A new approach to the study of human factors in stope productivity

by A. C. LAWRENCE B. Econ., D. Com. (S.A.) (Member)

SYNOPSIS

The extent of the improvement in mean performance which could be achieved by reducing the variance between stoping gangs is examined, and it is shown that a worthwhile gain would result if variance were reduced by as little as 5 to 15 per cent. The problem of identifying human factors which contributed towards variance in gang performance was examined in one gold mine. A total of 342 'observations' on 49 stoping gangs were gathered, each observation consisting of a set of figures for 36 variables for one gang for one week. The variables included 'stope factors' such as face length, 'gang factors' such as the ethnic composition of the gang, and 'supervisory factors' such as the experience of the miner. These variables were related to 'tons trammed per week' as a measure of work performance. The findings showed that certain of the predictor variables accounted for 66 per cent of the variance in gang performance and about two thirds of this could be attributed to gang and supervisory factors, that is to the 'human factors'. The method suggests a basis for a new approach to the identification of human factors and is a promising step towards optimizing gang performance.

SINOPSIS

Die omvang in die verhoging van die gemiddelde arbeidsproduktiwiteit wat verkry kan word deur die variansie tussen die werkspanne te verminder, is ondersoek en daar is gevind dat daar aansienlike voordeel verkry kan word deur slegs hierdie variansie met 5 tot 15 persent te verlaag. 'n Totaal van 342 waarnemings in 49 afbouplekke is op 'n goudmyn gedoen en elke waarneming het bestaan uit 'n stel van 36 veranderlikes, vir 'n enkele werkspan vir een week. Die veranderlikes het ingesluit ‚afboufaktore' soos die lengte van die afboufront, ‚werkspanfaktore' soos die etniese samestelling van die werkspan en ‚toesighoudingsfaktore' soos die ervaring van die mynwerker. As maatstaf vir werkverrigting is al hierdie veranderlikes in verband gebring met die hoeveelheid tonne wat vervoer is in een week. Die bevindings het getoon dat sekere voorspellings veranderlikes bygedra het tot 66 persent van die variansie in werksprestasie van die werkspan en ongeveer twee derdes hiervan kan toegeskryf word aan werkspan- en toesighoudingsfaktore, m.a.w. die menslike faktore. Hierdie metode dui op die grondslag vir 'n nuwe benadering in die uitkenning van menslike faktore wat kan bydra tot die verhoging in werksverrigting van 'n werkspan.

INTRODUCTION

It is well known that, as in the case of other work groups, the "human element" has an important influence on the performance of stoping gangs. For example, such factors as the abilities of the individuals in a gang, their experience in mining and their nationalities, the numerical strength of the gang, the proficiency of their boss boy, their ability to withstand environmental stresses such as heat and noise, and the experience of the miner and other supervisors, are among the factors which are sometimes mentioned as relevant to the performance of a gang.

The precise effect which these human variables have on work done has not been established, however, with the result that mine managements have not been in a position to organize work groups in such a way as to optimize the utilization of the human resources available to them.

There are several reasons for the lack of progress towards the better understanding of the effects of these various human factors. In the first place, the question arises as to *how much* improvement can be effected in this way. Without some assessment of the possible gain, there is little incentive to utilise human resources better. Secondly, human behaviour is most complex and each of the different relevant variables does not act independently on work performance and is therefore not susceptible to separate study. Instead, there is considerable interaction between factors. Both the boss boy's proficiency and the experience of the men in his gang may be relevant to a gang's performance, but the importance of boss boy proficiency itself may depend upon the experience of the men. For example, the contribution of a proficient boss boy may be less if his gang is experienced in mining than if they are novices. It is not sufficient, therefore, to simply identify the factors which relate to gang performance, but it is also necessary to explain how they interact with one another. This is not easily done. Thirdly, progress in the study of human factors in stope productivity has been seriously handicapped by the lack of a suitable methodology with which to deal with the problem.

This paper describes a new approach which has yielded encouraging results when applied on one mine. At this stage, attention is drawn more to the method used than to the detailed findings of the investigation. Although the latter were true for the mine concerned at the time of the study, evidence has not yet been accumulated to show to what extent the findings can be generalized to other mines, or to what extent advantage can be taken of the findings in the form of practical application.

THEORETICAL IMPROVEMENT IN MEAN GANG PERFORMANCE BY REDUCING VARIANCE

Different stoping gangs attain different levels of production which may, for example, be distributed

*Human Sciences Laboratory, Chamber of Mines of South Africa, Johannesburg.

about a mean $\bar{x}_a$ as shown in Fig. 1(a). Some gangs produce at a level above the mean and others at a level below the mean and there may be considerable spread or "variance" in the distribution.

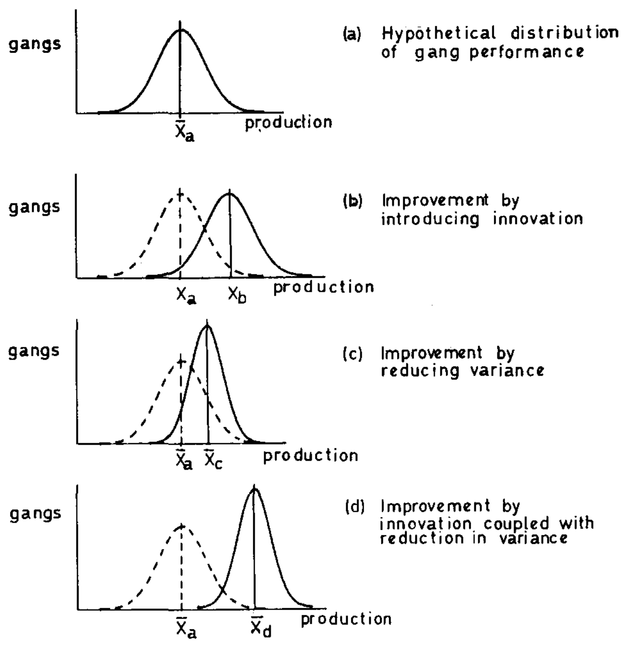

Fig. 1—Effects of innovation and reduction in variance on mean gang performance

Two basic approaches may be postulated for improving the mean performance of stoping gangs. One would be to introduce some innovation to move the whole distribution so that the new mean $\bar{x}_b$ is higher than $\bar{x}_a$, as in Fig. 1 (b). In this case, the performance of every gang has been improved by an amount $(\bar{x}_b-\bar{x}_a)$ but the variance has remained unchanged. This is to say, the spread about $\bar{x}_b$ in the new distribution is the same as was the spread about $\bar{x}_a$. There is no limit to the improvement which can be effected in this way *provided that a suitable innovation can be introduced.*

A second approach would be to establish why some gangs already perform better than others and to use this knowledge to improve the performance of the weaker gangs. For example, in Fig. 1 (a), if a characteristic of the gangs producing at a level higher than $\bar{x}_a$ is identified and introduced into the low producing gangs, the effect would be to reduce the variance in the distribution by narrowing the spread between gangs, and to move mean production to a new value $\bar{x}_c$ higher than $\bar{x}_a$, as in Fig. 1 (c). If there is no improvement in the upper limit of the distribution, as may well be the case, the amount of improvement which can be effected in this way may be more modest than the possibilities indicated in Fig. 1 (b).

Maximum improvement in performance would, of course, be attained if innovation was introduced together with a narrowing of the variance, as shown in Fig. 1 (d)

This paper is concerned with the improvement which can be achieved by identifying human factors which characterise high producing gangs and introducing these into low producing gangs, that is by reducing variance. The gain which can be achieved in this way is dependent upon:

(a) the shape of the distribution of gang performance,
(b) the variance in gang performance due to human factors before introducing the change,
(c) the nature of the change, and the extent to which variance is reduced.

Let $\bar{x}_1$=initial mean performance, and
s_1=initial standard deviation, so that the initial variance is s_1^2 and the initial limits of the distribution are $(\bar{x}_1 \pm 3s_1)$ approximately.

Assume (i) that the performance is normally distributed, and (ii) that the nature of the change is such that the initial upper limit of the distribution cannot be exceeded.

Then let the initial variance be reduced by a proportion p, so that the variance of the new distribution is $s_2^2=s_1^2\ (1-p)$ and the new standard deviation is $s_2=s_1\sqrt{(1-p.)}$

Since the upper limit of the distribution remains unchanged, the maximum value for the mean $\bar{x}_2$ of the new distribution will be approximately $3s_2$ below the upper limit which is $(\bar{x}_1+3s_1)$.

$$\text{Thus } \bar{x}_2 = (\bar{x}_1+3s_1)-3s_2$$

$$= \bar{x}_1+3s_1-3s_1\sqrt{1-p}$$

$$= \bar{x}_1+3s_1\ (1-\sqrt{1-p})$$

and the proportional increase in $\bar{x}_1$

$$=\frac{\bar{x}_2-\bar{x}_1}{\bar{x}_1}$$

$$=3\frac{s_1}{\bar{x}_1}\ (1-\sqrt{1-p})$$

With a normal distribution the maximum possible value for

$$s_1=\frac{\bar{x}_1}{3} \text{ approximately, so that } \frac{s_1}{\bar{x}_1}\leq\frac{1}{3}.$$

The increase which can be expected under the above assumptions, with different reductions in total variance are shown in Fig. 2.

To facilitate the calculation the assumption has been made that gang performance has a "normal" distribution, and that the maximum possible value for s is therefore $x/3$ approximately. An examination of performance distributions for several gold mines has shown, however, that they are more typically skewed positively, that is, they have more gangs performing below the mean than above. The s/x ratio is usually about 0,5. The shape of the typical distribution is *not* normal but is more nearly "$\sqrt{x}$-normal". That is, the square roots of the production measure are closer to a normal distribution than the measure itself.

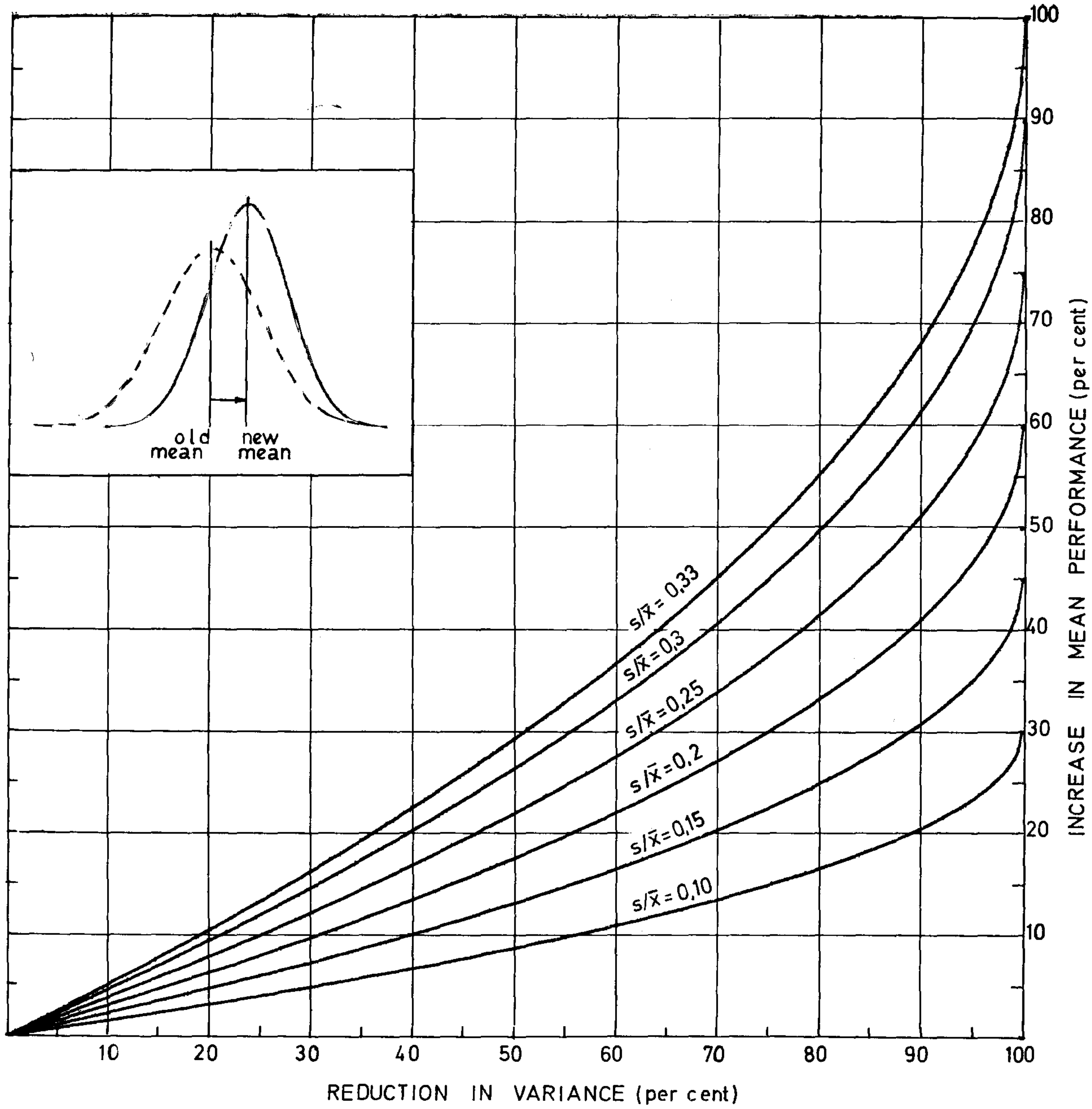

Fig. 2—Theoretical effect of reduction in variance on mean if performance has a 'normal' distribution

In such a case, the identification of characteristics associated with the relatively few gangs in the "tail" at the high end of the distribution, may permit increases in the mean far greater than those in Fig. 2, when variance is reduced. Thus, when the foregoing principles are applied to a $\sqrt{x}$-normal distribution, small reductions in variance result theoretically in considerable improvement in the mean, as shown in Fig. 3.

The overall improvement which should be attainable in practice, by reducing variance or spread in gang performance, probably lies between the limits suggested by Figs. 2 and 3. The improvement should be better than Fig. 2 because of the positive skewness of a typical distribution. On the other hand, it should be less than Fig. 3 because typical distributions are not quite as skew as $\sqrt{x}$-normal and, in addition, it seems unlikely that the variance in the relevant human factors would be spread evenly through the long tail at the high end of the distribution.

In general it would not seem to be unreasonable to expect an improvement in mean performance of the order of, or better than, 10 per cent, if the variance between gangs could be reduced by about 5 to 15 per cent. Before variance can be reduced by attending to human factors, however, it is necessary to *identify* those factors which contribute to the variance and the amount of the variance so contributed. This was the aim of the analysis described below.

METHOD

Weekly data relating to 49 stoping gangs were gathered

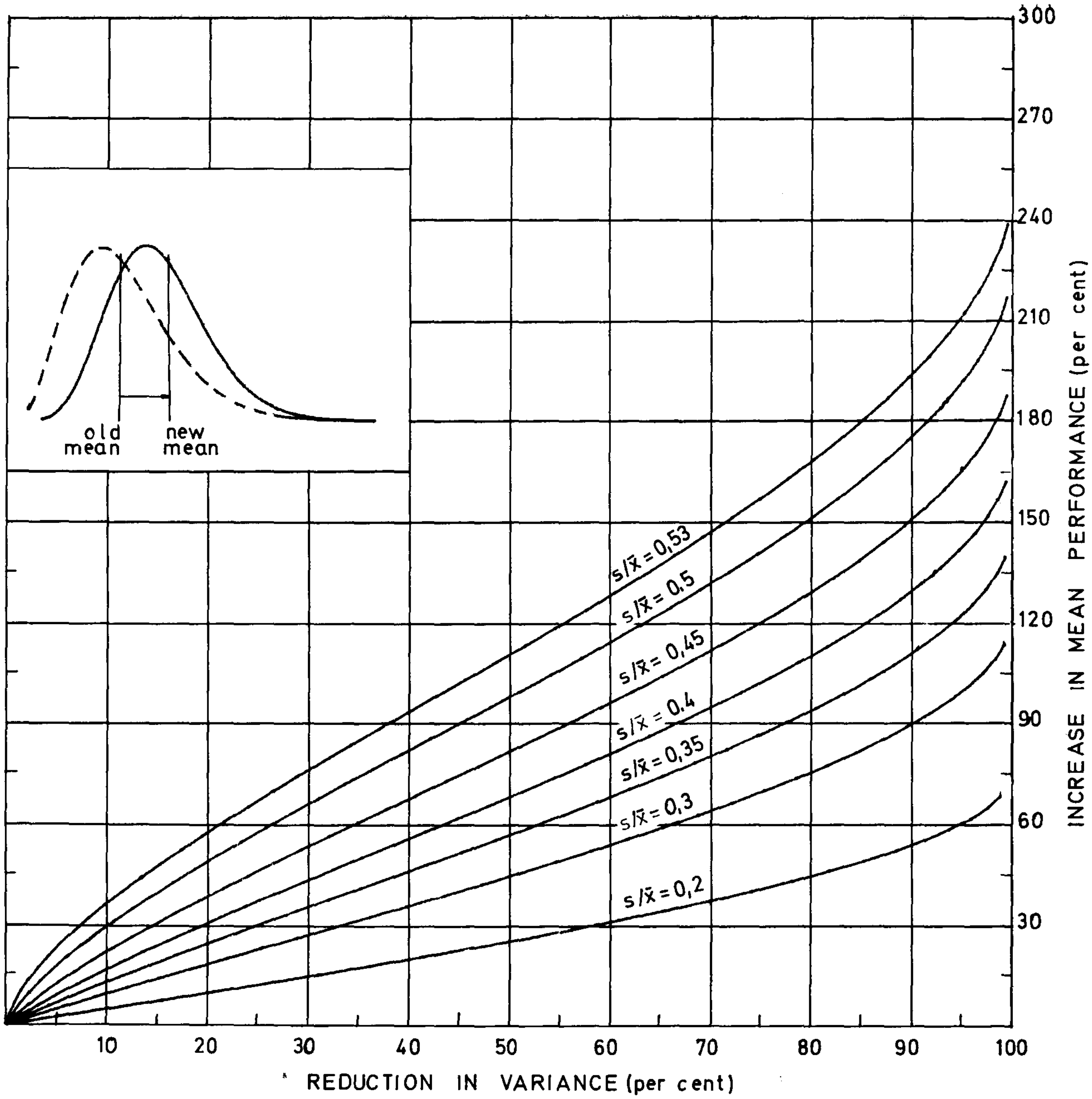

Fig. 3—Theoretical effect of reduction in variance on meanif performance has a '$\sqrt{x}$-normal' distribution

on one mine over a period of nine weeks. Although interest lay primarily in the effect of "human" variables on stoping performance, it was necessary to make due allowance for the contribution of "technical" factors relating to stope conditions and stope design. Data were therefore gathered on 36 variables divided into three groups, as follows:

Stope factors — Variables which described the conditions and design of a stope "before" the gang entered (7 variables).

Gang factors — Variables which described the composition of the gang (including boss boys) and the movement of men to and from the gang (20 variables).

Supervisory factors — Variables which related to miners, shift bosses and mine overseers (9 variables).

A total of 342 usable "observations" were obtained, each observation consisting of a set of figures for all 36 variables for one gang for one week. The criterion of work performance was "tons trammed per week", frequently referred to in the remainder of this paper as "tons".

Two computerised techniques developed by the Institute for Social Research at the University of Michigan were used in conjunction for the analysis. These were AID[1] (Automatic Interaction Detector) and MCA[2] (Multiple Classification Analysis).

The general strategy was to establish first, by means of AID, which of the stope variables best explained the total variance, which of the gang variables best explained the remaining variance, and which of the supervisory variables best explained the variance unaccounted for by stope and gang variables. Next, interactions between the selected variables were allowed for by constructing a single variable for the stope factors, another for the gang factors and a third for the supervisory factors. Finally, MCA was used to establish to what extent these three compound factors accounted for the variance in the performance criteria.

AID ANALYSIS

Summary statistics for gang performance expressed in "tons" are given in Table I.

TABLE I

TONS TRAMMED PER GANG PER WEEK

N	Mean (tons)	Standard deviation	Standard error
342	558,2	246,9	13,4

Stope factors

The large standard deviation in Table I indicated the presence of considerable variance in the 342 observations. The AID program was used first to examine how the seven stope variables could best account for this variance and the results of the analysis are shown in the form of a "tree" in Fig. 4.

The tree reads from left to right. It shows that the AID program found that the best partition of the total variance in "tons" occurred by splitting the 342 observations into two subgroups on the basis of "access time". Observations from stopes with an access time of less than 30 minutes had a mean of 683,9 tons per week, whereas observations from stopes with an access time of more than 30 minutes had a mean of only 433,9 tons per week. The program next examined the variance in each of these subgroups and found that "face length" was the best predictor in each case. The program continued the process of splitting groups in this way until at least one of the following constraints caused the process to terminate:

(i) The variance in the group to be split was less than 0,1 per cent of the total variance.
(ii) The split of a group would have reduced the unexplained variance by less than 0,1 per cent.
(iii) A split would have resulted in a subgroup of less than 20 observations.

Fig. 4 shows that of the seven stope variables four were identified as contributing towards the variance in "tons" as follows:

VARIABLES IDENTIFIED	VARIABLES NOT IDENTIFIED
1. Working places	5. Dip
2. Access time	6. Reef mined
3. Face length	7. Whether gang was stoping only, or *both* stoping and developing.
4. Stoping method	

An examination of the results showed interactions between the selected variables. For example, although in general "tons" increased with an increase in face length this was not so for stopes with an access time of less than 30 minutes. With face lengths of less than 61 metres, the normal disadvantages associated with short face lengths appeared to be largely offset by shorter access time. On the other hand, the advantage of face lengths exceeding 140 metres appeared to be offset somewhat if access time exceeded 30 minutes.

Interactions of this nature between the selected variables indicated that the analysis of each variable in isolation would not be meaningful, and that the effects of interacting variables would have to be taken into account. The four selected variables were therefore combined into a single compound variable, named "stope factors" with 11 categories corresponding to the final groups obtained in the analysis. These groups are tagged 1 to 11 in Fig. 4.

Thus, based on 24 observations, highest production (mean of 901,1 tons per week) occurred in stopes having an access time of less than 30 minutes, a face length exceeding 140 metres and using the rolling-pile method of stoping (tag 1 in Fig. 4). At the other extreme, lowest production (mean of 304,1 tons per week, based on 60 observations) occurred in stopes having an access time of more than 30 minutes and a face length of less than 61 metres (tag 11). Other combinations of access time, face length, stoping method, and number of working places were associated with production levels between these two extremes.

The mean production shown for each group in Fig. 4 indicated the *best prediction* that could have been made about the performance of gangs described in terms of their stope variables. The AID program next compared these predictions with each observation of performance and calculated the unexpected "residuals". Thus if a gang which met the conditions specified for tag 1 (Fig. 4) had an observed production of 950,5 tons instead of 901,1 tons as predicted in Fig. 4, then the unexpected "residual" for this gang would have been

$950,5 - 901,1 = +49,4$ tons

In other words, its production for this week was 49,4 tons higher than would have been predicted from the stope factors.

As expected, the mean residual for all gang was close to zero (Table II) although the residuals ranged from less than -200 to more than $+150$ tons per week. The standard deviation was reduced in comparison with the original value in Table I, but it was still sufficiently large to show that considerable variance remained unexplained by the stope factors.

TABLE II

RESIDUAL 'TONS' AFTER ALLOWING FOR STOPE FACTORS

N	Mean residual (tons)	Standard deviation	Standard error
341	$-1{,}29$	173,5	9,4

Gang factors

Table II shows the variance remaining in stope performance after allowing for the stope factors. The AID program was next applied to examine which of the 20 variables relating to the stoping gangs could best account for this residual variance, and the resulting tree is shown in Fig. 5. Nine of the 20 variables were

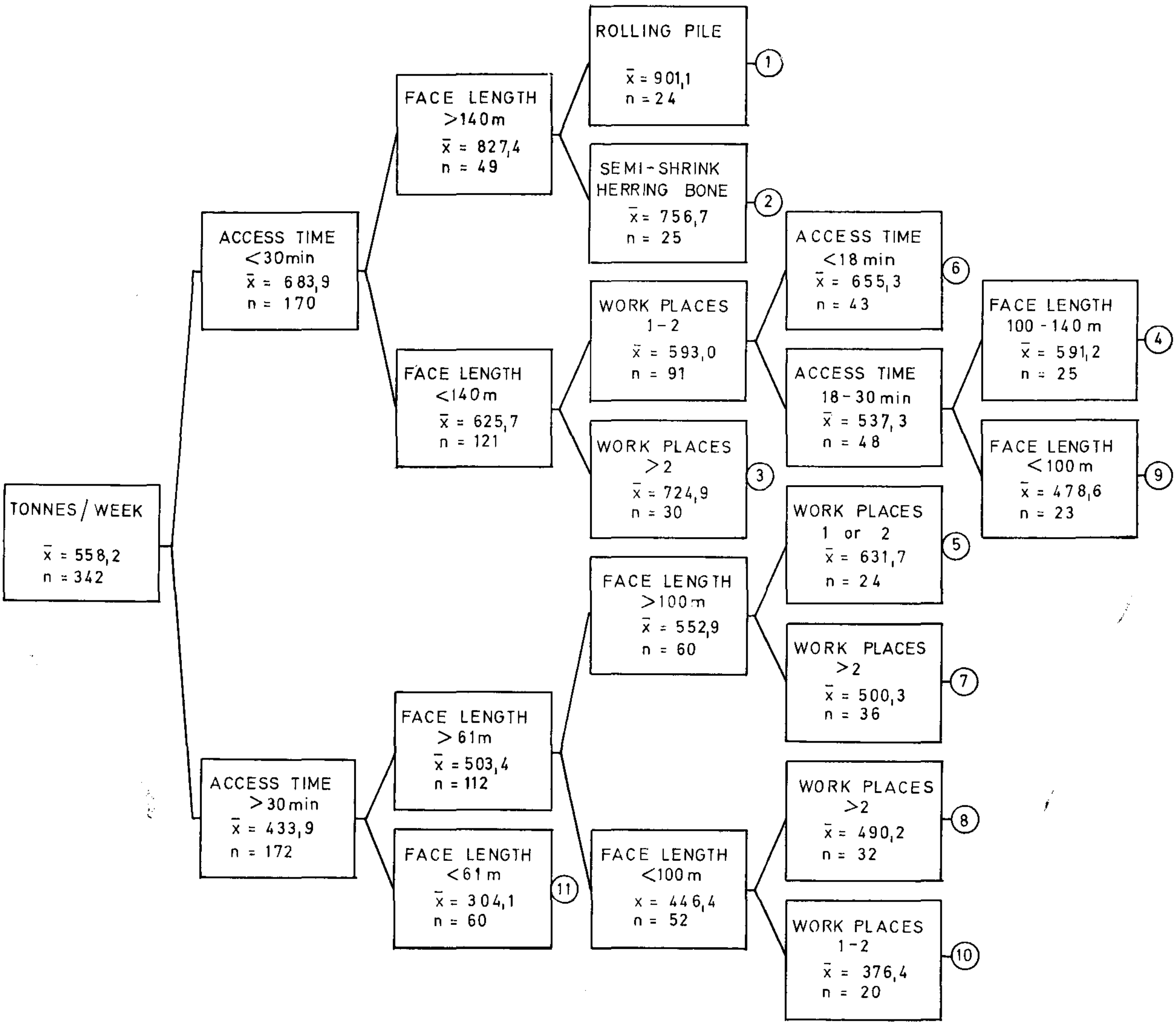

Fig. 4—Tree showing interactions between stope factors and 'tons'

identified as the best predictors of the residual "tons" as follows:

VARIABLES IDENTIFIED	VARIABLES NOT IDENTIFIED
1. Gang strength	10. Boss boys — Tswana*
2. Gang homogeneity (predominance of one ethnic group)	11. Boss boys—Shangaan*
3. Boss boys (number in gang)	12. Boss boys—Malawi*
4. Boss boys—*X*hosa*	13. Boss boys joining
5. Boss boys—Basotho*	14. Boss boys leaving
6. Gang—Tswana*	15. Boss boys absent
7. Gang—Shangaan*	16. Gang—Malawi*
8. Gang—Basotho*	17. Gang—*X*hosa*
9. Gang—Others	18. Gang joining (during week)
	19. Gang leaving (during week)
	20. Gang absent (during week)

As in the case of the stope factors, the selected gang variables were found to interact with one another, and to allow for these effects the nine selected variables were combined into a single compound variable named "gang factors". This variable had 11 categories corresponding to the final groups obtained with the AID analysis. These groups are tagged 1 to 11 in Fig. 5. For example, the group tagged 2 in Fig. 5 shows that, based on 33 observations, gangs with less than 8 per cent or more than 12 per cent of Basotho boss boys, 8 to 12 per cent Xhosa boss boys, and less than 8 per cent of men from the miscellaneous ethnic groups, had a mean production which was 129,1 tons *higher* than would have been predicted from the "stope factors" for these gangs.

The AID program next compared the residual actually occurring in each observation with those which would have been predicted on the basis of the grouping in Fig. 5, and a new set of residuals was calculated. For example, a gang with the conditions described by tag 3 in Fig. 5 would be expected to have had a residual of +66,6 tons. If the actual residual for such a gang was +50,0 tons then the new residual for that week which was unexplained after allowing for the gang factors was 50,0 − 66,6 = −16,6 tons.

*Proportion of this ethnic group

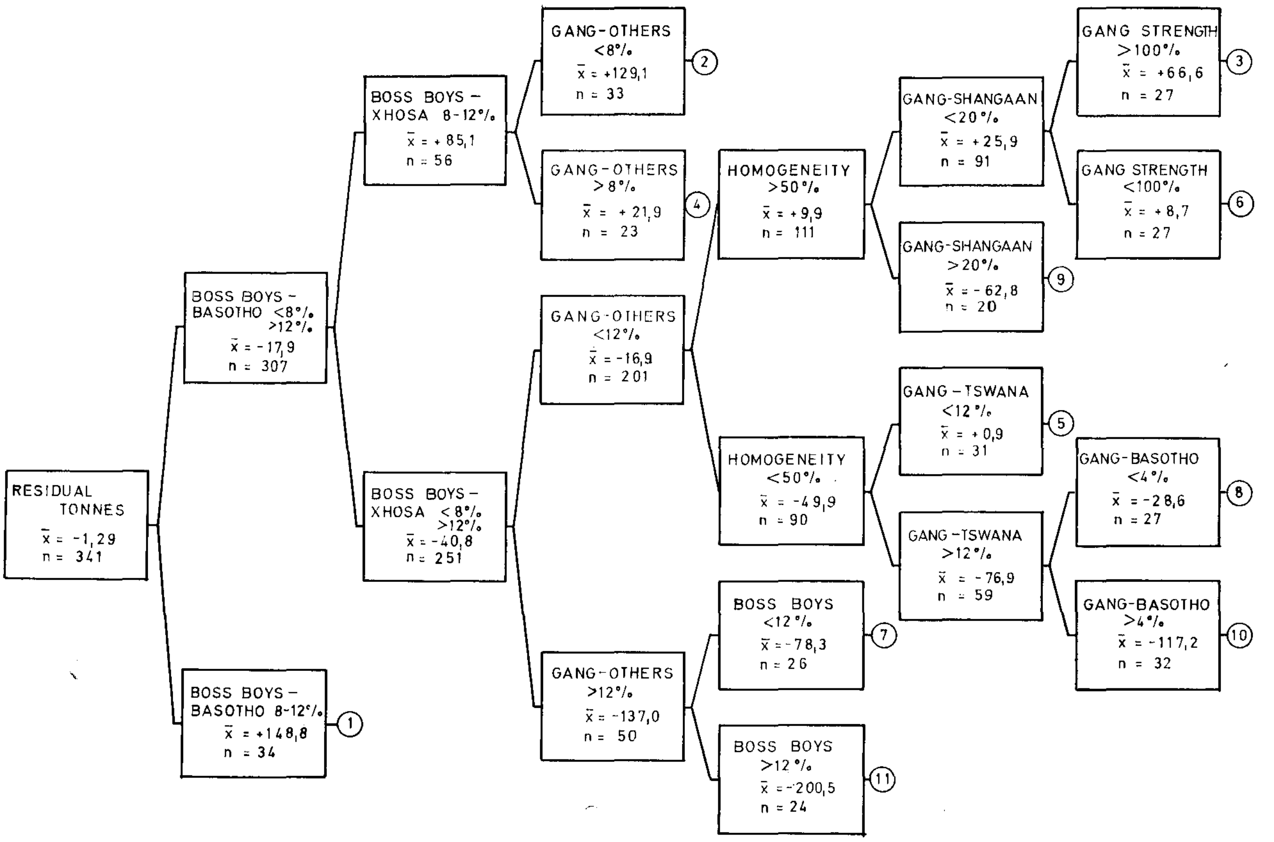

Fig. 5—Tree showing interactions between gang factors and residual 'tons'

The summary statistics for this new residual are shown in Table III. Although the standard deviation was further reduced in comparison with Tables I and II, there was still a good deal of unexplained variance.

TABLE III

RESIDUAL 'TONS' AFTER ALLOWING FOR STOPE AND GANG FACTORS

N*	Mean residual (x)	Standard deviation	Standard error
334	−0,93	145,3	8,0

Supervisory factors

The final step in the AID analysis was to determine which of the nine variables relating to the supervision of the gang could best explain the variance remaining after both stope factors and gang factors had been taken into account. The resulting tree is shown in Fig. 6. Six of the nine supervisory variables were found to be relevant as follows:

VARIABLES IDENTIFIED

1. Miner's shifts (number of shifts normal miner present during week)
2. Miner's experience (total)
3. Shift boss's experience (total)
4. Supervisors' total experience (combined *total* experience of miner, shift boss and mine overseer)
5. Number of different miners in charge of gang during week)

VARIABLES NOT IDENTIFIED

6. Mine overseer's presence (normal or relief)
7. Supervisor's mine experience (combined experience of miner, shift boss and mine overseer on this mine)
8. Whether normal shift boss or relief
9. Mine overseer's experience on this mine

*The lower N was due to the program's omission of a few observations as the result of missing data.

To allow for interactions between the six selected variables they were combined into a single compound variable named 'supervisory factors' having ten categories corresponding to the final groups identified by the AID analysis. These groups are tagged 1 to 10 in Fig. 6. For example, the 44 observations in the group tagged 7 referred to gangs with miners who had a total mining experience exceeding 3 600 shifts and who were present for the full 6 shifts in the week. The production of these gangs was 23,0 tons *below* the overall mean.

MCA ANALYSIS

It has been described how the AID program was used to examine the relationship on one mine between 36 different variables and stope performance as measured by 'tons'. The analysis identified 19 of the variables as relevant but to allow for interactions between them, they were compressed into three compound variables and named 'stope factors', 'gang factors' and 'supervisory factors', respectively.

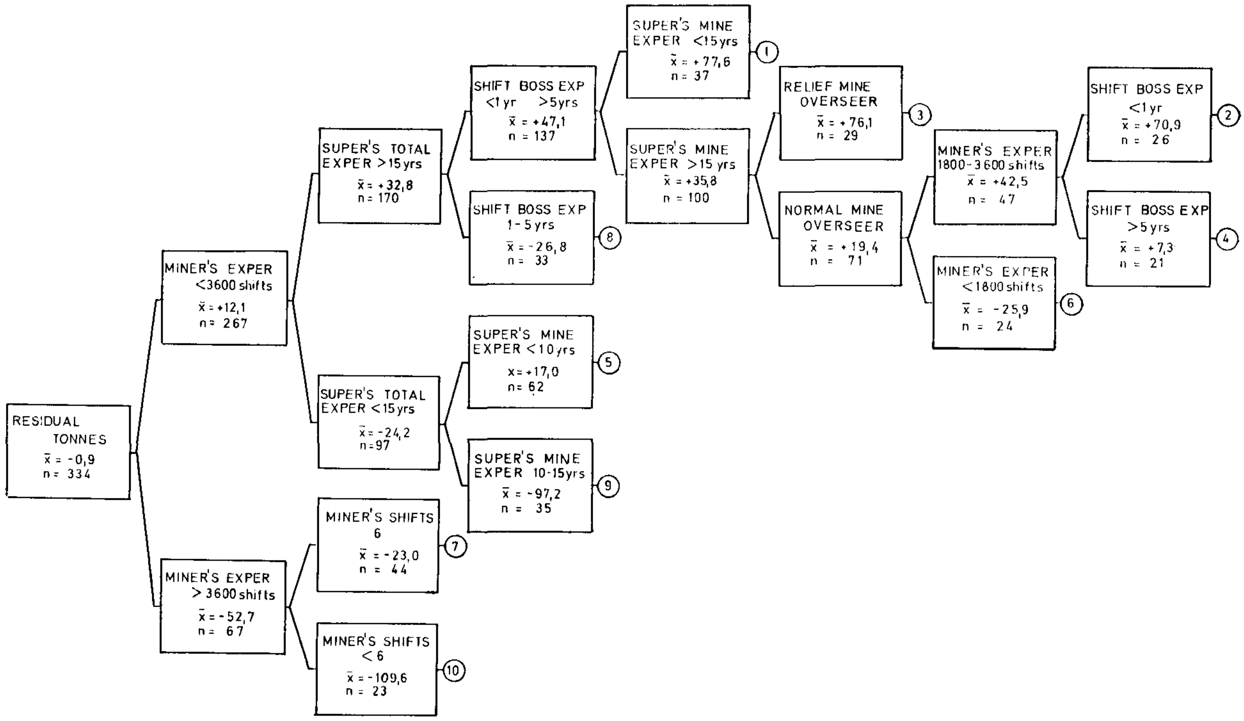

Fig. 6—Tree showing interactions between supervisory factors and residual 'tons'

The next step was to establish to what extent these three groups of variables, taken individually or together could account for the total variance in the observed production. In so doing, allowance was made for the possibility that the three group factors may themselves have been correlated. For example, some favourable supervisory consideration, such as the experience of mine overseers and shift bosses, may have resulted in favourable stope design or favourable gang arrangements. The MCA program was used for this step.

MCA assesses how several predictors simultaneously determine a dependent variable. It assumes, for example, that each gang's performance in 'tons' is composed of a series of additive 'coefficients' (deviations from the grand mean) corresponding to the particular category to which the gang belongs for each predictor.

Thus $x_1 = X + a_1 + b_1 + c_1 + e_1$

where x_1 = mean tons for gang 1.

X = grand mean tons for all gangs.

a_1 = coefficient showing adjustment to be made to X as a result of the category to which gang 1 belongs for 'stope factors' (Table IV).

b_1 = coefficient similar to a_1 but adjusting for 'gang factors' (Table V).

c_1 = coefficient similar to a_1 but adjusting for 'supervisory factors' (Table VI).

e_1 = remaining 'error' unaccounted for in gang 1.

In calculating the adjustment coefficients, the program

TABLE IV

MCA COEFFICIENTS FOR 'STOPE FACTORS'

Compound variable 'stope factors'			Original variables			
Code	N	Coefficient (tons)	Access time (minutes)	Face length (metres)	Working places	*Stoping method
1	19	+251,4	< 30	> 140		1
2	25	+156,5	< 30	> 140		2 and 3
3	30	+128,1	< 30	< 140	3 or more	
4	25	+ 82,9	18-30	100-140	1 and 2	
5	24	+ 71,4	> 30	> 100	1 & 3 or more	
6	43	+ 64,3	< 18	< 140	1 and 2	
7	33	− 14,7	> 30	> 100	2	
8	32	− 52,7	> 30	61-100	3 or more	
9	23	− 68,8	18-30	< 100	1 and 2	
10	20	−163,1	> 30	61-100	1 and 2	
11	56	−215,4	> 30	< 61		

*Stoping method 1 = Rolling-pile
2 = Semi-shrinkage
3 = Herring bone

makes due allowance for correlations between the predictors, so that the coefficients generated for a particular predictor may be considered as an estimate of the effects of that predictor alone.

A total of 330 of the original 'tons' observations were usable for the MCA analysis. The grand mean for these observations was 548,8 tons per week (standard deviation=226,2).

Stope factors

Table IV shows the 'coefficients' produced by the MCA program for each of the 11 categories of the compound variable 'stope factors'. The codes 1 to 11 in Table IV correspond to the groups identified by tags 1 to 11 in Fig. 4.

Thus, based on the 19 observations in category 1 (code 1), if a gang worked in a stope with an access time of less than 30 minutes a face length of more than 140 metres, and using the rolling-pile method, its production was predicted to be 251,4 tons *above* the grand mean for all stopes, that is 548,8+251,4=800,2 tons per week. On the other hand, if the stope had an access time exceeding 30 minutes and a face length of less than 61 metres (code 11), the gang's performance would be expected to be 215,4 tons *below* average, that is 548,8−215,4=333,4 tons per week. These values are different from those observed in Fig. 4 because the MCA program made appropriate adjustments to isolate the effect of 'stope factors' from 'gang factors' and 'supervisory factors'.

Reading down the 'access time' column in Table IV shows that, in general, short access time was linked with high production. However, interactions with other variables tended to reduce the advantage of short access time. Thus gangs falling in code 9 had an access time of only 18 to 30 minutes but production was predicted at 68,8 tons below average, apparently due to their having a total face length of less than 100 metres spread over only one or two working places.

Similarly, reading down the 'face length' column shows that long face lengths tended to be associated with high production although this advantage was offset, for example, by long access time (codes 5 and 7). The effect of different numbers of working places was less clear. In general, the number of working places seemed to be important only if face length was between 61 and 140 metres. Under these conditions it was preferable to have three or more working places rather than only one or two. Even under the unfavourable conditions of rather short face length (61 to 100 metres), and long access time (over 30 minutes), it was better to have at least three working places rather than one or two (codes 8 and 10).

Different methods of stoping appeared to be relevant to the level of production only in the case of stopes with short access times and having faces exceeding 140 metres in length (codes 1 and 2).

It will be noted that very small differences in performance were predicted for certain codes. For example, the coefficients for gangs falling under codes 4, 5 and 6 were very alike. The rank order of the categories in such cases must be treated with reserve.

Gang factors

Table V shows the 'coefficients' produced by the MCA program for each of the 11 categories of the compound variable 'gang factors'. The codes 1 to 11 in Table V correspond to the groups identified by tags 1 to 11 in Fig. 5.

Moderate proportions (8 to 12 per cent) of Basotho boss boys or Xhosa boss boys were associated with high production (codes 1, 2 and 4 in Table V). There was low production (codes 7 and 11) by gangs containing a high proportion (more than 12 per cent) of men from the miscellaneous ethnic groups (that is, other than Tswana, Shangaan, Malawi, Xhosa and Basotho). However, this effect seemed to be offset somewhat by a moderate proportion of Xhosa boss boys (code 4).

Gangs which were relatively homogeneous (that is, predominantly of one ethnic group) tended to be more productive if they were at or above full strength (code 3). Gang homogeneity seemed to be undesirable, however, if the gang included a large proportion of Shangaan (code 9).

Low proportions of Tswana and Basotho were better

TABLE V

MCA COEFFICIENTS FOR 'GANG FACTORS'

Compound variable 'gang factors'			Original variables (all per cent)								
Code	N	Coefficient (tons)	* Boss boy Basotho	* Boss boy Xhosa	Gang other	Homogeneity	Boss boys	Gang Shangaan	Gang Tswana	Gang strength	Gang Basotho
1	31	+147,7	8-12								
2	32	+133,2		8-12	< 8						
3	26	+ 48,8			< 12	> 50		< 20		> 100	
4	23	+ 28,3		8-12	> 8						
5	31	+ 9,8			< 12	< 50			< 12		
6	60	− 11,8			< 12	> 50		< 20		< 100	
7	26	− 26,7			> 12		< 12				
8	27	− 44,7			< 12	< 50			> 12		< 4
9	18	− 56,9			< 12	> 50		> 20			
10	32	− 99,7			< 12	< 50			> 12		> 4
11	24	−176,6			> 12		> 12				

*The large majority of gangs outside the 8-12 per cent range on these variables, were less than 8 per cent.

TABLE VI

MCA COEFFICIENTS FOR 'SUPERVISORY FACTORS'

Compound variable 'supervisory factors'			Original variables					
Code	N	Coefficient (tons)	* Miner's shifts	Miner's experience (shifts)	Shift boss's experience (years)	Mine overseer's presence	Supervisors' mine experience (years)	Supervisors' total experience (years)
1	37	+128,5		< 3600	< 1 > 5		< 15	> 15
2	26	+ 87,4	6	1800-3600	< 1	Normal	> 15	> 15
3	29	+ 39,8		< 3600	< 1 > 5	Relief	> 15	> 15
4	21	+ 13,8	6	1800-3600	> 5	Normal	> 15	> 15
5	62	− 1,9		< 3600			< 10	< 15
6	24	− 8,5	< 6	< 1800	< 1 > 5	Normal	> 15	> 15
7	44	− 21,8	6	> 3600				
8	33	− 49,8		< 3600	1-5			> 15
9	35	− 82,7		< 3600			10-15	< 15
10	23	−108,2	< 6	> 3600				

*Number of shifts normal miner present during week.

than high proportions (codes 5, 8 and 10). A high proportion of boss boys was a disadvantage only when the gangs contained large proportions from the miscellaneous ethnic groups (code 11).

Supervisory factors

Table VI shows the MCA 'coefficients' for the ten categories of the compound variable 'supervisory factors'. These categories correspond to the groups tagged 1 to 10 in Fig. 6.

The influence of two of the original variables are shown clearly. Absence of the normal miner was associated with low performance (codes 6 and 10), and miners with less than 3 600 shifts of mining experience were associated with higher production than were miners with longer experience (codes 2, 4 and 7 for full attendance, codes 6 and 10 with absentees). This appeared to show that the younger miners were either performing or being placed more effectively than the older men.

The influence of the other variables was less clear. In general, if the combined mining experience of miner, shift boss and mine overseer was less than 15 years, production tended to be low (codes 5 and 9) and this was particularly so if this experience had been confined to this mine (code 9).

Inexperienced shift bosses (less than one year as a shift boss) and more experienced shift bosses (more than five years) were linked with higher producing gangs (codes 1 to 4 and 6). Also in one category the presence of a relieving mine overseer seemed to have a beneficial effect (compare codes 3 and 6). However, as is pointed out later, care must be taken in generalizing from the findings relating to shift bosses and mine overseers because the number of individuals involved was much less than the number of gangs.

Joint effects

The coefficients given in Tables IV to VI are additive and the effect on mean production of a combination of different categories of the stope, gang and supervisory factors can therefore be estimated easily. For example, if a gang could have been arranged in such a way that code 1 for each of the three factors was applicable, then it can be predicted that production would have been increased above the grand mean (548,8 tons) to a value of $548{,}8+251{,}4+147{,}7+128{,}5=1\ 076{,}4$ tons per week.

Similarly, it is clear that the advantages of favourable stope conditions, for example, could easily have been offset by unfavourable gang and supervisory arrangements. Thus, taking the extreme case of a gang in category 1 on stope factors but in category 11 on gang factors and category 10 on supervisory factors, it can be predicted that its production would have been $548{,}8+251{,}4-176{,}6-108{,}2=515{,}4$ tons per week.

Table VII shows the variance which was explained by the stope factors, gang factors and supervisory factors individually and jointly. The results of the appropriate F tests showed that the findings were all highly significant (the probability of these findings having occurred by chance was less than one in a thousand).

Stope factors alone accounted for 47,8 per cent of the variance, gang factors alone for 23,1 per cent and supervisory factors alone for 23,5 per cent. The sum of these percentages does *not* reflect the total variance explained, however, because the three factors were correlated and hence each one accounted for some of the variance explained also by the other two.

The analysis showed that the three group factors taken together explained 65,7 per cent of the total variance (corresponding to a correlation $R=0{,}81$) and that gang and supervisory factors *together* explained 40,4 per cent of the total variance ($R=0{,}68$). Thus the contribution of the stope factors over and above the gang and supervisory factors was only 65,7 − 40,4 = 25,3 per cent of the variance.

Whereas 47,8 per cent of the variance could be predicted from stope factors alone, nearly half of this could also have been predicted from the gang and supervisory factors. In other words, the "technical" stope considerations were not independent of the "human factors". This finding reveals clearly the inadequacy of regarding "technical" and "human" factors as independent considerations.

Stability of findings

To assess the stability of the findings (that is whether or not another set of observations would have yielded similar results) the observations were divided into two approximately equal halves on a random basis. An MCA analysis was then performed separately on each half, working on the hypothesis that if the findings were stable, the results for each half and for both halves together would have been similar. As shown in Table VIII, the parameters for the halves did not differ markedly from those for the whole group, indicating that the overall parameters were reasonably stable.

DISCUSSION

The analysis has shown how the different variables included in the investigation could best explain the variance in the 342 weekly observations of the performance of stoping gangs. In this sense the findings are correct and accurate. However, in interpreting the findings it is necessary to bear the following considerations in mind:

Possible misidentification of predictors

A total of 36 variables were selected initially on theoretical grounds as likely to be relevant to stope performance, and the analysis determined which of these variables could best predict stoping performance. Nineteen were identified as predictors of "tons trammed per week".

Caution must be exercised in accepting the predictors identified, for two reasons. In the first place identification of a predictor does not confirm that it has been named correctly. For example, in Table V it was shown that an 8 to 12 per cent Basotho content among boss boys was associated with high production. Although this was true, the Basotho boss boys may not have been the *cause* of the high production. The finding may have occurred as the result of the observations having come from gangs which had some other characteristic in common *as well as* this proportion of Basotho boss boys (for example, the stopers may all have been particularly proficient). This other characteristic, which was not included in the variables examined, may have been the real cause of the high production. However, bearing in mind that nine was the maximum number of observations for any one gang, and that no group much smaller than 20 observations was permitted to be isolated in the analysis, the possibility of this type of occurrence was reduced. Thus, in the above example the conclusion about Basotho boss boys was based on 31 observations which must have been drawn from at least four stopes. It would seem to have been an unlikely coincidence that these four (or more) gangs were correctly identified as high producers, but on the basis of their particular proportion of Basotho boss boys instead of on the basis of some other variable. The possibility of such errors would nevertheless be diminished by analyzing a larger number of observations and increasing the minimum permissible number in the final groups.

A second consideration is the extent to which one variable may have "substituted" for another during the analysis, resulting in the rejection of the true predictor as less relevant, and the incorrect selection of the other. A good example of this possibility is shown in Fig. 5. In the third stage of the tree, two splits were made on the variable "gang others" (the proportion of men in the gang from the miscellaneous ethnic groups). The next best predictor in one of these cases was "gang homogeneity" (the extent to which the men in the gang were dominantly of one ethnic group) but the AID analysis found "gang others" to be the marginally better predictor. Clearly these two variables are related, high "gang others" implying low "gang homogeneity" but not necessarily vice versa. In this case, despite the selection of "gang others" as the relevant predictor, it may not have been the presence of certain minority ethnic groups but the absence of homogeneity which was the true characteristic identified. The avoidance of mis-

TABLE VII

VARIANCE EXPLAINED BY STOPE, GANG AND SUPERVISORY FACTORS

Variance explained		F test	
by	per cent	F	p
Stope factors	47,8	29,2	< 0,001
Gang factors	23,1	9,6	< 0,001
Supervisory factors	23,5	11,0	< 0,001
All three (R^2)	65,7	22,7	< 0,001
Gang and supervisory (R^2)	40,4	12,0	< 0,001
Stope, over and above gang and supervisory	25,3	21,7	< 0,001

TABLE VIII
STABILITY OF OVERALL FINDINGS

Parameter		First half (N=167)	Second half (N=163)	Both halves (N=330)
Mean (tons)		543,0	552,7	547,8
Standard deviation		229,9	223,0	226,2
Variance explained by	Stope factors	52,5%	43,9%	47,8%
	Gang factors	23,1%	27,1%	23,1%
	Supervisory factors	26,1%	24,0%	23,5%
	All three groups (R^2)	69,1%	65,5%	65,7%

identification of variables in this way requires a careful assessment of the relative merits of the variables included in the analysis and the omission of those which substitute for others.

Generality of findings

There is no particular interest in explaining only the 342 observations included in this study. It is more important to know to what extent the findings may be accepted as typical of stoping performance on this mine and on other mines. However, any attempt to generalize the findings beyond the 342 observations should take the following considerations into account:

(i) The findings are meaningful, even for this mine, only if the number of observations was sufficient to represent typical effects of the variables. A sufficient number of observations is particularly important for an AID analysis, as the number remaining in each group decreases rapidly as the program proceeds. The final groups in Fig. 4 to 6 contained a mean of only 32 observations each and this is a comparatively small number on which to base important conclusions about the relevant variables. A better number would be of the order of 100. This would require about 1 000 initial observations of stoping performance, or more if additional predictors were included in the analysis. A larger number of observations in each category would permit a more stable identification of their relative merits.

(ii) Similarly, since each shift boss and mine overseer had several gangs under his control, the number of mine overseers and shift bosses included in the analysis was much smaller than the number of gangs. Hence the findings relating to supervisory variables may be based on too few men to be reliable.

(iii) Findings of this type are useful only if they remain relatively stable over time. For example, certain gang factors may be pertinent only with the particular ethnic composition of the labour force available on the mine at the time of the study. If this should change over time, changes in the appropriate predictors may be expected.

(iv) Numerous variables not included in this study would have to be taken into account before the findings could be extrapolated to other mines. For example, unusual features of this mine, or of its management, may have resulted in the identification of a unique set of predictors. Similarly, such matters as the influence of mining Groups, geographical location, and age and size of the mine would have to be allowed for before findings could be generalized across mines. However, the utility of broad generalizations is open to question. A specific analysis for an individual mine would be much more useful in identifying variables which can be manipulated to advantage by management on that mine.

Unexplained variance

Although the variables selected for inclusion in the analysis succeeded in together explaining 66 per cent of the variance in the 'tons' criterion, a large proportion of the variance was not accounted for.

The reasons for this unexplained variance were probably of two kinds. Firstly, certain important variables may not have been included in the analysis. For example, environmental considerations such as "stoping width" or "wet bulb temperature" were not taken into account. Similarly, the variables relating to the gang did not include measures of the men's physical and mental capacities, nor of their competence, experience and attitudes towards their work. At the supervisory level, no assessments were made of the competence of miners, shift bosses or mine overseers, nor of their "styles" of managing their sections. All of these variables would be expected to have some effect on gang performance, and if it had been possible to include them they should have further reduced the unexplained variance. There are problems, of course, in gathering reliable data relating to several of these variables.

The second source of unexplained variance may be attributed to "errors "in measurement and records, and to fluctuations in performance which occurred purely by chance in an unpredictable manner. Inaccuracies were particularly likely in the case of the estimates of "tons trammed per week". With any analysis of this type, a residual of such error variance would thus be expected to occur.

CONCLUSIONS

This study has shown that the complex interactions between a large number of human variables can be analysed with fairly high precision from easily gathered survey data. The analysis explained a considerable proportion (66 per cent) of the variance in the performance of stoping gangs on one mine and showed that about two thirds of this could be predicted from human variables in the form of "gang" and "supervisory" factors.

The analysis also emphasized that there were interrelationships not only among the "human" variables and among the "technical" variables but also between these two groups of variables.

If it is possible to explain such a large proportion of the variance in stoping performance in terms of human factors, it should be feasible to introduce organizational changes which would reduce the variance by at least 5 to 15 per cent. As shown previously, a reduction of this magnitude should effect an improvement in the mean performance of stoping gangs of the order of 10 per cent or more.

It seems likely that this type of analysis should be more useful if applied on particular mines to identify features which can be optimized on those mines, rather than by attempting to generalize across mines.

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