Human factors in stope productivity —a field experiment

by K. F. MAUER*, M.A. (Visitor)
and A. C. LAWRENCE*, B.Econ., D.Com. (Member)

SYNOPSIS

An experiment in which three human variables were manipulated in eight stopes was conducted in a gold mine over a period of roughly six months. The three variables, which each had two levels, concerned the degree of movement from gangs, the quality of the Bantu production supervisors, and the extent to which gangs were composed of a single ethnic group (Malawians). Time was included as a variable with three levels in the analysis of the findings. On the average, stable gangs produced 12 per cent more than gangs with a high percentage of transfers, gangs with better production supervisors were more successful by nearly 9 per cent than those with poorer production supervisors, and homogeneous gangs were more productive than heterogeneous ones by as much as 15 per cent. In addition, it was found that a number of the variables exercised a joint influence on stope productivity and that the effects of the variables were accentuated by the length of time they had been in operation.

SAMEVATTING

'n Eksperiment waarin drie menslike faktore in agt afbouplekke oor 'n tydperk van ongeveer ses maande gemanipuleer is, is in 'n goudmyn uitgevoer. Die drie veranderlikes, elk met twee vlakke, het gehandel oor die mate waarin daar beweging van mense uit werkspanne was, die gehalte van Bantoe-produksietoesighouers en die mate waarin werkspanne uit 'n enkele etniese groep (Malawiërs) bestaan het. Tyd is as 'n veranderlike met drie vlakke by die ontleidings van die bevindinge ingesluit. Stabiele spanne het gemiddeld 12 persent beter geproduseer as dié met 'n groot persentasie verplasings, spanne met beter produksietoesighouers het ongeveer 9 persent beter gepresteer as dié met swakker produksietoesighouers en homogene werkspanne was soveel as 15 persent meer produktief as heterogene spanne. Daarbenewens is ook bevind dat 'n aantal veranderlikes 'n gemeenskaplike invloed uitoefen op afbouplek-produktiwiteit en dat die uitwerking van die veranderlikes wat gebruik is, beklemtoon is deur die tydsduur waarin hulle in werking was.

INTRODUCTION

A good deal of research has revealed the presence of significant correlation between various human factors and work performance. Although such findings are useful in identifying those human factors that play a part in work performance, two considerations limit their practical utility. Firstly, the cause and effect relationship is not always clear. For example, does an authoritarian style of management result in low production as is often suggested, or does low performance result in an authoritarian style? Secondly, even if the causal direction can be correctly inferred, it is seldom clear to what extent other considerations will interfere with the application of the findings in practice. For example, high turnover of labour may be shown to result in low production, but it does not follow that adequate steps can be taken in practice to reduce turnover and thereby raise production.

The solution to the first problem lies in a research design that experiments with or manipulates, in a controlled manner, those variables thought to cause changes in production (the *independent* variables), and that assesses the effect of these manipulations on some measure of work performance (the *dependent* variable or *criterion*). An experimental design also solves the second problem, provided that the experiment is conducted in a natural setting in the *field*, that is, under actual working conditions rather than artificial or laboratory conditions.

This paper describes a field experiment that examined the effects of three human factors over a period of time on the productivity of eight stoping gangs in a gold mine.

WORK PERFORMANCE CRITERION

The choice of a criterion for the assessment of stope productivity posed certain problems. While it was generally agreed that the most adequate measure of stoping performance would be one based on monthly survey measurements, the use of such figures would have required the extension of the experiment over a considerable period of time to ensure sufficient observations for statistical evaluation. A proposal to conduct the experiment over a period of a year or more was likely to have met with resistance from the participants. Even while people might initially have been agreeable, interest in the research might have lagged, and stopes included at the outset might have become worked out before valid conclusions could have been reached.

A measure of stoping productivity that was readily available in the mine was *tons trammed per stope per week*. Although clearly not as reliable as survey measurements, it appeared that these figures would provide an adequate criterion for the purposes of the experiment.

INDEPENDENT VARIABLES

The four independent variables included 'time' (with three levels) and three human factors (each with two levels).

The latter were selected from among those that had been shown to be related to gang performance in

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

previous exploratory research similar to that described by Lawrence[1], and that could be manipulated with comparative ease in the mine. The aim of the experiment was to determine the extent to which changes in these four variables resulted in changes in the criterion.

Time

The experiment was conducted over a period of about six months, and for the analysis this was divided into three periods of approximately equal length. These three levels are referred to as *time 1*, *time 2*, and *time 3*.

Ethnic composition of stoping gangs

The proportion of Malawian workers employed in the mine was considerably greater than that of any other tribe. To test the hypothesis that ethnic homogeneity was conducive to higher productivity, the ethnic structures of four of the eight gangs involved in the experiment were changed so that Malawians were in the majority. The Malawian content of these gangs was raised from about 35 per cent to more than 50 per cent. These gangs were then referred to as the *homogeneous* gangs and constituted Level 1 of this variable.

The ethnic structure of the other four gangs was changed so that no one tribe exceeded more than 30 per cent of the gang complement. These gangs formed Level 2 and were referred to as the *heterogeneous* gangs.

Mobility of men in stoping gangs

Mobility of mineworkers from one gang to another as the result of transfers was fairly considerable in the mine. Exploratory analysis suggested that movement of less than 4 per cent per week occurred in only 37 per cent of gangs, that in 54 per cent of gangs movement was between 4 and 9 per cent, and that the remaining 9 per cent of gangs had movement in excess of 9 per cent.

To test the hypothesis that excessive mobility had a detrimental effect on productivity, at least 12 per cent of the men in the gangs were transferred every week from four of the experimental gangs. Once a man had been transferred from a gang, he was not allowed to return to that gang. These gangs were called *mobile* and constituted Level 1 of this variable.

To limit the extent to which miners and shiftbosses were likely to resent the experimental treatments, these men decided which Bantu were to be transferred from the mobile gangs each week. Transfers were not allowed in the other four gangs, and the only movement was that resulting from the expiry of individual contracts. This never amounted to more than 4 per cent per week during the course of the experiment. These gangs were called the *stable* gangs and formed Level 2 of this variable.

Quality of supervision of stoping gangs

In the preceding exploratory study it had been found that a number of variables associated with Bantu production supervisors bore a relationship to stope production. It was therefore decided to include a factor related to the quality of Bantu supervision in gangs. A schedule[2] designed to assess the on-the-job performance of Bantu production supervisors was employed for this purpose. The schedule contained 52 items, which constituted four scales related to job performance. The scales were called *subordinate relations*, *production and communication*, *accident prevention*, *and physical job requirements*.

Miners and shift bosses assessed their Bantu production supervisors by means of the schedule, and for Level 1 of this variable four of the experimental gangs were allowed production supervisors who were graded as at least stanine 6 on the *production and communication* and the *subordinate relations* scales. This meant that the performance of the production supervisors in these gangs was equal to or better than that of the upper 40 per cent of Bantu production supervisors in general.

For Level 2 of this variable, the other four gangs were allocated Bantu production supervisors who were rated at stanine 4 or less. In other words, the performance of production supervisors in these gangs was no better than that of the lower 40 per cent of Bantu production supervisors in general.

EXPERIMENTAL DESIGN

To accommodate the four independent variables effectively, the eight stoping gangs were arranged in a conventional 2x2x2x3 factorial design[3, 4], as shown in Table I. Each cell of the table represents a different combination of the three human factors split over the three periods of time. For example, the first cell describes conditions $A_1B_1C_1$, which applied to one gang during the three time periods T_1, T_2, and T_3. Hence, the code $A_1B_1C_1T_1$ represents, for time period 1, the gang that was *homogeneous* (A_1), *stable* (B_1), and that had *production supervisors of better quality* (C_1).

For optimum results, the eight stopes in which the gangs worked should have been identical in all respects. Although the mine had roughly eighty production stopes at the time of the experiment, it was only with considerable difficulty that eight stopes could be found that approximated the experimental requirements. However, with the assistance of mine management, an attempt was made to ensure that the stopes were equivalent in terms of reef (all were situated in the Kimberley reef area), wet-bulb temperature, access time, face length, gang strength, ability of the responsible contractor, and stoping method (largely determined by the dip of the reef). In addition, it was necessary to ensure that the selected stopes had an expected life of at least six months.

A further consideration in the choice of stopes was that they should not be too close to one another. This was necessary to limit the extent to which various treatments might have contaminated one another, thereby confounding the results.

The stopes were also split across two shafts. To counteract the possible influences of different styles of management, the treatments were allocated in such a manner that two homogeneous gangs were situated at each shaft. A similar strategy was followed with regard to the mobile gangs. However, this was not possible with the Bantu supervision variable and, as a result, three gangs with 'better' supervision were situated at the same shaft and only one at the other.

Once the experiment had been set

up, it remained necessary to exercise constant control over the treatments imposed upon the various stopes to ensure that conditions were being met. A number of problems arose in the six-month period during which the experiment was being conducted. These problems related to fears on the part of shift bosses that production output would decrease, a pressure burst that occurred in one of the experimental stopes, difficulties experienced in maintaining homogeneous conditions associated with year-end labour intakes, and an observed falling-off of interest among mine personnel towards the end of the experiment.

ANALYSIS OF RESULTS

Approximately twenty weekly measures of tons trammed were obtained for each combination of factors in Table I. As historical information about weekly tons trammed was not available, the base level for each stope was estimated by the calcu-

TABLE I
ARRANGEMENT OF THE EXPERIMENTAL TREATMENTS IN THE EIGHT STOPES

Supervision	Time period	Homogeneous (A_1)		Heterogeneous (A_2)	
		Stable (B_1)	Mobile (B_2)	Stable (B_1)	Mobile (B_2)
Better supervision (C_1)	Time 1 (T_1)	$A_1B_1C_1T_1$	$A_1B_2C_1T_1$	$A_2B_1C_1T_1$	$A_2B_2C_1T_1$
	Time 2 (T_2)	$A_1B_1C_1T_2$	$A_1B_2C_1T_2$	$A_2B_1C_1T_2$	$A_2B_2C_1T_2$
	Time 3 (T_3)	$A_1B_1C_1T_3$	$A_1B_2C_1T_3$	$A_2B_1C_1T_3$	$A_2B_2C_1T_3$
Poorer supervision (C_2)	Time 1 (T_1)	$A_1B_1C_2T_1$	$A_1B_2C_2T_1$	$A_2B_1C_2T_1$	$A_2B_2C_2T_1$
	Time 2 (T_2)	$A_1B_1C_2T_2$	$A_1B_2C_2T_2$	$A_2B_1C_2T_2$	$A_2B_2C_2T_2$
	Time 3 (T_3)	$A_1B_1C_2T_3$	$A_1B_2C_2T_3$	$A_2B_1C_2T_3$	$A_2B_2C_2T_3$

TABLE II
DEVIATION (%) IN TONS TRAMMED PER WEEK FROM BASE LEVEL

Supervision	Time period	Homogeneous (A_1)		Heterogeneous (A_2)	
		Stable (B_1)	Mobile (B_2)	Stable (B_1)	Mobile (B_2)
Better supervision (C_1)	T_1	—5,39	18,57	—2,49	—9,22
	T_2	—13,24	38,41	3,91	—26,90
	T_3	11,21	46,53	1,35	—8,38
Poorer supervision (C_2)	T_1	2,29	0,44	11,17	—15,85
	T_2	16,52	—3,45	41,28	—43,89
	T_3	24,25	—21,68	27,99	—44,52

TABLE III
ANALYSIS OF VARIANCE FOR MEAN WEEKLY PERCENTAGE DEVIATIONS FOR TONS TRAMMED

	Source	Sum of squares	*df*	Variance estimate	*F*-Value	*p*
Main effects	*A*	8 374,44	1	8 374,44	43,46	< 0,001
	B	7 663,22	1	7 663,22	39,77	< 0,001
	C	1 882,48	1	1 822,48	9,46	< 0,003
	T	557,11	2	278,55	1,45	Not sig.
Second-order interactions	*AB*	21 756,27	1	21 756,27	112,90	< 0,001
	AC	4 502,76	1	4 502,76	23,37	< 0,001
	AT	921,86	2	460,93	2,39	Not sig.
	BC	25 204,87	1	25 204,87	130,79	< 0,001
	BT	2 776,31	2	1 388,15	7,20	< 0,001
	CT	2 092,47	2	1 046,24	5,43	< 0,005
Third-order interactions	*ABC*	376,84	1	376,84	1,96	Not sig.
	ABT	3 692,48	2	1 846,24	9,58	< 0,001
	ACT	640,23	2	320,12	1,66	Not sig.
	BCT	4 227,48	2	2 113,74	10,97	< 0,001
Fourth-order interaction	*ABCT*	78,03	2	39,02	0,20	Not sig.
	Error	24 666,50	128	192,71		

lation of linear regressions for the performance figures for the first six weeks of the experiment and setting $x=0$ in $y=mx+b$. To allow for the different levels of production in the eight stopes, the percentage deviation was calculated each week from the base level. The mean percentage deviations for each of the 24 treatments are shown in Table II, and the results of the analysis of variance in Table III.

DISCUSSION

By means of the analysis-of-variance technique it is possible to evaluate the separate and joint influence of several independent variables on the experimental criterion. As the technique does not rely on a single set of observations but rather on all observations for all treatments in which a condition occurs, the findings are more stable and there is less chance of misinterpretation than with some other techniques.

If the level for rejection of the null hypothesis is set at the $p=0{,}005$ level, it can be seen from Table III that the only effects that were not significant were the main effect for time, the second-order interaction between homogeneity and time, the third-order interactions between homogeneity, mobility, and rated quality of Bantu supervision and between homogeneity, supervision and time, and the single interaction between all four factors.

In general, the p-values were so small that the differences reflected in Table III could not be attributed to chance.

Where an interaction exists, it indicates that a factor has different effects on the criterion under different conditions of a second factor, and under these conditions it may be misleading to view the main effects of a factorial experiment individually. However, the findings are more readily understood if main effects as well as second- and third-order interactions are reviewed.

MAIN EFFECTS

Ethnic Homogeneity

Fig. 1 (A) shows that those gangs with more than 50 per cent Malawians had a mean overall improvement of 10,5 per cent per gang in tons trammed per week when interactions with other variables were ignored. In the case of the ethnically heterogeneous gangs, however, weekly production was depressed to the extent of 4,3 per cent per week on the average during the course of the experiment.

The advantage resulting from the creation and maintenance of gangs in which one ethnic group predominated was relatively large, and the apparent loss of production associated with the random allocation of labour makes the introduction of the former condition appear worth while.

Mobility

The difference in productivity between mobile and stable gangs was slightly smaller than the difference in the preceding case. In those gangs in which movement was restricted, production increased by an average of roughly 10 per cent per week. The mean loss, on the other hand, in the four mobile gangs amounted to 3 per cent per week per gang—a difference of 13 per cent.

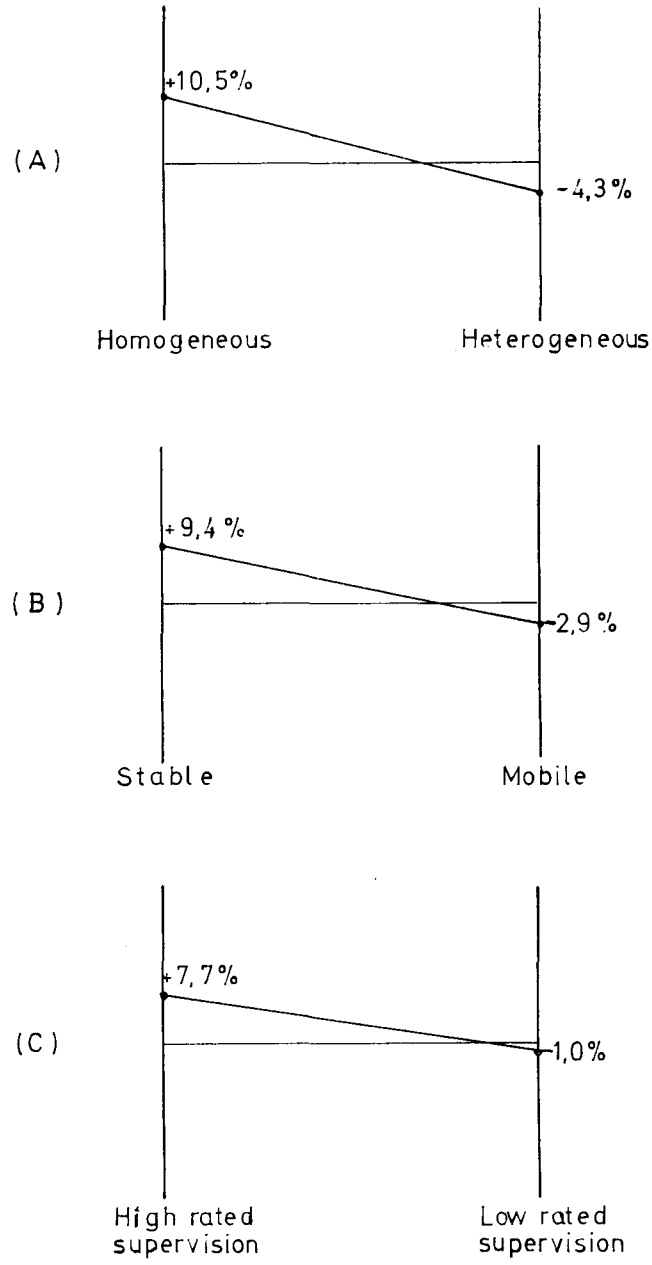

Fig. 1—Main effects

This is illustrated clearly in Fig. 1 (B).

Quality of Bantu Supervision

Fig. 1 (C) illustrates the findings regarding the rated quality of production supervisors as assessed by miners and shift bosses in relation to stope productivity.

The four gangs that were assessed as having better-quality production supervisors showed a mean weekly increase of nearly 8 per cent per gang. In the gangs with supervision that was assessed as less adequate, production output dropped by 1 per cent per week.

SECOND-ORDER INTERACTIONS

Mobility in Gangs

The main effect illustrated in Fig. 1 (B) has shown that, in general, the four mobile gangs suffered a drop in mean production of only about 3 per cent, while the performance of stable gangs increased by 9 per cent. However, the significant second-order interactions listed in Table III showed that the impact of gang mobility could be judged only if other variables were taken into account.

Firstly, these percentages were the mean or average figures for the whole experiment, but the impact of gang mobility was found to have accumulated over time as shown in Fig. 2 (A). By the end of the third time period, stable gangs had improved by nearly 16 per cent, while the mobile gangs had dropped by more than 6 per cent. In addition, the effects appeared to be continuing; there was no indication that the trends would not have continued if the experiment had been of longer duration.

Secondly, as shown in Fig. 2 (B), the combination of gang mobility with gang heterogeneity resulted in a drop in production of 27 per cent, whereas stable gangs improved their performance by nearly 13 per cent, even under heterogeneous conditions. Under homogeneous conditions, the difference between mobile and stable gangs was less marked. In fact, the homogeneous gangs functioned somewhat better under mobile conditions, although the reasons for this are not yet fully understood. It seems that the effect of mobility in a homogeneous gang was entirely different from that in a heterogeneous gang. Perhaps, when a gang was essentially of one ethnic group, there was not much disruption as a result of men joining and leaving, and, in fact, the mobility may have served a useful purpose by bringing the men fresh news of their families and homeland and so on.

Thirdly, Fig. 2 (C) shows how the effect of mobility was dependent also on the quality of Bantu supervision. Poor supervision coupled with gang mobility was associated with a *drop* in production of 21 per cent, whereas gang stability compensated for poor supervision and was associated with an *increase* in production of 21 per cent.

Gang mobility under conditions of 'good' supervision seemed to have a beneficial result. It is likely, however, that Fig. 2 shows that so-called 'good' Bantu production supervisors were those who could cope with the highly mobile conditions that exist in the industry, and that they had not been trained in the leadership skills necessary to capitalize on the benefits inherent in stable gangs. Presumably, the poorer production supervisors had less influence on their gangs and did not interfere with their potential to produce effectively. If this hypothesis is correct, one would expect that, if production supervisors had been trained to benefit from gang stability, the performance of their gangs would have been reflected by a line such as that shown dotted in Fig. 2 (C).

In general, it is clear that excessive mobility was a serious consideration so far as gang production was concerned.

Quality of Supervision

The effect of Bantu production supervisors of different calibre was also subject to the influence of variables other than mobility. The arrangement of production supervisors did not have an immediate effect on the performance of the gangs but, as time passed, the output of the gangs with the better supervisors improved by 15 per cent, whereas the gangs with poorer supervisors deteriorated by 5 per cent—Fig. 2 (D).

Also, the better production supervisors were able to achieve more with homogeneous gangs than was possible with heterogeneous gangs—Fig. 2 (E). Heterogeneity resulted in a fall in output regardless of the quality of the supervisors.

THIRD-ORDER INTERACTIONS

The two significant third-order interactions listed in Table III emphasize further the importance of the time element to the introduction of changes such as those in the experiment. There is sometimes a tendency when organizational changes are made to look for or to be influenced by short-term results and perhaps to discontinue worthwhile innovations before sufficient time has been allowed for the effects to be demonstrated.

The third-order interaction illustrated in Fig. 3 (A) shows that the second-order interactions between homogeneity and mobility changed over the course of time. Had there been no time effect, the two diagrams in Fig. 3 (A) would have resembled that in Fig. 2 (B).

Stable gangs tended to produce superior long-term results irrespective of whether the gangs were composed predominantly of Malawians or of a variety of tribes. The opposite tendency was observed where gangs were mobile. It was evident that mobility combined with heterogeneity produced the largest overall drop in productivity. This effect was magnified by the passage of time with decreases of 37 and 31 per cent during the last two periods. Although there was a slight upward tendency in productivity for these gangs over the last period of time, this appeared to have been attributable to the reluctance on the part of shift bosses to continue transferring men, which resulted in the required percentage of transfers not being maintained during the closing phase.

The interaction shown in Fig. 3 (B) is rather perplexing. Under stable gang conditions, the gangs under Bantu production supervisors with lower assessments produced better results than the gangs under better supervisors. There was a tendency for gangs with better supervision to show an improvement in the last time period of the experiment, whereas those with poorer supervision dropped off in output. This may have been a result of the

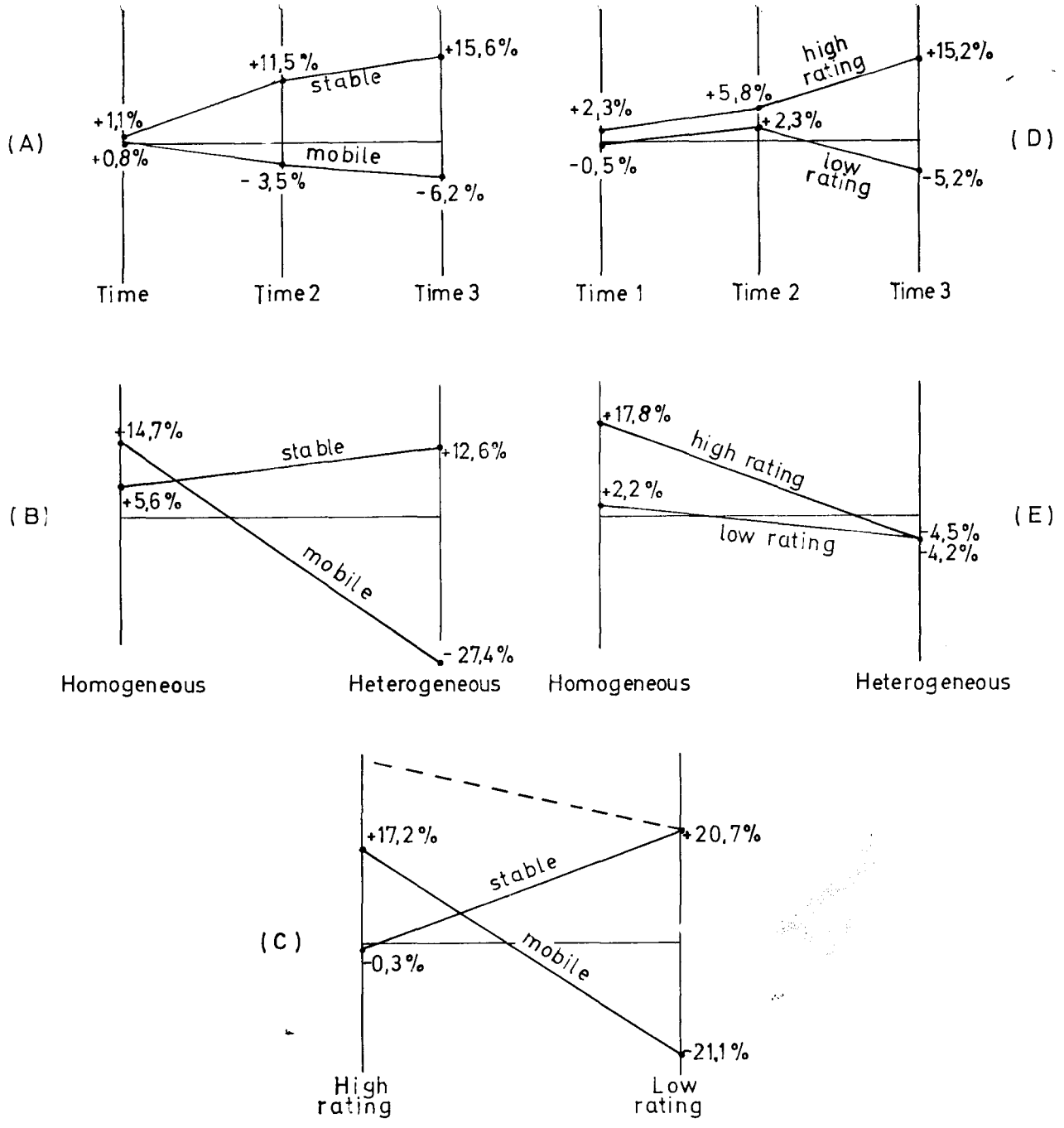

Fig. 2—Second-order Interactions

rearrangement of Bantu production supervisors, and, if the experiment had been extended and if these trends had continued, the stable gangs with better supervision may have emerged as the higher producers.

Under mobile conditions, the gangs that had better-quality production supervisors showed an increase of nearly 27 per cent per week in tons trammed per gang at the end of the experiment. The combination of inadequate supervision and mobility exerted a strong negative influence on productivity, which increased with time. The mean production loss per week in those gangs with a combination of mobile conditions and supervisors with low ratings amounted to 34 per cent per week at the conclusion of the experiment.

CONCLUSION

Field experiments that involve human beings and their work performance are not always easily designed. The following are some of the more important considerations that were taken into account in the experiment described in this paper.

(a) There are moral and ethical limits to the extent to which human beings can be experimented with.

(b) The level of work performance is influenced not by one human factor but by numerous factors acting and interacting simul-

taneously. The number of human factors that can be experimented with simultaneously is usually restricted by practical considerations to three or four.

(c) A change in a relevant human factor is unlikely to have an *immediate* effect on work performance. The effect is more likely to be revealed only over a period of time, and the experiment must continue long enough to permit this.

(d) On the other hand, the maintenance of experimental conditions over a lengthy period in a field setting is seldom easy. Uncontrolled variables that were expected or hoped to remain constant during the experiment might change for reasons beyond the control of the experimenter. Also, the experiment is likely to interfere to at least some extent with the normal work organization, and to require extra involvement for some personnel. It is desirable therefore for the duration of the experiment to be as short as possible.

(e) There is a danger that, unless specific steps are taken to avoid this, the design of the experiment or the presence of researchers may affect the subjects of the experiment in an unknown and uncontrolled manner.

The results of a properly designed field experiment have considerable utility, however. Mobility as the result of transfers between gangs is a common feature of gold mining, and the experiment described here has shown how excessive mobility in stoping gangs can seriously interfere with gang performance. This is particularly the case if mobility is

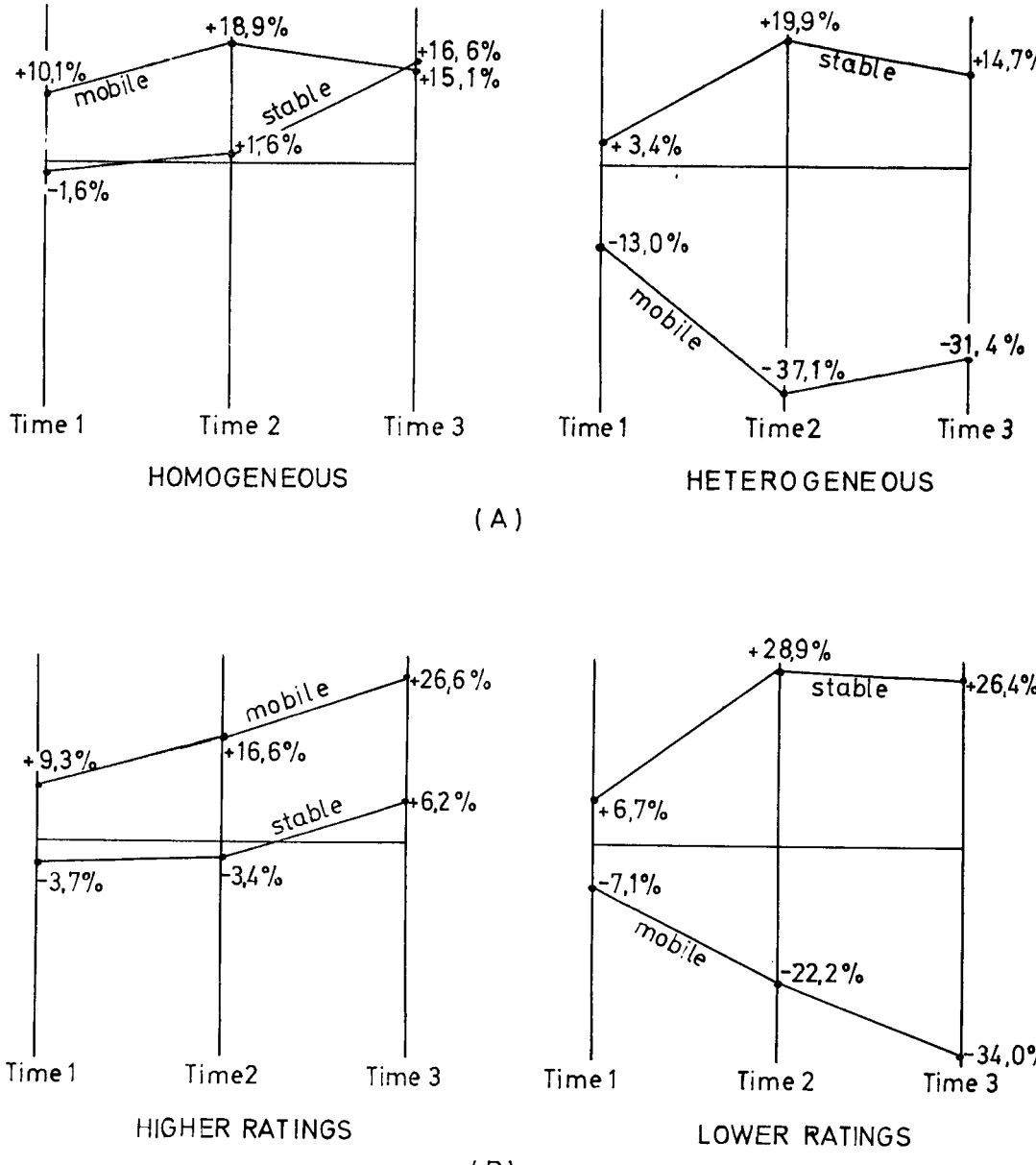

Fig. 3—Third-order interactions

coupled with heterogeneous gangs, as is normally the case, and is continued over a long period of time.

The findings have also suggested that Bantu production supervisors need training in the utilization of the human resources available to them. In particular, there should be considerable advantage in training supervisors to develop 'team' concepts in their gangs and to capitalize on gang stability.

It has also been shown that relative ethnic homogeneity (at least for Malawians) was conducive to increased productivity in terms of tons trammed. The reasons for this influence are probably to be sought in the increased extent to which members of the gang were able to communicate with one another, and the greater cultural similarity between members, which would have reduced the need for individuals in gangs to adjust to unfamiliar socio-cultural norms of fellow-workers. If this were the case, benefits should accrue from homogeneous gangs irrespective of the ethnic origin of the men. On the basis of the findings, however, this generalization is unwarranted, and further research is needed on this factor.

REFERENCES

1. LAWRENCE, A. C. A new approach to the study of human factors in stope productivity. *J. S. Afr. Inst. Min. Metall.*, Nov. 1972.
2. MAUER, K. F. The African production supervisor in the South African mining industry. Durban, University of Natal, unpublished M.A. thesis, 1972.
3. EDWARDS, A. L. Experimental design in psychological research. London, Holt, Rinehart and Winston, 3rd edition, 1968.
4. SCHEFFE, H. The analysis of variance. New York, John Wiley and Sons, 1959.

Notices

Competition for Student Members of the South African Institute of Mining and Metallurgy

Each year the Institute offers a prize (or prizes should the entries warrant it) of up to R100 for the best paper or dissertation on a topic appropriate to the interests of the Institute. The competition is open to all Student Members of the Institute.

A Student Member who is in full time study at a university may submit the dissertation or thesis he has to write in part fulfilment of his university degree, provided that it is presented in a manner and on a topic suitable for publication in the journal.

Entries for 1973 should reach the Institute by 31st December, 1973.

Eleventh International Mineral Processing Congress

The above Congress is to be held in Cagliari, Italy, during the first ten days of May, 1975. Papers will be grouped under the following general headings:

Comminution and agglomeration
Classification and thickening
Flotation
Electric and magnetic separation
Chemical and biological processes
Control and testing
Process design
Plant management and practice
Ecological problems and waste treatment.

Abstracts of papers intended for inclusion in the Congress Proceedings should be written in one of the four official languages of the Congress (English, French, German, and Russian), and should be submitted before 31st December, 1973. The authors of approved abstracts will be expected to submit two copies of the completed manuscript before 31st August, 1974.

All correspondence and enquiries should be directed to Comitato Organizzatore XI IMPC, Istituto di Arte Mineraria, Piazza D' Armi—C.P. 236, 09100-Cagliari-Italy.

Twelfth Annual International Symposium on Computer Applications in the Mineral Industry

The above symposium is to be held in Golden, Colorado, from 8th to 12th April, 1974. The technical sessions will deal with the following topics:

Exploration
Geostatistics
Ore-reserve assessment
Financial evaluation and planning
Mine planning and scheduling
Mine-system design and evaluation
Mining operations
Process Modelling.

Enquiries should be addressed to Dr Donald W. Gentry, Mining Department, Colorado School of Mines, Golden, Colorado, U.S.A.