting speed between the two operators (10.1 compared to 9.2 ft/min., $p < 1\%$). The second method of analysis revealed an upturn in production during the last interval of the shift ($p < 1\%$ for % cut time, $p < 0.1\%$ for % delay time). There were otherwise no differences of note.

The following is a summary of operator comments:-

- A. An improvement would result if it were possible for the operator to control the machine from either end rather than relying on the "dead man's handle" when towards the front of the machine. (Bi-Di Shearer)
- B. The interchanging of jobs on the face, (midshift, alternate shifts or on a rota basis) would provide a variety for machine operators, would develop a knowledge of the conditions on the face and would also alleviate boredom. One operator however disagreed suggesting the variety of methods favoured by different drivers would cause friction within the team and between shifts if changes were continually being made.
- C. Notification in advance of future deployment (rather than waiting until the day the current face finishes) would be appreciated.

The various limits to performance on the faces were considered to include:

- A The advance in the preheads being below the face advance and poor conditions at the face ends.
- B. Faults on the face causing excessive cleaning up such as timbering over supports and obtaining and setting holding down props on the A.F.C. delay the power supports men.
- C. The unsuitable design of powered supports - debris in the travelling track being carried forward by hoses and bulky legs.

All the operators regarded conveyor stoppages to be the main cause of delay.

6.3 Discussion

The results show no decrement in performance during the shift due to the continual effort required to crawl when controlling the machine. This result is surprising when the general nature of the work is examined. However, it does not mean that the task of machine operating cannot be improved. For improved machine design or working environment can give a more convenient working place, resulting in a cleaner output and increased performance.

No decrement in performance during the shift was found, the reasons for this are unclear but possibilities include:-

- (1) The work is not sufficiently severe;
- (2) The operator paces himself;
- (3) The machine is not capable of travelling at speeds which stress the operator.

It is thought that in the case of installations A and B where Trepanners were in use it was the third of these possibilities, but in the case of installation C, it appears that there was a combination of all three.

Another aim of the study was the concern that the machine operator's performance should not impede the performance of the system. The operator's comments show that on installations A and B there was certainly no possibility of the machine or operator limiting the output of the faces. This was not the case with installation C. The production study showed that the output of the faces did not vary with individual operators. Examination of delays also indicated that these did not vary with individual operators. For installations A and B the speed of cutting did not vary between operators, but for installation C the speed of cutting by the two operators differed consistently by 10%. There is an apparent anomaly in this result for installation C. The operators show no significant differences between total output and delays, yet the speeds of cutting were different. It is thought that this was due to the fact that the machine delays played a much more important part in determining the output than the machine speed.

These results indicate that the factor of overwhelming importance is the length of delay times. A description of these delays and what measures may be taken has been given in section 2.3. Once these are reduced the indication is that the next bottle-neck will be the speed of the machine and more attention will be needed in the design of the machine (section 3) and the support system (section 4).

In the case of installation C, it is believed that the difference in the speed of cutting was due to differences in skill of the operators. These differences in skill may be reduced by the development of training methods to increase the performance of the slower operators.

The views of operators concerning job rotation are mixed. There does appear to be an argument in favour of job rotation:-

- (1) When there is absence. It takes some time for the new operator to become familiar with the controls. It is likely that during this time accidents and major disruptions are more likely.
- (2) The advantages of the men understanding how each man's task contributes to the team would be seen in greater flexibility.

- (3) The increased variety in the work would reduce problems of posture and the amount of routine inherent in these jobs.
- (4) The reduction of noise exposure to safe levels (section 5.1) resulting from shorter work exposures.

There are reasons why such rotation may not be welcomed by some operators. The view has been expressed that different operators use different methods and difficulties would arise. This, again, is a matter of training, and could be overcome if a proper analysis and training programme were implemented. In view of the advantages, it is felt that if face teams wish to apply job rotation it should be encouraged.

7. CONCLUSIONS

The work of machine operators in three thin seam installations has been analysed. It is considered that the equipment and conditions are typical in many respects of other thin seam power loader faces. Therefore, the following conclusions are of general relevance to thin seam power loader mining.

7.1 The Machine Operator and his task

Training and Skills

- 7.1.1 The training of operators to control the power loader, as reported, consisted of accompanying an experienced operator for a period of 0 - 10 shifts.
- 7.1.2 During the training period the man is expected to learn the new task by watching and imitating an experienced worker.
- 7.1.3 In the thin seam conditions it is difficult to provide an opportunity for the new worker to see and handle the controls.
- 7.1.4 Experienced operators have reported the difficulties they have in teaching new men on production faces. This is because the experienced operator is responsible for safety and production. He finds it impractical to give the new worker an opportunity to handle the controls due to the impossibility of correcting mistakes.
- 7.1.5 The training does not give an opportunity for the trainee to attain the standard of output or quality control of an experienced worker.

Physical Work Load

- 7.1.6 Travelling to and from the face occupies 12 - 20% of the machine operators' underground shift. The physical work load when walking to the coal face can exceed the work load of operating the machine (compare tables 7 and 12). The physical work load of travelling is much reduced where man-riding is provided (Table 7).

- 7.1.7 The task of operating the machines comes into the classification of light to moderate work (175 - 350 watts).

Driving Task

- 7.1.8 Controlling the power loader machine occupies 16 - 42% of the machine operators' underground time. This comprises of monitoring the conveyor, monitoring the power loader, steering procedure, stall procedure and monitoring roof supports. As seams become thinner it is more difficult to see or hear when the conveyor stops; also it becomes awkward to reach the controls of the machine. All operators showed great concern with the danger of workmen being struck by picks when the machine was started. With one exception, operators considered the use of the whistle as a warning was not entirely satisfactory. The most efficient and safest position for steering the machine is generally towards the front of the machine for each direction of travel. Following the stalling of a machine the procedure to get the machine started is a trial and error method.

Operating Systems

- 7.1.9 Machine ancillary work of operators comprises 7 - 10% of the shift time. The face techniques varied and hence the time for pushover varied. The work of altering ploughs and deflector plates during the machine turn-round involved clambering over the conveyor side plates and conveyor structure to get to the face side and to return afterwards. The lack of space and obstructions to movement can make this arduous and this routine required the driver to move to a place of potential danger.

- 7.1.10 The lost time on the face, caused by delays not connected with the machine cycle of operations, was 11 - 28% of the shift time. These delays were classified by cause. Organizational, geological and mechanical factors were those of the greatest magnitude.

- 7.1.11 The lost time due to outbye causes was 4 - 5% of the shift time.

7.2 The Power Loader Machine

- 7.2.1 Where the seam thickness and roof supports restricted the operators view so that he could not see over the machine casing, considerably more movements with greater associated difficulty were required by the operators than in thicker seam conditions.

- 7.2.2 The start sequences in which the operator reached over the machine to operate water valves when the machine was moving were dangerous. This was because at that time material or roof stone could travel under the machine and lift it to the roof causing injury.

7.2.3 The individual controls were designed without the benefit of ergonomic information for their design. There were, therefore, a number of aspects for which the controls did not match up with modern machine requirements. These requirements which were not met included the stereotype between the movement of the mechanism and control. These were often not clear. The force required to operate the control was too high the rotation required by the arm was of too great an angle and there was often insufficient space to grasp the control.

7.3 The operator and his workspace

7.3.1 In the confined space of the travelling track, the operator was forced to crawl on his hands and knees in order to control the machine. Knee protection was used by all operators. Nevertheless, the development of bent knee in some operators will be unavoidable with this method of working (Williamson, 1972).

7.3.2 The recommended height for the design of passage-ways for crawling on hands and knees is 81 cm (32 inches). The available height of the installations studied was less than this recommendation. For prone crawling it has been recommended that a height of 43 cm (17 inches) is desirable. This height was generally exceeded, except at installation B where design of rams and pipes caused the collection of debris on the floor.

7.3.3 Photographs were taken of 8 men in static positions of crawling postures at heights of 76 cm (30 inches) and 56 cm (21 inches) and body dimensions measured. These were recorded and compared to existing anthropometric data.

7.3.4 The maximum width of men, when crawling, was the elbow width. At the lower height more space was required for elbow movement.

7.3.5 At the lower height turning in the travelling track could not be achieved without moving into the spaces between adjacent supports.

7.3.6 The angular construction and size of cross members and hoses at floor level in the travelling track aggravated the difficulty of crawling.

7.4 The operator and his environment

7.4.1 Noise

7.4.1.1 The chief source of noise that the machine operator was exposed to was that of the power loader. The noise levels of the machines were in the order of 93 - 98 d B (A) when cutting and loading. The background noise was negligible from a consideration of noise induced hearing loss.

7.4.1.2 Using the average machine operating times for the month of study and the measured noise levels, the equivalent continuous sound levels were calculated. These calculations were made on a shift basis for each installation.

The levels were 91, 91 and 89 dB (A) for the day shifts. The afternoon shift calculations gave 89 dB (A) for all three installations.

7.4.1.3 Analysis of operators' comments and calculated speech interference levels showed that on occasions operators had difficulty in communicating.

7.4.2 Lighting

7.4.2.1 All three installations studied relied on the operators' use of 'specular' type cap lamps for illumination with no mains lighting.

The illumination was measured and it was concluded that three aspects of the lighting design were important, the short range tasks, (less than 2 metres from operator's eyes) the long range tasks and the background illumination.

7.4.2.2 The luminance was sufficient for detail vision and above the recommended levels for short range tasks. It was insufficient to allow colour discrimination.

7.4.2.3 In the case of long range tasks, the luminance was sufficient for detail vision at 5 metres but not at 20 metres distance. The level recommended to perform specific tasks was not attained in either position.

7.4.2.4 The background illumination does not provide a distribution of light adequate for peripheral vision.

7.4.3 Climate

The environmental temperatures were measured and found to range from 18 - 22°C. As the comfort zone for this type of work is 16 - 24°C conditions were satisfactory for the three installations.

7.5 The operator and face performance

No decrement in performance occurred during the shift due to the continued effort required to crawl when controlling the machine. The output of the faces did not vary with individual machine operators. In the case of delays, it was also found that these did not vary with individual operators. For installations A and B the speed of cutting did not vary individual operators, but for installation C the speed of cutting by the two operators differed consistently by 10%.

8. RECOMMENDATIONS

8.1 The machine operator and his task

8.1.1 To overcome the difficulties of training operators in thin seams the following proposals are made:-

8.1.1.1 The training should include formal practical instruction for the specific machine to comprise:

- (a) Start up and shut down procedures;
- (b) Operation and function of the controls;
- (c) Working knowledge of electrical and hydraulic supply system of the machine;
- (d) Identification of faulty running;
- (e) Working limitations of the machine;
- (f) Stability of the machine under adverse travelling and gradient conditions;
- (g) Correct loading procedures;
- (h) Hazards due to operating the machine in confined conditions;
- (i) Emergency procedures;
- (j) The basic maintenance and lubrication required by the servicing schedule.

8.1.1.2 To overcome the difficulty of learners in seeing what is happening and making the correct control actions in thin seams there are two possibilities:-

- (a) The design of computer aided graphic displays. These would be built in conjunction with the controls of machines. During training the operator would be able to see the result of a control action upon a display screen.
- (b) That operators should accompany experienced men initially in seams of above 4 feet thickness. In this way they would be more able to see the movements of the experienced man and the reactions of the machine.

8.1.1.3 Training methods must include the opportunity for operators to handle the controls and to develop those skills which only come with practice.

8.1.1.4 For existing machine drivers it is recommended that additional advice be provided to help them in making machine control decisions. These men are very familiar with the machines they operate. Nevertheless, it is considered that attendance at a 'machine operators' discussion group' would be conducive to safer and

and improved practices. The following suggestions are made for the organisation of these discussions:-

- (a) The period allocated for the discussion be 2 hours. It being devoted to one type of machine.
- (b) The membership of the group be 4 - 5 machine operators and a deputy, together with a safety engineer or mechanization engineer and a mechanical engineer.
- (c) That the engineers should each make a short presentation of 10 minutes with well prepared visual aids. These to be followed by periods of open discussion of approximately 20 minutes.
- (d) It may be advantageous to arrange the meeting at an area training centre or area workshop, where the machine under discussion is available.
- (e) A person be appointed to organize and make arrangements for the 'machine operators' discussion groups'.
- (f) Individual chairmen be appointed to be responsible for the running of each group. These persons to be briefed by the organiser. They will be responsible for running an individual group, to introduce the participants, control the discussion and summarize the discussion. Finally, reporting back of the groups progress to the organizer. These chairmen could be chosen from branches of training, safety and mining.

8.1.2 Wherever possible man-riding facilities should be provided to take operators as near as it is possible to the face. This is especially necessary where there are long distances, gradients or low height conditions.

8.1.3 The optimum position for an operator to control these machines is towards the front of the machine for each direction of travel, and the machine controls should be arranged to achieve this wherever possible.

8.1.4 Pre-start warnings to operate before picks begin to move should be incorporated in machines.

8.1.5 The use of mechanisms to remove the need for operators to go onto the face side in order to alter plough and deflector plates should be extended.

8.2 The power loader machine

8.2.1 Dust suppression controls are fitted locally and are in a variety of positions in relation to the machine. It is possible to introduce immediate measures to reduce the risk of accident by arranging all water spray controls which are used in conjunction with starting and stopping procedures to be placed away from the face side and near the travelling way.

8.2.2 Effective duplication of controls at each end of the machines is needed.

- 8.2.3 The positioning of controls by the travelling track is desirable and all controls need ergonomic design.
- 8.2.4 The use of more automatic and properly designed portable control equipment can diminish the amount of movement required by operators.
- 8.2.5 It does appear that the monitoring aspect of the operator's task cannot be replaced. However, the routine repetitive sequences, such as starting and stopping in relation to the face conveyor and automatic steering, are facilities which might be incorporated and which would relieve in the design of the machine the necessity for much movement around the machine.
- 8.2.6 New controls and modifications should be made in conjunction with ergonomic advice on the capabilities and limitations of operators.

8.3 The operator and his workspace

- 8.3.1 It is recommended that a system should be designed to transport the operator in a prone position along the travelling track. The design of the system should give the operator sufficient room to move his elbows.
- 8.3.2 If this is not possible and operators must continue to crawl in these confined spaces, the following recommendations are made:-
 - 8.3.2.1 The continued use of knee pads should be supplemented by instruction in early self-diagnosis of beat knee. This would enable more effective treatment for the complaint to be made.
 - 8.3.2.2 The floor of the travelling track be designed with consideration for the operators' hands and legs. A level and smooth surface would be advantageous. The present structures on the floor of the travelling track act as hurdles.
 - 8.3.2.3 There is a problem in thin seams concerning the width of the travelling track. The difficulties are the elbow room and the space to turn round. Where possible support designs with low profiles should be selected. As an indication of the additional space desirable, the following recommendations are presented:-

For crawling on hands and knees	
Height	81 cm (32 inches)
Width	63.5 cm (25 inches)
For prone crawling	
Minimum Height	43 cm (17 inches)
Width	101.6 cm (40 inches)

8.4 The operator and his environment

8.4.1 Noise

When cutting, the power loaders emitted noise at levels greater than 90 dB (A). Long term research should be initiated to find the sources of this noise and reduce the intensity. In the short term, where the exposure of operators is unduly high, a method of protecting the operator by job rotation has been proposed (section 5.1.1).

8.4.2 Lighting

While the lighting of the cap lamps was sufficient to prevent nystagmus, it was not sufficient for the work task or general safety. Therefore, it is suggested that a system of general lighting (designed for the roof support system) be used in conjunction with portable lighting by cap lamps.

8.4.3 Climate

The conditions were found to be within the comfort zone of 18 - 22^oC. It is proposed that the ventilation design for faces should continue to aim for temperatures within this zone.

8.5 The operator and face performance

8.5.1 The outputs of these installations were not limited by the performance of the power-loader or the operator, therefore, the primary recommendation must be that continued efforts are required to reduce the delays on the face and outbye.

8.5.2 Once these delays are reduced, the bottle-neck will be the speed of the machine. It has been shown that the speed of the Bi-Di shearer studied depended upon the operator. Therefore, in this case the improvements in the training and design of machinery for the operator made in this report are necessary. These improvements will make the task of machine operating easier and safer.

8.5.3 If face teams wish to apply job rotation it should be encouraged.

9. ACKNOWLEDGEMENTS

Mr R Rawlinson encouraged the work and provided the facilities for the technical assistance. A large number of people have assisted in this study. Mr G Sanders requested the study. The Area and Mine staff in the South Midlands were very co-operative.

Detailed studies were made with 6 machine operators and special thanks must be given to them for their very willing help.

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The authors also wish to acknowledge the assistance of Mr B Ward in co-ordinating the work of the Area.

APPENDIX A.

MECHANICAL LOADER OPERATOR

(From Mine Workers in Miscellaneous Mines
'Outline Training Syllabuses' Ceramics, Glass
and Mineral Products, Industry Training Board,
March, 1971)

1. Basic Knowledge
 - 1.a The appropriate sections of the Mines and Quarries Act, 1954 and Regulations.
 - 1.b The contents of Book 6 - Workmen at miscellaneous mines.
 - 1.c Company and local Mine Regulations.
 - 1.d Environmental hazards and safe working.
 - 1.e Fire precautions and fire fighting procedures.
 - 1.f Ventilation and its purpose.
 - 1.g Mine dust, gas and flooding hazards.
 - 1.h Corrosive action of mine water.
 - 1.i Procedure and precautions during blasting operations.
 - 1.j Accident and rescue procedures; first aid and medical facilities.

2. Basic Skills
 - 2.a Ability to communicate.
 - 2.b Ability to co-ordinate hand and foot movements.
 - 2.c Use of hand tools.
 - 2.d Manual handling (e.g. correct methods of lifting).

3. Job Knowledge
 - 3.a The function and inter-dependence of other members of the work team.
 - 3.b Principles of strata control, ground conditions and various methods and types of support used for roof and sides.
 - 3.c General knowledge of safe working methods.
 - 3.d Transport rules - knowledge of vehicle movement routes in the mine.
 - 3.e Track laying, laying rails, crossings and turntables.
 - 3.f Importance of good illumination at the work site.

- 3.g Code of Operational Signals.
- 3.h Operation and function of controls of loading machine.
- 3.i General principles of relevant motive power system and functions of the various parts.
- 3.j Start and shut down procedures.
- 3.k Maintenance and lubrication in accordance with servicing schedules.
- 3.l Identification of faulty running.
- 3.m Working knowledge of compressed air, electrical and hydraulic supply systems of the machine where applicable.
- 3.n Working limitations of the machine.
- 3.o Stability of the machine under adverse travelling and gradient conditions.
- 3.p Correct loading procedure.
- 3.q Positioning of machine for loading vehicles when trackless mining operations are involved.
- 3.r Hazards due to operating the machine in confined conditions.
- 3.s Recognition of product material from waste.
- 3.t Feed sizes acceptable to crusher.
- 3.u Emergency procedures.

4. Job Skills

- 4.a Observance of working conditions before beginning operations and responsibility to nearby workmen.
- 4.b Ability to interpret signals and signs of direction and location underground, geography of underground workings.
- 4.c Ability to recognise and evaluate mining hazards.
- 4.d Ability to receive, transmit and act in accordance with a code of audible and visual signals.
- 4.e Ability to read and follow line diagrams and surveyor's marks where necessary.
- 4.f Ability to drive and operate the machine safely, including loading, fitting, slewing and discharging.
- 4.g Ability to sort product material from waste.
- 4.h Ability to recognise faulty running and symptoms of mechanical and electrical breakdown.

- 4.i Ability to carry out routine inspections and testing of the machines in accordance with general orders and regulations.
- 4.j Ability to carry out routine maintenance, simple running repairs and adjustments.
- 4.k Ability to complete record cards and report sheets of machine condition and inspections.
- 4.l Good housekeeping - maintenance of clean working floor in area of operation.

5. Background Knowledge

- 5.a Local geology and general principles of mining.
- 5.b Basic company organisation products and production methods, including nature of mineral mined and its uses.
- 5.c Basic economics of the mine.
- 5.d Importance of quality.
- 5.e Appreciation and knowledge of operation of vehicle being loaded.
- 5.f Appreciation of other operating duties in area of work.
- 5.g Contents of manufacturers' handbooks on all equipment used in the drilling operation.

APPENDIX B

EXTRACTS FROM TRAINING REGULATIONS RELEVANT
TO COAL FACE MACHINE OPERATORS

National Coal Board, Scheme of Training for coal face workers (approved by the Minister of Power for the purposes of Regulation 10 (2) of the Coal Mines (Training) Regulations, 1967)

8. The basic training shall comprise a minimum overall period of 100 days for persons 18 years or over at the commencement of training and 100 days or until 18, whichever is the longer, for persons under 18 years.
11. The basic training shall cover the main operations of coalfilling; packing/withdrawing of supports, ripping and conveyor moving, together with the subsidiary or incidental work connected with the operations. Where a coal-getting machine is used, trainees may not operate it except as part of the further training required by this scheme (section IV) for the training of coal-getting machine operators.
22. Improvership shall normally follow immediately after the completion of basic training and shall comprise a minimum period of 40 days.

IV TRAINING OF COAL-GETTING MACHINE OPERATORS

26. Before a person is authorised by the Manager to be an operator, or an assistant operator, of a coal-getting machine (see paragraph 11 above) he shall:
- (i) have at least six months practical experience of work for coal production after completion of improvership; this experience and his improvership to include, wherever possible, experience of a face worked by the machine of the type he is to operate;
 - (ii) receive further training comprising practical and theoretical instructions as will, together with his practical experience, satisfy the Manager that he is competent to operate or assist in operating the machine of the type on which he will be employed. Minimum periods for this instruction shall be established locally.
27. After a person has completed the further training he shall receive a certificate (in accordance with Regulation 11 (1) (b) of the Coal Mines (Training) Regulations, 1967) indicating that he has received such training and is competent to be employed in operating a coal-getting machine of the type.
28. Before a person is employed as a coal-getting machine operator he shall spend a period as an assistant operator.

APPENDIX C

SYMBOLS SENSORY MOTOR PROCESS CHARTS OF
STALL PROCEDURES

K = Kinaesthesia
MOT = Motion class
V = Vision
D = Decision
M = Memory
T = Touch
S = Sound

V

Planning, depends on choice of actions open to the operator from that point.

W

Control, once a movement is planned where accuracy and care are required for guidance or there are small local variations in conditions to be overcome.

^

Check, when a motion element has been completed there may still be doubt as to whether or not the desired result has been achieved.

O

Initiate

⊙

Stop

Motion Classes

Reach	R
Move	M
Turn	T
Position	P (less than 1 inch)
Apply Pressure	AP
Grasp	G
Release	RL
Hold	H

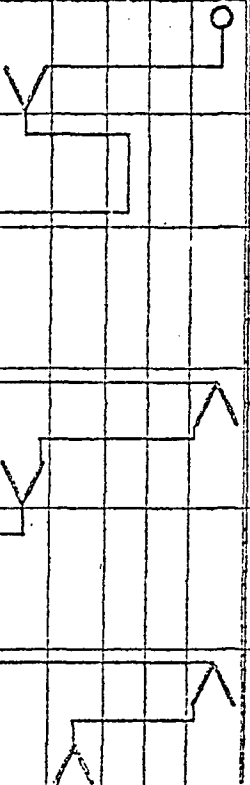
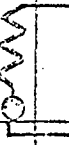
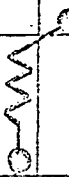
Vision

Viewing to left of machine	1
Viewing controls	2
Viewing to right of machine	3

ANDERSON BOYES SHEARER STALL PROCEDURE 1

- C2 -

LEFT HAND			BRAIN				RIGHT HAND				
K	T	MOT	M	D	VISION			MOT	K	T	
					1	2	3				
											This method used 52% of the time depends on operator being near controls and cause of stalling
											To haulage direction control
											Turn haulage direction control to horizontal switching haulage off
											Check motor running light (If not procedure 2)
											Turn haulage direction control on to correct direction
											Check motor sound and machine moving satisfactorily



LEFT HAND			BRAIN				RIGHT HAND					
K	T	MOT	M	D	VISION			S	MOT	K	T	
					1	2	3					
												This method used 18% of the time.
												Pitch of motor changes
		R										To haulage direction control
		T 30										Turn to horizontal, switching haulage off
												Motor stalling
		R										To power supply
		T 145										Turn power supply off
		T 145										Turn power supply on
												Check motor running light
		R										To haulage direction control
		T 30										Turn haulage direction control to correct direction
												Check motor sound and machine moving satisfactorily.

ANDERSON BOYES SHEARER STALL PROCEDURE
- C4 -
3

LEFT HAND			BRAIN				RIGHT HAND					
K	T	MOT	M	D	VISION			S	MOT	T	K	
					1	2	3					
												This method used 30% of the time. Generally used when electric power trip out on overload.
												Pitch of motor changes
		R										To haulage direction control
		T 30										Turn haulage direction control to horizontal. switching haulage off
		R										Reach to power supply switch
		T 145										Switch off power supply
		R										Reach to face side of M/C for electric reverse switch.
		T 90										Reverse Power
		R										Reach to power supply switch
		T 145										Turn power on
												Check motor running satisfactorily
		R										To haulage direction control

	T 30					Haulage on in reverse	
							Check M/C moves away from buttock
	T 30						Haulage off
	R						Reach to power supply
	T 145						Power Supply off
	R						Reach to face side of machine for electric reverse switch
	T 90						Reverse power
	R						Reach to power supply
	T 145						Power supply on
							Check motor running satisfactorily
	R						To haulage direction control
	T 30						Haulage on to correct direction
						Check pitch of motor and machine moving forward	

APPENDIX D

ANTHROPOMETRIC DATA RESULTS AND INTERPRETATION

This section includes anthropometric data taken directly from the subjects and data interpreted from the analysis of the photographs.

Also included is a list of 't' values, together with their levels of significance, and a list of correlation coefficients.

Table D1. Table of Means, Standard Deviations, and 95th Percentiles of Anthropometric Data
(All dimensions given in centimetres)

Number of subject	Age (Yrs)	Stature	Acromiale ht.	Bi-iliac diam.	Bi-acromial diam.	Sitting ht.
001	28.806	176.4	145.7	29.8	40.0	91.7
002	30.589	166.2	137.4	28.3	38.5	89.6
003	29.962	169.4	139.1	31.4	36.4	88.7
004	29.113	170.2	143.4	28.0	36.1	87.5
005	28.151	173.8	147.2	28.9	37.2	90.8
006	33.606	174.9	143.1	27.8	40.0	93.1
007	27.578	161.7	132.0	28.7	39.0	84.3
008	36.455	168.4	140.4	28.8	35.9	87.8
Means	-	170.2	141.0	28.9	37.9	89.18
S.D.s	-	4.83	4.91	1.17	1.71	2.76
95th percent-iles	-	179.6	150.60	31.19	41.25	94.48

TABLE D2

TABLE OF DIMENSIONS WITH THE ROOF HEIGHT OF THE RIG
 FIXED AT 76 cm
 (All dimensions given in centimetres)

SUBJECT NUMBER	MALLEOLUS -KNEE JOINT	KNEE JT. -G TRONCH	STYLIOR-OLECRONON	OLECRONON-ACRONION	NUDE ACRONION HEIGHT	NUDE G.T. HEIGHT	CLOTHED ELBOW WIDTH	NUDE ELBOW WIDTH	CLOTHED HIP WIDTH	NUDE HIP WIDTH	CLOTHED BUTTOCK HEIGHT	NUDE BUTTOCK HEIGHT	CLOTHED STEM LENGTH	NUDE STEM LENGTH
001	41.13	45.28	26.14	31.29	58.55	48.98	54.93	46.65	44.02	35.38	65.97	60.40	101.66	90.17
002	36.60	37.32	24.21	26.30	52.85	38.61	55.90	50.27	43.23	34.81	62.33	51.95	93.93	87.36
003	38.76	40.38	23.08	31.61	58.15	39.17	52.84	46.65	47.25	34.48	63.81	50.83	99.05	86.36
004	42.06	43.27	25.98	31.29	60.00	43.99	55.74	47.53	44.36	34.41	58.99	54.45	98.31	85.58
005	42.06	40.05	26.06	23.63	57.59	40.54	62.01	56.86	46.02	35.34	61.24	50.10	103.86	92.94
006	41.45	41.58	25.17	29.52	57.59	40.62	60.32	53.08	46.04	33.97	53.79	54.93	101.07	91.60
007	39.19	41.90	23.18	29.16	55.66	39.73	55.26	52.52	42.71	34.26	53.80	53.71	95.86	83.60
008	39.88	38.93	24.54	30.08	56.70	39.49	55.66	53.16	43.81	34.88	60.10	54.17	99.00	89.25
Means	40.15	41.09	24.79	29.73	57.14	41.51	56.58	50.84	44.68	34.66	59.99	53.82	99.09	88.53
S.D.s	1.91	2.53	1.25	1.77	2.15	3.26	3.02	3.69	1.38	0.5	4.39	3.19	3.23	3.15
95th percent-iles	43.89	46.05	27.24	33.19	61.34	47.88	62.49	58.04	47.38	35.64	68.59	60.07	105.44	94.68

TABLE D3

TABLE OF DIMENSIONS WITH THE ROOF HEIGHT OF THE
RIG FIXED AT 56 CM
(All dimensions given in centimetres)

SUBJECT NUMBER	NUDE ACROMION HEIGHT	NUDE G. TROCHANTERIC HEIGHT	CLOTHED ELBOW WIDTH	NUDE ELBOW WIDTH	CLOTHED BUTTOCK HEIGHT	NUDE BUTTOCK HEIGHT	CLOTHED STEM LENGTH	NUDE STEM LENGTH
001	36.92	45.52	57.10	56.79	53.36	50.35	101.07	91.55
002	48.66	36.91	59.36	57.02	53.75	52.06	96.59	93.86
003	50.75	40.59	68.65	68.53	53.29	52.75	101.42	92.13
004	53.08	41.98	57.99	55.98	51.82	50.43	101.86	89.57
005	49.62	31.37	68.20	67.56	50.81	44.25	107.94	95.22
006	48.58	41.26	71.18	78.18	55.34	54.89	103.20	96.14
007	46.25	38.69	68.69	73.99	53.97	52.61	92.83	87.10
008	50.83	29.92	59.76	62.98	49.71	39.24	101.30	92.30
Means	48.08	32.28	63.91	65.25	52.76	49.57	100.77	92.23
S.D.s	4.90	5.34	5.83	8.37	1.84	5.21	4.47	2.95
.95th percent -iles	58.04	49.33	75.33	81.65	56.36	59.77	109.52	98.03

TABLE D4
 TABLE SHOWING THE ARM/LEG LINK ANGLES AT
 BOTH THE ROOF HEIGHTS

SUBJECT NO.	ROOF HEIGHT 76 cm		ROOF HEIGHT 56 cm		ANGULAR CHANGE	
	ELBOW ANGLE	KNEE ANGLE	ELBOW ANGLE	KNEE ANGLE	AT ELBOW	AT KNEE
001	165°	75°	99°	54°	+ 66°	+ 21°
002	179°	62°	156°	61°	+ 23°	+ 1°
003	175°	47°	134°	52°	+ 41°	- 5°
004	160°	55°	127°	45°	+ 33°	+ 10°
005	190°	58°	180°	34°	0°	+ 24°
006	175°	49°	161°	54°	+ 14°	- 5°
007	175°	62°	151°	62°	+ 24°	0°
008	170°	55°	173°	28°	- 3°	+ 27°

TABLE D 5

TABLE OF RESULTS OF 't' TEST

TESTS FOR DIFFERENCES IN THE FOLLOWING	VALUE OF 't'	LEVEL OF SIGNIFICANCE
Acromion height with roof heights at 76 cm and 56 cm	3.90	p 0.01
Nude buttock height - roof heights 76 cm and 56 cm	2.07	p 0.1
Clothed buttock height - roof heights 76 cm and 56 cm	3.90	p 0.01
Clothed elbow width - roof heights 76 cm and 56 cm	3.92	p 0.01
Clothed stem lengths - roof heights 76 cm and 56 cm	2.02	p 0.1
Clothed and nude hip width	16.70	p 0.001
Clothed and nude elbow width - roof height 76 cm	7.26	p 0.001
Clothed and nude elbow width - roof height 56 cm	1.17	p 0.20
Clothed and nude buttock height - roof height 76 cm	3.82	p 0.01
Clothed and nude buttock height - roof height 56 cm	2.59	p 0.05
Clothed and nude stem length - roof height 76 cm	14.85	p 0.001
Clothed and nude stem length - roof height 56 cm	7.36	p 0.001

This Appendix contains the results of the measurements made of temperature, air velocity and barometric pressure at the installations.

The results of two analyses of variance calculations to examine the sources of variation for the dry bulb and the wet bulb temperatures. The sources of variation examined were the day (of the week), the positions, and the installation.

Table E1 Ventilation Measurements - Installation A

Position on face	Time of Measurement	Temperature Reading °C			Velocity M/S	Barometer KN/m ²
		Dry Bulb	Wet Bulb	Globe		
10m from M/G	Monday	21.1	20.0	21.1	0.77	103.56
Mid-face	Day	21.7	20.6	21.7	0.76	103.56
10m from T/G	Shift	21.1	20.0	21.1	0.80	103.56
10m from M/G	Wednesday	21.7	20.6	21.7	0.72	104.23
Mid-face	Day	21.1	20.0	21.1	0.86	104.23
10m from T/G	Shift	21.7	20.0	21.7	0.69	104.23
10m from M/G	Friday	21.1	20.0	21.1	0.82	103.05
Mid-face	Afternoon	21.7	20.6	21.7	0.87	103.05
10m from T/G	Shift	21.7	20.6	21.7	0.73	103.05

Table E2 Ventilation Measurements - Installation B

Position on face	Time of Measurement	Temperature Reading °C			Velocity M/S	Barometer KN/m ²
		Dry Bulb	Wet Bulb	Globe		
10m from M/G	Monday	21.0	19.0	21.0	0.55	100.00
Mid-face	Day	21.5	19.5	21.5	0.60	100.00
10m from T/G	Shift	21.0	20.0	21.0	0.60	100.00
10m from M/G	Wednesday	21.5	19.5	21.5	0.65	100.16
Mid-face	Day	21.0	19.5	21.0	0.60	100.16
10m from T/G	Shift	21.5	20.0	21.5	0.67	100.16
10m from M/G	Friday	21.0	20.0	21.0	0.65	99.91
Mid-face	Afternoon	21.0	19.5	21.0	0.62	99.91
10m from T/G	Shift	21.0	20.0	21.0	0.60	99.91

Table E3

Ventilation Measurements - Installation C

Position on face	Time of Measurement	Temperature Reading °C			Velocity M/S	Barometer KN/m ²
		Dry Bulb	Wet Bulb	Globe		
1.0m from M/G	Monday	18.3	17.8	18.3	1.55	105.1
Mid-face	Day	18.3	17.8	18.3	1.41	105.1
1.0m from T/G	Shift	18.3	18.0	18.3	1.14	105.1
1.0m from M/G	Wednesday	18.9	18.3	18.9	1.36	95.66
Mid-face	Day	18.9	18.3	18.9	1.15	95.66
1.0m from TEG	Shift	18.9	18.3	18.9	1.00	95.66
1.0m from M/G	Friday	19.4	18.9	19.4	1.54	105.1
Mid-face	Afternoon	19.4	18.9	19.4	1.37	105.1
1.0m from T/G	Shift	19.4	19.1	19.4	1.31	105.1

Table E4 Analysis of Variance on Results of Dry Bulb Temperature Measurements

Test for first order interaction

Source of variation	df	Sum of squares	Mean square	F
Day	2	0.75	0.375	
Position	2	0.03	0.015	
Installation	2	35.85	17.925	
Day x Position	4	0.59	0.148	1.56
Position x Installation	4	0.05	0.013	0.13
Day x Installation	4	1.32	0.330	3.47
Second order interaction	8	0.38	0.095	
	26			

As the first order interactions are not significant these are pooled with the second order interactions to form a new estimate of error.

Test of significance of Day Position and Installation

Source of variation	df	Sum of squares	Mean square	F
Day	2	0.75	0.375	3.21
Position	2	0.03	0.015	0.13
Installation	2	38.85	17.925	153.20
Error	20	2.34	0.117	
	26			

Table E6

Analysis of Variance on Results of Wet Bulb
Temperature Measurements

Test for first order interaction

<u>Source of variation</u>	<u>df</u>	<u>Sum of squares</u>	<u>Mean square</u>	<u>F</u>	<u>F.95</u>
Day	2	1.36	0.68		
Position	2	0.21	0.11		
Installation	2	16.76	8.38		
Day x position	4	0.28	0.07	0.78	3.84
Position x installation	4	0.41	0.10	1.11	3.84
Day x Installation	4	0.73	0.18	2.00	3.84
Second Order Interaction	<u>8</u>	0.71	0.09		
	26				

As the first order interactions are not significant these are pooled with the second order interactions to form a new estimate of error.

Test of significance of Day Position and Installation

<u>Source of variation</u>	<u>df</u>	<u>Sum of squares</u>	<u>Mean square</u>	<u>F</u>	<u>F.99</u>
Day	2	1.36	0.68	6.18	5.85
Position	2	0.21	0.11	1.00	5.85
Installation	2	16.76	8.38	76.18	5.85
Error	<u>20</u>				
	26				

APPENDIX F

THE OPERATOR AND FACE PERFORMANCE

Machine Operator fatigue may cause a decrement in performance towards the latter end of the shift. It has been suggested that this problem may be alleviated by changing the operator halfway through the shift. This section investigates whether production declines by comparing the values of various relevant variables measured during the two halves of the shift.

Data on production were collected as part of this study over a four week period. During this time two operators at each of three installations worked morning and afternoon shift for alternate weeks (see Figure F1). Measurements of time spent cutting, time delayed and distance cut and other variables were taken for successive fifteen minute periods throughout each shift.

In order to investigate the effect of fatigue, each shift was divided into two periods. The first ran from the beginning of the shift for three hours; the second ran from then to the end of the shift. Values of the variables of interest were obtained for each time period by accumulating the values for the constituent fifteen minute intervals. Since the time periods were not of equal duration, it was not realistic to analyse these values of time and distance cut. Instead the following three variables were calculated:

$$\begin{aligned} \text{percentage of time spent cutting} &= \frac{\text{time spent cutting} \times 100}{\text{duration of time period}} \\ \text{per time period (\% cut time)} & \\ \\ \text{percentage of time delayed per} &= \frac{\text{delay time} \times 100}{\text{duration of time period}} \\ \text{time period (\% delay time)} & \\ \\ \text{cutting speed (ft/min)} &= \frac{\text{Distance cut during time}}{\text{period}} \\ &\quad \text{time spent cutting} \end{aligned}$$

The values of these variables for the two time periods have been investigated by means of the Analysis of Variance technique for each of the three installations. Other factors of interest were included in the analysis. These were: differences between weeks, between days, between morning and afternoon shifts and between operators. Production is affected by short and long term random disturbances and the analysis was designed to allow for these.

At two installations no production took place on certain shifts because of machinery problems. Since no production for a whole shift affects both time periods within that shift equally, it is clear that missing shifts do not bias the mean values for the time periods. Mean values for weeks, days and shifts will, however, be affected, depending on where the missing shifts fall.

As the time periods are of unequal duration, the analyses should, theoretically, have been weighted by this variable (the cutting speed analysis should have been weighted by cutting time). Since the mean values of the possible weighting variables were not too dissimilar, it was felt that an unweighted analysis would be adequate.

Table F1 shows the mean values of the variables for the first installation; the corresponding analysis of variance figures are given in Table F2. No production took place on the Thursday and Friday of week four; the means for that week and those days are, therefore, reduced. There was no production for one other time period. Examination of the results shows that there is no sign of operator fatigue, since the two mean values for the time periods are very similar. Apart from the days and weeks effects there are no other differences of any great significance.

The results from the second installation are presented in Tables F3 and F4. No production took place on one Friday in week two; one operator worked a double shift on Thursday of the same week. There was no production during one other time period. The results show that the overall percentage of time spent cutting was about half of that of installation 1, although the cutting speed was about the same. There is no evidence of any deterioration in performance between time periods. There are also no other results worthy of comment.

The grand means on Table F5 shows that production was the highest of the three at the third installation. Compared to the others, no production was lost for complete shifts at this face during the study. This is also the only installation to show differences in production over the two time periods. Inspection of the data revealed that the percentage of time spent cutting was consistently greater for the second time period across shifts, days and operators. This difference was about 8% and was unlikely to have occurred by chance ($p < 1\%$). The speed of cut was also different between time periods ($p < 5\%$). The only other difference worth noting was a difference of 0.9 ft/min between the two operators ($p < 1\%$).

There is some evidence from installations 1 and 3 that the operators performance varies according to shift. For example, at installation 1 production is higher during weeks 1 and 3 compared to weeks 2 and 4. For weeks 1 and 3 operator A worked the morning shift and B the afternoon shift, while they interchanged for weeks 2 and 4.

The analysis has so far shown no decrement in performance over the shift. There are a number of reasons why this has occurred. Firstly, there may be no effect of fatigue. Secondly, there may be an effect due to fatigue, but the work done in driving the machine was generally not arduous enough to cause a reduction in production. Lastly, the previous analysis by considering production by time periods rather than by energy expended obscured any fatigue effect. In order to test the validity of these three reasons, an analysis was performed which investigated production after certain increments of work had been completed.

Distance cut per shift was taken as a measure of work. During the period of study this varied between 0 to just over 2,000 feet in one shift. In order to examine the relationship between fatigue and production it was clearly necessary to examine only those shifts where a substantial footage of coal had been cut. A limit of 1,500 feet was taken arbitrarily;

this gave 24 shifts during which production could be studied. Twenty-one of these shifts were worked at the third installation; both operators were fairly evenly represented over these 21 shifts.

Each shift was divided into four intervals, determined by distance cut. The first interval ran from the beginning of the shift to the time when the operator had cut 500 feet of coal. The second ran from there to the 1,000 feet point; the third from there for another 500 feet. The last interval was variable and ran from the 1,500 feet point to the end of the shift. (The last interval was sometimes rather short). For each of these intervals three variables were calculated. These were the variables employed in the previous analysis, namely: % cut time, % delay time and cutting speed. It was again necessary to take percentages since the time taken for an operator to cut 500 feet varied considerably both within a shift and between shifts.

The results for the 24 shifts are shown in Figure F2. This shows the mean values for the three variables for the four time periods. The mean values of % cut time show no evidence of a drop in production with distance cut. In fact, there is evidence of a burst of production at the end of the shift. The % delay time figures show the same story. The speed of cut values, however, appear to show a small but consistent drop throughout the shift. The statistical significance of the differences between the means separately for each of the three variables has been investigated. The analyses of variance (Table F7) show evidence of differences between the values of % cut time and % delay time not due to chance variation ($p < 1\%$ and 0.1% respectively). There is, however, no significant evidence at all that the true speed of cutting deteriorates over the shift in the manner indicated by the mean values.

Two approaches to the problem of production and operator fatigue have revealed no evidence of decline in performance over the shift. This result does not rule out such effect if operators are called upon to cut more coal than the six in this study did during the four weeks. If and when improvements in machinery and organisation are brought about, these problems need to be re-examined.

Figure F1
 Layout of Results of Machine Performances for
 each Installation

WEEKS		1					2					3					4					
DAYS:		M	T	W	TH	F	M	T	W	TH	F	M	T	W	TH	F	M	T	W	TH	F	
S H I F T	O	TIME PERIOD 1	*	*	*	*	*					*	*	*	*	*						
	1	TIME PERIOD 2	*	*	*	*	*					*	*	*	*	*						
	O	TIME PERIOD 1						*	*	*	*	*					*	*	*	*	*	*
	1	TIME PERIOD 2						*	*	*	*	*					*	*	*	*	*	*
S H I F T	O	TIME PERIOD 1						*	*	*	*	*					*	*	*	*	*	*
	1	TIME PERIOD 2						*	*	*	*	*					*	*	*	*	*	*
	O	TIME PERIOD 1	*	*	*	*	*					*	*	*	*	*						
	1	TIME PERIOD 2	*	*	*	*	*					*	*	*	*	*						

OP is an abbreviation for operator

* 3 values obtained: percentage of time spent cutting
 percentage of time delayed
 speed of cutting (ft/min)

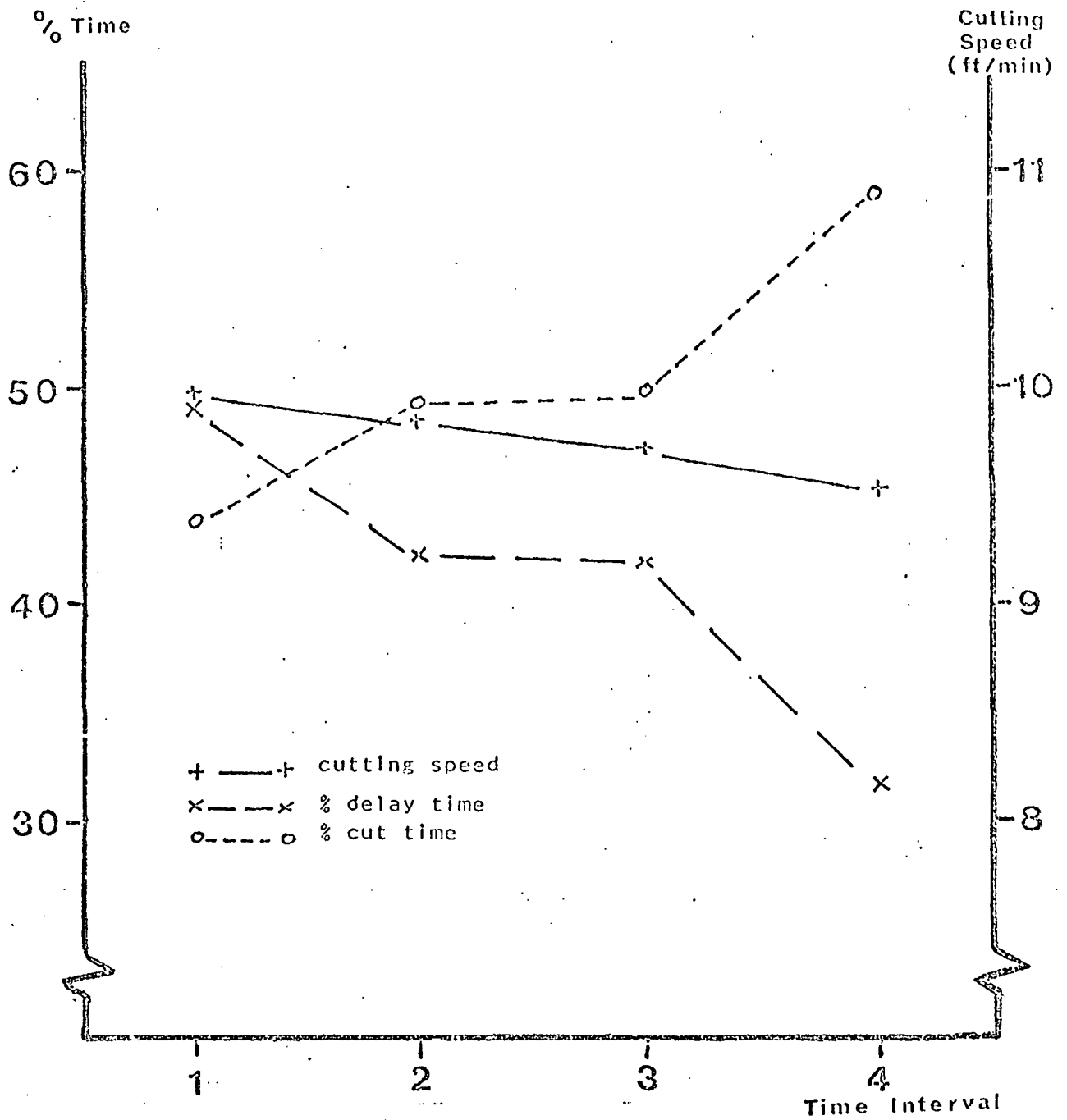


Figure F2.. Production During Each Of Four Intervals Defined By Work Completed.

Table F1

Mean Values for Installation 1

<u>Time Periods</u>	1		2		
% cut time	30.7		30.4		
% delay time	61.1		61.9		
speed of cut	8.1		7.8		
<u>Weeks</u>	1	2	3	4	
% cut time	37.6	25.9	37.4	21.4	
% delay time	52.4	67.0	52.8	73.8	
speed of cut	9.7	8.8	8.4	4.8	
<u>Days</u>	M	T	W	TH	F
% cut time	35.3	33.5	36.7	21.4	25.9
% delay time	54.2	59.9	53.3	72.9	67.2
speed of cut	9.1	8.3	8.9	6.7	6.7
<u>Shifts</u>	1		2		
% cut time	29.4		31.7		
% delay time	63.2		59.8		
speed of cut	7.9		8.0		
<u>Operators</u>	A		B		
% cut time	30.8		30.3		
% delay time	61.7		61.3		
speed of cut	7.7		8.2		
<u>Grand Mean</u>					
% cut time			30.6		
% delay time			61.5		
speed of cut			7.9		

Table F2

Analysis of Variance Table for Installation 1

<u>Source of Variation</u>	<u>Degrees of Freedom</u>	<u>Mean Squares</u>		
		<u>% cut time</u>	<u>% delay time</u>	<u>speed of cut</u>
Week Stratum				
Shift x Operators	1	3824	6333	101.1
Residual	2	104	229	87.8
Total	3	1344	2264	92.2
Days within Weeks Stratum				
Between days	4	693	1143	21.6
Days x Shift x Operators	4	181	340	18.8
Residual	8	495	718	20.9
Total	16	466	730	20.5
Shifts within Days Stratum				
Between shifts	1	113	224	0.6
Between Operators	1	4	3	5.8
Days x Shifts	4	47	95	0.8
Days x Operators	4	71	151	2.1
Residual	10	176	179	1.3
Total	20	117	150	1.6
Time Periods within Shifts Stratum				
Between Times	1	2	11	2.3
Days x Times	4	188	248	2.3
Shifts x Times	1	46	7	0.0
Operators x Times	1	6	5	2.0
Days x Shifts x Times	4	100	59	0.9
Days x Operators x Times	4	31	62	1.3
Shifts x Operators x Times	1	33	126	1.6
Residual	24	78	126	1.5
Total	40	81	116	1.5

Table F3

Mean Values for Installation 2

<u>Time Periods</u>	1		2		
% cut time	13.0		14.4		
% delay time	83.8		82.2		
speed of cut	8.1		8.2		
<u>Weeks</u>	1	2	3	4	
% cut time	18.0	12.4	7.2	16.0	
% delay time	77.2	85.1	90.9	79.9	
speed of cut	9.2	6.6	6.9	9.4	
<u>Days</u>	M	T	W	TH	F
% cut time	13.8	13.0	13.5	15.9	12.1
% delay time	83.0	84.7	82.3	80.1	84.7
speed of cut	9.0	9.3	8.0	8.7	5.7
<u>Shifts</u>	1		2		
% cut time	14.3		13.0		
% delay time	82.8		83.1		
speed of cut	8.5		7.8		
<u>Operators</u>	A		B		
% cut time	14.5		12.8		
% delay time	81.9		84.0		
speed of cut	8.0		8.3		
<u>Grand Mean</u>					
% cut time			13.7		
% delay time			83.0		
speed of cut			8.2		

Table F4

Analysis of Variance Table for Installation 2

<u>Source of Variation</u>	<u>Degrees of Freedom</u>	<u>Mean Squares</u>		
		<u>% cut time</u>	<u>% delay time</u>	<u>speed of cut</u>
Week Stratum				
Shift x Operators	1	88	86	0.7
Residual	2	616	1024	55.8
Total	3	440	711	37.5
Days within Weeks Stratum				
Between Days	4	32	60	34.7
Days x Shifts x Operators	4	91	109	16.7
Residual	8	90	141	16.5
Total	16	76	113	21.1
Shifts within Days Stratum				
Between Shifts	1	35	1	10.5
Between Operators	1	60	86	2.0
Days x Shifts	4	42	48	6.2
Days x Operators	4	17	51	10.4
Residual	9*	96	73	10.4
Total	20	63	60	9.1
Time Periods within Shifts Stratum				
Between Times	1	38	53	0.3
Days x Times	4	31	19	0.4
Shifts x Times	1	22	16	3.8
Operators x Times	1	4	53	1.8
Days x Shifts x Times	4	34	56	2.5
Days x Operators x Times	4	89	64	2.2
Shifts x Operators x Times	1	3	3	0.0
Residual	23*	44	72	1.2
Total	40	43	60	1.4

*One missing value estimated for when one operator worked a double shift.

Table E5

Mean Values for Installation 3

<u>Time Periods</u>	1		2		
% cut time	38.5		46.7		
% delay time	54.6		45.8		
speed of cut	9.5		9.9		
<u>Weeks</u>	1	2	3	4	
% cut time	45.2	37.3	48.1	39.9	
% delay time	46.2	55.5	45.6	53.4	
speed of cut	9.8	9.4	9.8	9.6	
<u>Days</u>	M	T	W	TH	F
% cut time	42.3	41.7	40.4	40.9	47.7
% delay time	50.4	52.4	52.3	51.3	44.6
speed of cut	9.6	9.9	9.4	9.4	9.9
<u>Shifts</u>	1		2		
% cut time	42.5		42.7		
% delay time	49.9		50.4		
speed of cut	9.6		9.7		
<u>Operators</u>	A		B		
% cut time	43.1		42.1		
% delay time	49.1		51.3		
speed of cut	9.2		10.1		
<u>Grand Mean</u>					
% cut time			42.6		
% delay time			50.2		
speed of cut			9.7		

Table F6

Analysis of Variance Table for Installation 3

Source of Variation	<u>Degrees of Freedom</u>	<u>Mean Squares</u>		
		<u>% cut time</u>	<u>% delay time</u>	<u>speed of cut</u>
Week Stratum				
Shift x Operators	1	1294	1443	1.6
Residual	2	75	23	0.3
Total	3	482	496	0.8
Days within Weeks Stratum				
Between Days	4	139	167	0.8
Days x Shifts x Operators	4	70	58	1.6
Residual	8	159	180	2.0
Total	16	132	146	1.6
Shifts within Days Stratum				
Between Shifts	1	0	5	0.3
Between Operators	1	18	98	15.0
Days x Shifts	4	157	191	0.4
Days x Operators	4	133	165	0.3
Residual	10	65	77	2.1
Total	20	92	115	1.9
Time Periods within Shifts				
Between Times	1	1327	1547	3.3
Days x Times	4	62	67	0.9
Shifts x Times	1	17	20	0.0
Operators x Times	1	24	69	0.2
Days x Shifts x Times	4	154	143	0.9
Days x Operators x Times	4	135	112	1.3
Shifts x Operators x Times	1	70	146	0.1
Residual	24	109	123	0.3
Total	40	137	151	0.6

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12. GLOSSARY OF TERMS USED

12.1 Mining terms

These are as defined in BS 3618 - A glossary of mining terms.

12.2 Ergonomic terms

Anthropometry	The science concerned with human body dimensions.
Candelas per square meter	The unit of luminance
Clo's	The term clo is used to describe the insulation quality of clothing. The average insulation provided by clothing worn by people sitting comfortably at rest, in an environment of 27°C, is equal to 1 Clo.
Comfort zone	The range of values of various climatic parameters within which people subjectively assess themselves as being comfortable.
Control dynamics	The direction and extent of movement of the control and the force required to move it.
Decibel (dB)	The range of acoustic powers of interest in noise measurements is about one billion to one ($10^8:1$). For convenience these powers are related on a decibel scale which is logarithmic. The decibel scale can be used to express the ratio between any two powers or any two sound pressures.
dB(A)	The 'A'-weighted sound level in decibels.
Ergonomics	System design with the characteristics of the human operator as the frame of reference.
Equivalent continuous sound level (Leq)	Leq can be regarded as a notional sound level which, in the course of an 8-hour period would cause the same 'A' weighted sound energy to be received as that due to the actual sound over the actual working day.
Fractional Exposure	This can be regarded as the dose of 'A'-weighted sound energy received expressed as a fraction of the dose received from exposure to 90 dB(A) for 8 hours.

Glare	Glare occurs when there is unwanted light in the visual field preventing the eye from functioning at its full efficiency.
Illumination	The illumination of a surface is determined by the amount of luminous flux incident upon it.
Job	The series of tasks an operator is employed to carry out.
Job rotation	The rotation of jobs within a work team all team members being trained in all the required skills. This is to overcome difficulties induced where a 'team' of jobs contain a demanding or boring job.
Lumen	The unit of luminous flux through a unit solid angle from a uniform point source of one candle intensity. (A uniform point source of one candle intensity therefore emits 4π lumens).
Luminous flux	The total visible energy emitted by a source per unit time is the total luminous flux from the source.
Luminance (Brightness)	The luminance is determined by the light reflected from a surface.
Lux	One lux is one lumen per square meter
Motor output	The physical action which the human makes in response to processed information generally arising from the sensory input.
Operators workspace	The functional space to be occupied by the human operator during his job.
Optimum control position	The position at which the control is sited to facilitate speed and accuracy in location and operation of the control and to be within the boundaries defined in anthropometric data.
Perceptual ability	The ability of an operator to select pertinent signals or information from the large range impinging upon his senses.
Percentiles	For utility anthropometric data is presented in terms of percentiles. A percentile value is the percentage of people at or below that particular measurement value.

Peripheral vision	The visual field of an eye extends more than 90° on the temporal side of the eye. In the outer portion of the visual field peripheral vision is used, in which changes of brightness or movement are readily perceived. However objects or colours are not seen with any degree of definition.
Reflectivity	The relation between illumination reaching a surface and the resulting luminance, expressed as a percentage. Luminance = reflectivity x illumination.
Relative humidity	The ratio of the quantity of water vapour present in the atmosphere to the quantity which would saturate at the existing temperature.
Sedentary work	Work in which little physical effort is involved.
Sensory-motor task analysis	An analysis of the way in which an operator performs a task based on detailed inferences, made by the observer, about the information processing being conducted by the operator.
Sensory input	The information which the human operator receives from his surroundings, necessarily by means of his senses.
Skill	(Psychological) skill is concerned with all the factors which go to make up a competent, expert, rapid and accurate performance. It attaches to any performance and thus it is not limited to manual operations but also covers a wide range of mental activities.
Specular reflector	A reflector used in a lamp to concentrate the majority of light into a high intensity beam with little surrounding illumination.
Stereotypes	A stereotype is the relationship between a control movement and the resultant effect expected by most of the population.
Task	An identifiable component of work to be done by a human operator to achieve a specific result.
Visual field	That area which is visible when the head and eyes are kept still.
Visual task	A task in which the primary or usually the exclusive, sensory input is through the eye.

HEAD OFFICE:

Research Avenue North,
Riccarton,
Edinburgh, EH14 4AP,
United Kingdom
Telephone: +44 (0)870 850 5131
Facsimile: +44 (0)870 850 5132

Tapton Park Innovation Centre,
Brimington Road, Tapton,
Chesterfield, Derbyshire, S41 0TZ,
United Kingdom
Telephone: +44 (0)1246 557866
Facsimile: +44 (0)1246 551212

Research House Business Centre,
Fraser Road,
Perivale, Middlesex, UB6 7AQ,
United Kingdom
Telephone: +44 (0)208 537 3491/2
Facsimile: +44 (0)208 537 3493

Brookside Business Park,
Cold Meece,
Stone, Staffs, ST15 0RZ,
United Kingdom
Telephone: +44 (0)1785 764810
Facsimile: +44 (0)1785 764811

Email: iom@iom-world.org