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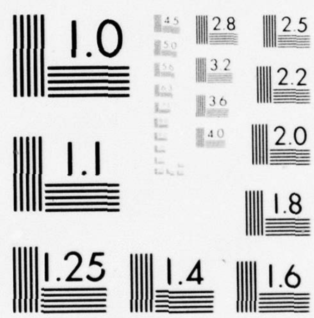

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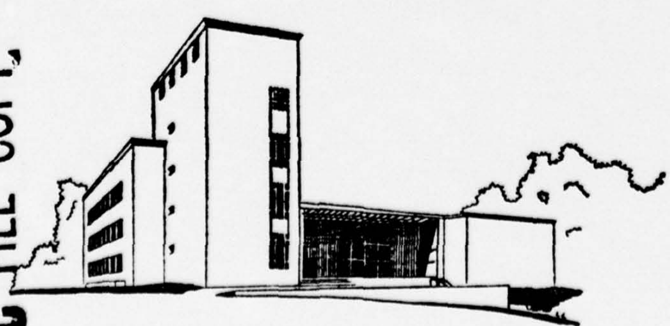

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This report presents three models for assessing one measure of organizational effectiveness--productivity. The models are delineated conceptually, empirically tested, and their advantages and disadvantages reviewed.

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Estimating Economic Consequences in Organizational Effectiveness Experiments

1. The Problem

A major thrust in current research on organizations is experimentation with new forms of work organization. The purpose of this research is to increase organizational effectiveness in both the public and private sectors. Two dimensions of organizational effectiveness which have received most of the attention are productivity and psychological outcomes from work. This paper examines methods to evaluate changes in productivity from an organizational intervention.

Most new forms of work organization experiments assume that changes can be brought about in economic dimensions such as productivity. Increases in productivity are beneficial to management and lead to greater earning opportunities for the worker. The problem posed by this assumption is how to determine whether productivity has increased.

A cursory review of the current literature on organizational effectiveness will show that there is no substantial evidence to document changes in productivity. Clearly there are a lot of claims. Both consultants and managers have said that productivity in the experimental organizations has increased (cf. Glaser, 1975); however, the validity of this information is questionable given the propensity of people involved in a study to overestimate the results (Gordon, 1975).

"Substantial" evidence means that quality data is available over a sufficiently long period of time and that there are sufficient controls available to separate out the effects of the experimental intervention from other variables that influence productivity. Most studies (cf. Glaser, 1975) simply assert that productivity is improved or increased by some percent without detailing the source of the data or identifying the cause of the change. The basic thesis in this paper is that production is a function of a number of controllable and uncontrollable variables. Changes in production can be affected by any combination of these variables. An organizational intervention simply adds another variable to this complex production function. Separating its effect is a complex analytical task.

Why have we not made more progress in estimating productivity differences? One reason is that much of the research in this area has been done by social scientists who are more interested in psychological than economic outcomes of work. Another reason is that many people involved in introducing organizational change have been more concerned with the process of change than with the outcomes. In other cases companies have not been willing to make economic data available, or the resources have not been available to analyze economic data. Another reason, and the central rationale for this paper, is that there have not been good analytic models available to assess productivity changes in organizational experiments. That is, we do not have a good methodology for estimating productivity changes.

2. The Setting

This paper examines several models used to estimate productivity differences in an experimental intervention in a coal mine. The forms of the models are presented at a general level to enable the models to be generalized to other settings. Clearly, some of the variables in the models will change in different settings, but the form of each model and the testing procedures will not.

The Rushton Mining Company entered into a Quality of Work (QOW) experiment in 1973 (Goodman 1977). One of the three sections (mining departments) became an experimental section. Autonomous work group teams were created in that section by outside consultants. While it is not possible to detail the experimental intervention (see Goodman, 1976), the communication, decision making, authority, and reward systems of that section were substantially modified. The basic hypothesis was that these changes would increase productivity levels and the quality of working life.

The design of this study permits comparing productivity of the experimental section against two other mining sections. In a sense these sections can serve as control groups to assist in isolating the effect of the experimental intervention on productivity. However, since these three sections are not perfectly matched as to men, machinery, and physical conditions the design is not truly an experimental design. At best this study can be classified as a quasi-experimental design; contrasts within the experimental section over time or between the experimental and control sections cannot definitively isolate the experimental effect on productivity.

A coal mine's production is generally stated in terms of tons produced (per section). The set of variables affecting production is complex. Some variables are controllable, such as the number of men working or the type of equipment. Other variables are uncontrollable such as the character of roof and runway conditions. In comparing differences in tons produced per section it is important to understand which variables contribute to production. For example, if the experimental section outproduces the control sections but the latter have very poor roof conditions, then the difference in productivity may be caused by uncontrollable physical conditions or the experiment. To analyze productivity differences we need to describe a production function which includes the major predictor variables, and then to identify whether there are shifts in the coefficients of these variables over time.

3. Testing Procedures

Since it is not possible to control nonexperimental variables (e.g., roof conditions) which differentially affect the experimental and control groups, it is necessary to statistically control for these differences. We have adopted three alternative methods for testing for productivity changes after correcting for changes in uncontrollable variables across the experimental and control sections. (Where not indicated otherwise, the experimental section prior to the experiment and the nonexperimental sections will be referred to as the control sections).

All three methods seek to identify differences in the structure of the production function (i.e., the relationship between resources used and quantities produced) between the experimental section and the control sections. Thus we began by estimating a separate production function for each section for each year. The appropriate positive or negative signs can be specified a priori for almost all variables in the production function equation. For example, output should be positively related to working time and to the roof and runway condition variables. Before accepting the estimated equation for an individual section, we have required that all coefficients which are significantly different from zero have the predicted sign. In the few instances in which initial estimates did not satisfy the requirement, we have attempted to determine whether exceptional circumstances (e.g., unusual physical conditions) in a particular section might have given rise to an unreasonable coefficient estimate. In some cases, dummy variables were introduced to account for such special circumstances.

The first and simplest procedure is to test for differences in the constant term in the production function across sections. Differences, if any, in the sections, including differences caused by the experiment, are assumed to affect only the constant term. Given this assumption, the homogeneity of the sections in the control group or a subset of the control group can be tested by an analysis of variance, i.e., by testing whether a significantly higher proportion of variance is explained by allowing a different constant term for each section than by imposing the same constant term across all sections. If the experiment enhanced productivity, this would be reflected by a higher constant term in the production function for the experimental section than in the production functions for the control sections. The _t_-test can be applied to determine whether the difference in the constant term between the experimental and control groups is significant.

The above approach has the advantage of being both simple to apply and easy to interpret. The disadvantage of the procedure is the assumption that the coefficients on both the controllable and uncontrollable variables are the same across the experimental and control sections. It is not obvious, a priori, that this should be the case. For example, if the result of the experiment is that the men work more efficiently in the presence of adverse conditions, this would be reflected on the coefficients of the conditions variables rather than the intercept. The two additional tests described below do not require such restrictive assumptions.

A second method is to test for differences in any of the estimated coefficients of the production function across the sections. The maintained (null) hypothesis is that all the coefficients in the production function are the same in all sections. The alternative hypothesis is that one or more of the coefficients differ across sections. Thus, if the experiment resulted in a significant change in the production function in the experimental section, the maintained hypothesis should be rejected when the experimental section is compared to the control sections.

The maintained hypothesis in the first step of the test is that the coefficients in all six sections are the same. The alternative is that the coefficients in all six are different. Since the tests are sequential, the form of each subsequent test will depend on the outcome of the one preceding.[1] One simple sequence is as follows: If the null hypothesis of the first test is rejected, the production functions of the sections are not all alike. The second step would then be to test whether the production function is the same for all control sections. If so, the control groups would be combined to yield a single production function, and this function would then be compared to the experimental section. Selective testing of subsets of the coefficients would determine more precisely which of the coefficients differ between the experimental and control section production functions.

A great many other outcomes are possible. The control sections might be found to differ among themselves. The sections might be the

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[1] The probability of obtaining a given conclusion is not independent of the test sequence. Ideally, we would like to compute the probability of obtaining a particular conclusion taking account of the test sequence. However, in the absence of knowledge of the true values of the parameters of the model, such a calculation is not possible. Thus, confidence regions for a given level of significance are determined by treating each step of the test sequence as independent of the outcomes of previous steps in the sequence. This rather unsatisfying procedure appears to be widely employed since no generally applicable alternative procedure is available.

same in each year and different across years. The control and experimental sections might be found to be all alike. Rather than enumerate all possible sequences, we will defer further discussion until the results section where the actual test sequence is presented.

The second testing procedure described above also has several limitations. The power of the analysis of variance test is much greater when one uses a single production function for the five control sections[2] in a test against the experimental section than when one tests the five control sections, each with a different production function, against the experimental section. For a given level of significance, one may get ambiguous results from the analysis of variance test because the power of the test changes when different combinations of coefficients or sections are tested. A second problem is that individual coefficients may be different in the experimental section relative to the control sections, but some may be higher and others lower so that the net effect on productivity would not be clear cut.

The third method used to test the experimental section against the control sections is designed to provide an alternative which would potentially be conclusive if the analysis of variance test were

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[2] Here each set of annual data is counted separately since a separate production function is estimated for each section for each year.

ambiguous for either of the reasons identified above. This procedure requires only the production functions for the control sections. The values of the variables observed in the experimental section are substituted into the estimated production functions for the control sections. This provides a prediction of the amount which would have been produced had the resources from the experimental section been used in the control sections under similar physical conditions. The actual average weekly production from the experimental section can then be compared to the predicted average from the equations for the control sections. If the predicted amount from the control sections was significantly lower (higher) than actual production from the experimental section, one would conclude that under similar physical conditions the experimental section was more (less) productive than the control sections. The relevant test statistic has the $\underline{t}$ distribution. The derivation of the test statistic is provided in the Appendix.

Relative to the second method, the third method of comparison has the advantage of simplicity; the information on productivity is summarized in a single statistic comparing mean actual output of the experimental section with mean predicted output from using the same resources in the control section. The second advantage relative to both of the alternative tests is that one need not estimate a production function for the experimental section. For purposes of this test, any shifting of the production function of the experimental section will be reflected in the production of that section. Finally, the power of the test is greater than the analysis of variance test because the latter test compares the sections along several dimensions (as many dimensions as there are estimated coefficients) while the former test is based on a single dimension (production).

The evaluation results are not based exclusively on any one of the above tests. The multidimensional nature of the analysis of variance test enables one to identify differences among the sections which may not be reflected in the production figures. These differences are of interest in themselves as a supplement to the simpler test of differences in productivity. The test for differences in the constant terms is the logical first step in attempting to pinpoint differences in the production functions.

4. Methodology

Sample

The analyzed data set consists of 92 weeks in 1973 and 1974 for the three sections--experimental (South), North, and East. The sample year 1973 starts at 1/2/73 and ends at 12/1/73. From these 48 weeks two were deleted which represent the miners' vacation period in July. Therefore, the 1973 data are based on 46 weeks.

The experimental year begins in the first week of December 1973 and runs through 11/9/74. From these 49 weeks the two-week vacation plus another week lost from the memorial week strike (8/17/74 to 8/24/74) were deleted leaving 46 weeks for analysis. In the remaining period in November and in the first week of December there was no production because of the national coal strike. Since there were only a few remaining actual production weeks in December and since the work in that period was under a new contract, we decided to include those weeks in the 1975 data.

Variables

Table 1 describes the major variables used in the analysis. The label or acronym, variable name, and description are given; then the operational form and source of the data are identified. The means and standard deviations are for all three sections for the 1973 and 1974 time periods.

Our prior expectations about the coefficients are indicated in Table 2. Since we are using a linear approximation to the production function, and the conditions variables may shift the function up or down, we do not have *a priori* expectations concerning the sign of the constant term. Improvements in conditions should increase production as indicated by the positive signs on the physical conditions variables in the table. The moves variable is designed to measure the distance of the miner from the feeder and should thus be negative. Since pillaring is more productive than developmental mining we expected a positive effect on the pillaring variable. Increases in crew size should enhance production giving a positive sign to the man-days variable. Delays were expected to have no effect beyond the reduction in working time. Since delays have been deducted from potential crew time in constructing ACWOT, we expect zero coefficients on the delay variables when delays are entered separately. Crew time should have a positive effect on production.

5. Results

The production function estimates are presented in Table 3. A comparison of the coefficient estimates across the various sections reveals that, where coefficients are statistically significant, they do have the anticipated sign.

We now turn to the results derived from our tests. The first method of testing will serve to indicate whether there were differences in any of the intercepts of the model across the sections.

In row 1 of Table 4 we require the intercept for the five control sections to be the same and test to determine whether the intercept for South 74 (experimental) is significantly different. The estimated difference of -48.9 is not significant. In row 2, all of the section intercepts are allowed to be different with South 73 used as a reference. The coefficients for North 73 and North 74 are significantly lower than the coefficients for South 73 at the five percent level, and the coefficient for East 74 is significantly lower at the ten percent level. This result indicates that the intercepts for the control group are different, and this is confirmed by row 3 of Table 4 which includes only the five control sections. North has a significantly lower intercept than the remaining control sections in both years. In the remaining three rows, the intercept of each section in 1974 is compared to the 1973 intercept. The difference is significant only in North.

The results in Table 4 provide no evidence that the intercept has been shifted by the experiment. This conclusion emerges in the first row when South 74 is compared to the entire control group and in the last row when South 74 is compared to South 73. The results in Table 4 do, however, suggest that there are significant differences among the intercepts of the sections in the control group. The results of method two below provide a more general test for differences in any of the coefficients across the sections.

In row 1 of Table 5 we test whether individual production functions for the six sections fit the data significantly better than a single function applied to all six. At the five percent significance level, the sections are not significantly different. Since the power of the F-test varies considerably when various sections are combined, we present the results of several alternative tests. The results in the second row indicate that the control sections are not significantly different. When a single function for the control section is tested against the experimental section in row 3, the difference proves to be significant at the one percent level.

Further evidence of the similarity of the control sections is provided in rows 4 and 5. In row 4, a single function for the three sections in 1973 is tested against separate functions for each section and no significant difference is found. In row 5, the combined control group in 1973 is compared to the combined control group in 1974 and again no difference is found.

Row 6 indicates no significant difference across experimental and control groups in 1974. However, when the experimental and control groups are combined in 1974 and tested against the combined control group in 1973, a significant difference is found as indicated in row 7. This should be contrasted to the results in 5 where no significant differences were found when the experimental section was not included in 1974. Finally, the models for each of the sections are compared across years in rows 8, 9, and 10. Here it is found that one of the control sections differs between 1973 and 1974, but the production function for the experimental section in 1974 is not significantly different from the production function in 1973.

Additional tests were conducted to explore possible differences between South 74 and the control group. In these tests additional dummy variables were included to allow the ROOF, RUNWAY, and PILLARING coefficients to differ for South 74 when it was included in estimating a single production function for the experimental and control groups combined. After differences are allowed in the coefficients of the three variables identified above, the production functions for the experimental and control sections are not significantly different.

The conclusion of the F-tests is that there is some relatively weak evidence that the experimental and control sections are different. The differences are attributable to the ROOF, RUNWAY, and PILLARING coefficients. These differences in the coefficients of the conditions variables may be attributable to the experiment though such differences would not have been predicted a priori. For example, it may be that the experiment caused the crew to work at the same productivity level independent of runway conditions giving rise to the insignificant coefficient on runway in Table 3 for South 74. The higher coefficient on pillaring indicated greater productivity in pillaring in the experimental section. If the higher coefficient on roof is to be attributed to the experiment, one would have to conclude that the experiment made productivity more sensitive to changes in roof conditions. Since the coefficients on roof and runway in South 74 differ in opposite directions from those of the control group, sampling errors rather than experimental effects may be the cause of these differences.

The results of the test of intercepts appear in some respects inconsistent with the results of the analysis of variance test. The intercept tests indicated no significant effect of the experiment while the analysis of variance tests indicate a significant difference between the experimental and control groups. Also, the intercept tests indicated that North differed significantly from the other control sections while the analysis of variance tests suggest that what differences exist are attributable to East.

The explanation of these seemingly inconsistent results is traceable to the underlying assumptions and the relative power of the tests. The intercept test is predicated on the assumption that differences, if any, will be reflected in the intercepts. Offsetting differences in the other coefficients may not be picked up by the intercept test. In contrast, the analysis of variance test allows for quite general differences, but the discriminatory power of the test is lower than that of the intercept test. Clearly, it is desirable to have a single summary measure of the effects of the experiment. The intercept test is unsatisfactory because there is no a priori reason to expect only the intercept to be affected. The analysis of variance test identifies differences but does not indicate the net effect of those differences on productivity. It is for these reasons that we developed the third method of testing for differences in productivity.

Both the intercept test and the analysis of variance test cast doubt on the hypothesis that all sections in the control group have the same production function. Therefore, we conducted the means test not only with the combined control group, but also using only South 73 as the control group. If unobserved variables are responsible for differences among the control sections, South 73 may be a more reliable control since such unobserved variables may differ less over time for a given section than they vary across sections.

The results of means tests are presented in Table 6. For the results in the upper half of the Table, the production function for South 73 was used to obtain predicted average weekly production. This prediction is obtained by substituting the independent variables observed in each week in South 74 into the estimated production function for South 73. The average of these predictions, denoted $\bar{y}_p$, was then subtracted from actual average production in South 74 to obtain the estimated difference, d. The difference is an estimate of the amount by which average weekly production in South 74 exceeded the amount which would have been produced had the same resources been used under similar physical conditions in South 73. The results in the bottom half of the Table were obtained by applying the same procedure using the production function estimated when the data from all the control sections were combined.

The results indicate that average tonnage produced per week in South 74 was not significantly different from the amount which would have been produced had the same resources been used in the nonexperimental sections under similar physical conditions. This conclusion is obtained using either South 73 or the combined nonexperimental sections as the control.

6. Discussion-Summary

The general results do not indicate any increase in productivity in the experimental section during the first experimental year. The reasons for these results can be classified as methodological or conceptual. One methodological problem may be that we have not stated the models correctly. That is, variables might be missing or some of the selected variables incorrectly operationalized. In reviewing the models we have used in this analysis there are some coefficients that appear different from what we would have predicted and in some cases we have introduced dummy variables to deal with special problems (e.g., special physical conditions) not captured by our regular measures. To deal with this issue we thought carefully about the appropriate conceptual model. We did not let either techniques or the data primarily guide our analysis. When anomalies have appeared in the data we have gone back to the original data sources to identify the actual daily events that were going on. To avoid ex post solution from this more detailed analysis, we always tried to recast these findings back into our conceptual framework.

Another methodological issue concerns the control groups. The lack of improvement in productivity might be explained by the fact that the other sections are not equivalent to the experimental section and the comparison with these groups is inappropriate. We have tried to respond to this question by developing a model that will be generalizable across sections. Indeed, the analysis examining the production functions across the different sections shows a great deal of similarity. The other analytic approach has been to treat each section as its own control group. That is, we compared the performance of the experimental section in the baseline with its performance in the experimental year. The overall strategy then is to acknowledge that there is a problem of equivalence, but at the same time to use analysis procedures and to consider alternative control groups. If we get a consistent picture across these different strategies, we can feel more certain about the validity of the results.

A third issue concerns problems of measurement. Unreliability in either the independent or dependent variables clearly will confound the analysis. To some extent this problem is outside of our hands because we do not have the resources to set up our own measurement system for the economic variables. In some cases we have analytically examined some of the ordinal scales used for measuring physical conditions to assess the validity of those measures. For the dependent variable we intend to relate the current figure against other measures of the same phenomena during the coming year to get a measure of concurrent validity.

Another measurement issue concerns potential biases in the measures. Here we would find a high degree of consistency (reliability) but validity would be low. The issue is that certain bosses could have overstated production as a reaction to the experimental induction. Bosses in the experimental section might have wanted to make the section look better while bosses in the control groups might have overstated production to make their section look comparable to the experimental section. Our own observations of this problem are the following: first, if overstating production figures by the foremen occurred it was generally a reaction to higher level management's demands for greater production. Our information suggests this pressure was in evidence during the baseline and experimental years and is a constant across sections. Second, our observations and interviews with the foremen in the experimental section indicated that overstating production did not occur as a function of the experiment; it might have occurred from production pressure. Third, there was some evidence that in some of the control crews production may have been overstated as a reaction to the experiment. This behavior however was not widespread and should not have affected the comparisons when we treated the experimental section as its own control.

The fourth issue concerns the level of aggregation used in this analysis. Our data have been examined on a weekly basis. It could be argued that our estimates would be more refined if we moved to a daily basis. This is an issue we hope to explore with the data from 1975 and 1976.

The last issue concerns the time period for analysis and this might be the most compelling issue. It takes a long time period to identify the results of a major change effort like the Rushton project. We are only evaluating performance during the first year. It is clearly appropriate to withhold any conclusions about productivity until the 1975 and 1976 data is examined.

7. Conclusions

In selecting a procedure for evaluating organizational effectiveness experiments, the following criteria are applicable. First, the procedure should be relevant, that is it should offer the potential of answering questions of interest concerning the effects of the experiment. Second, the conditions required for applicability of the procedure should be satisfied by the experimental environment.

In evaluating the economic consequences of an experiment, the primary question of interest will be determining whether the experiment increased productivity. If a change in productivity occurred, one may also want to pinpoint how the production function differs after the introduction of the experiment. Even if no effect on productivity is realized, there may be some interest in testing whether the experiment had any impact at all on the production process.

Of the three procedures considered in this paper, the two most appropriate for testing for differences in productivity are the intercept test and the means test. While both tests satisfy the first criterion, the means test will generally be preferable by the second criterion. The intercept test is based on the assumption that the experiment affects only the intercept and no other coefficients in the production function. There was no a priori reason for expecting this to be the case in the experiment discussed in this paper, and it is doubtful that one would generally have such strong prior information about the way in which an experiment might potentially affect the production function. The means test is particularly suitable for experiments in which the effects on the production function are uncertain since the test requires no assumption about the way in which the production function is changed.

Whether or not a change in productivity occurs, one may wish to test whether the production function is changed at all by the experiment. In addressing this question, the analysis of variance test is appropriate since it is intended to identify differences in any or all coefficients between the experimental and control groups. Should evidence of differences be found, tests for differences in subsets of the coefficients can be applied to pinpoint the differences.

Table 1

Variable Descriptions

ACRONYM	Variable Name	Meaning of Variable	Operational Form
COALBO	Coal and boney height added together	Height from ceiling to the floor	Inches
ROOF	Roof conditions	Quality of roof	1 to 5 scale 1 very bad 5 very g
RUNWAY	Runway conditions	Quality of runway	1 to 5 scale 1 very bad 5 very g
PILLARING	Pillaring	(See Baseline Report, 1975)	Number of shifts pilla per week
ABSEN	Number of total absences	Number of total absences	Total absences per wee
MOVES	Major moves	Measure of the distance between face and feeder	Assumes the value zero the weeks with a major (i.e., a move of more 299 minutes) and incre by one for each week without a major move
AVMAN	Average man days	Average man days worked per day of the week	Total man days worked week/days per week wo
MOMINDEL	Moves and miner delays	Moves and miner delays	Moves and miner delays minutes
COMDEL	Combined delays	Combined delays	Car, machinery, bolte physical, and miscella delays-minutes
EXOUTDEL	Autonomous work group obligation and outside delays	Autonomous work group and outside delays	Autonomous work group obligation and outside minutes
ACWOT	Actual crew working time	Actual crew working time	Maximum possible crew time (=5850)-total de minutes
DU	Denotes dummy variable	Introduced for periods of abnormal conditions	One during weeks when abnormal conditions prevail

Table 1

Variable Descriptions

Operational Form	Source	Mean	Standard Deviation
Inches	Company Records	64.0	4.8
1 to 5 scale 1 very bad 5 very good	Rating from superintendent	3.9	1.3
1 to 5 scale 1 very bad 5 very good	Rating from superintendent	3.5	1.7
Number of shifts pillaring per week	Company records	1.13	3.4
Total absences per week	Company records	4.8	4.0
Assumes the value zero for the weeks with a major move (i.e., a move of more than 299 minutes) and increases by one for each week without a major move	Created by analysts based on moves delay	1.7	1.8
Total man days worked per week/days per week worked	Created by analysts based on company records	18.4	2.6
Moves and miner delays-minutes	Created by analysts based on company records	452.9	428.0
Car, machinery, bolter physical, and miscellaneous delays-minutes	Created by analysts based on company records	782.2	650.6
Autonomous work group obligation and outside delays-minutes	Created by analysts based on company records	79.3	275.9
Maximum possible crew working time (=5850)-total delays minutes	Created by analysts based on company records	4231.0	894.0
One during weeks when abnormal conditions prevail	Created by analysts based on company records	---	---

Table 2

Variables Included in Production Function

Independent Variables	Anticipated Sign
CONSTANT	?
COALBO	+
ROOF	+
RUNWAY	+
ABSEN	-
MOVES	-
PILLARING	+
AVMAN	+
MONINDEL	0
COMDEL	0
ACWOT	+

Table 3

Production Model II

Medium Aggregated Delays

East 73

	Coefficient	T Value
CONSTANT	1845.	0.8051
COALBO	-49.33	-1.514
ROOF	-71.30	-0.9155
RUNWAY	178.7	3.268
ABSEN	-12.47	-0.5925
MOVES	-194.7	-2.404
AVMAN	45.21	1.472
EXOUTDEL	-1294.	-1.168
MOMINDEL	-0.1949	-0.7866
COMDEL	-0.05737	-0.3810
ACWOT	1.239	11.35

R^2 = 0.9125
Dw = 1.05

North 73

	Coefficient	T Value
CONSTANT	-2800.	-1.021
COALBO	-11.06	-0.2450
ROOF	149.7	1.194
RUNWAY	458.5	6.240
ABSEN	15.30	0.3376
MOVES	40.05	0.4176
AVMAN	108.9	1.274
DU 1 N73	-1619.	-2.103
EXOUTDEL	-2.987	-1.549
MOMINDEL	-0.1291	-0.3559
COMDEL	-.0.08661	-0.4794
ACWOT	1.090	6.984

R^2 = 0.9098
Dw = 1.917

South 73

	Coefficient	T Value
CONSTANT	-1392.	-0.6773
COALBO	12.76	0.4857
ROOF	68.41	0.7221
RUNWAY	-51.53	-0.4656
PILLARING	29.97	0.4976
ABSEN	-6.050	-0.1500
MOVES	-20.28	-0.3184
AVMAN	46.97	0.5458
DU 1-5 S73	-2644.	-4.719
EXOUTDEL	-2.357	-0.9867
MOMINDEL	-0.0604	-0.2107
COMDEL	0.0569	0.2032
ACWOT	1.011	6.794

R^2 = 0.8088
Dw = 1.5

East 74

	Coefficient	T Value
CONSTANT	-3238.	-1.660
COALBO	-22.32	-0.8761
ROOF	389.5	2.987
RUNWAY	11.40	0.1750
PILLARING	22.11	2.167
ABSEN	30.73	1.888
MOVES	-32.47	-1.198
AVMAN	196.6	3.008
EXOUTDEL	-0.3979	-0.5405
MOMINDEL	-0.2954	-1.667
COMDEL	-0.0186	-0.1123
ACWOT	1.000	10.41

R^2 = 0.8964
Dw = 2.0

North 74

	Coefficient	T Value
CONSTANT	-3896.	-1.385
COALBO	-14.73	-0.5448
ROOF	102.4	0.9332
RUNWAY	127.6	1.484
ABSEN	29.71	1.208
MOVES	17.32	0.2421
AVMAN	148.4	1.629
DU 23,39-43 N74	-1168.	-2.858
EXOUTDEL	-0.8868	-0.4327
MOMINDEL	0.1521	0.6654
MBCDEL	0.6526	1.639
COMDEL	0.2175	0.9918
ACWOT	1.238	7.330

R^2 = 0.8621
Dw = 1.597

South 74

	Coefficient	T Value
CONSTANT	-7947.	-1.642
COALBO	44.62	0.7431
ROOF	441.1	3.312
RUNWAY	-103.6	-0.9025
PILLARING	110.[illegible]	4.388
ABSEN	30.63	0.62[illegible]
MOVES	-115.0	-1.97
AVMAN	128.6	1.539
EXOUTDEL	-0.1092	-0.4884
MOMINDEL	0.01382	0.0507[illegible]
COMDEL	0.1283	0.4777
ACWOT	1.269	6.492

R^2 = 0.8322
Dw = 1.57

Table 3

Production Model II

Medium Aggregated Delays

North 73

…cient	T Value
…800.	-1.021
…1.06	-0.2450
…49.7	1.194
…58.5	6.240
…5.30	0.3376
…0.05	0.4176
…08.9	1.274
…619.	-2.103
….987	-1.549
….1291	-0.3559
…0.08661	-0.4794
….090	6.984

South 73

	Coefficient	T Value
CONSTANT	-1392.	-0.6773
COALBO	12.76	0.4857
ROOF	68.41	0.7221
RUNWAY	-51.53	-0.4656
PILLARING	29.97	0.4976
ABSEN	-6.050	-0.1500
MOVES	-20.28	-0.3184
AVMAN	46.97	0.5458
DU 1-5 S73	-2644.	-4.719
EXOUTDEL	-2.357	-0.9867
MOMINDEL	-0.0604	-0.2107
COMDEL	0.0569	0.2032
ACWOT	1.011	6.794

R^2 = 0.8088

Dw = 1.5

Total

	Coefficient	T Value
CONSTANT	-2287.	-3.448
COALBO	-4.247	-0.4983
ROOF	75.29	2.244
RUNWAY	155.9	5.952
PILLARING	45.27	4.162
ABSEN	17.01	1.783
MOVES	-82.45	-2.970
AVMAN	83.15	5.475
DU 1 N73	-1638.	-2.705
DU RUNW 5 N73	1079.	6.334
DU 1-5 S73	-1729.	-6.016
DU 23,39-43 N74	-1341	-5.133
COMDEL	-0.0218	-0.3006
MOMINDEL	-0.1663	-1.684
EXOUTDEL	-0.3037	-2.160
MBCDEL	0.1307	0.4083
ACWOT	1.143	20.39

R^2 = 0.8537

Dw = 1.400

… 74

…cient	T Value
…96.	-1.385
….73	-0.5448
…2.4	0.9332
…7.6	1.484
….71	1.208
….32	0.2421
…8.4	1.629
…68.	-2.858
…8868	-0.4327
…1521	0.6654
…6526	1.639
…2175	0.9918
…238	7.330

South 74

	Coefficient	T Value
CONSTANT	-7947.	-1.642
COALBO	44.62	0.7431
ROOF	441.1	3.312
RUNWAY	-103.6	-0.9025
PILLARING	110.1	4.388
ABSEN	30.63	0.62[illegible]
MOVES	-115.0	-1.97
AVMAN	128.6	1.539
EXOUTDEL	-0.1092	-0.4884
MOMINDEL	0.01382	0.05075
COMDEL	0.1283	0.4777
ACWOT	1.269	6.492

R^2 = 0.8322

Dw = 1.57

Table 4

Tests for Differences in Intercepts Across Sections

Sections Included In Regression	Section Coefficients* E73	N73	S73	E74	N74	S74
ENSEN, S74	B**	B	B	B	B	-48.9 (.30)
E73,N73,S73 E74,N74,S74	-60.6 (.35)	-597.5 (2.4)	B	-308.1 (1.8)	-321.3 (2.0)	-190.6 (.99)
E73,N73,S73 E74,N74	-9.1 (.05)	-535.7 (2.4)	B	-103.4 (.65)	-239.9 (1.98)	
E73,E74	B			-115.4 (.94)		
N73,N74		B			372.2 (1.91)	
S73,S74			B			-163.9 (.44)

* t-ratios are shown in parentheses.

** Sections denoted with a B in a given run were used as a base against which the remaining section intercepts were compared.

Table 5

Analysis of Variance Results

	Production Model II	
	DF	F
E73,N73,S73,E74,N74,S74 vs. TOTAL	56/203	1.39
E73,N73,S73,E74,N74 vs. ENSEN	44/169	1.10
ENSEN, S74 vs. Total	12/247	3.28*
E73,N73,S73 vs. ENS 73	21/102	.99
ENS73,EN74 vs. ENSEN	12/201	1.29
E74,N74,S74 vs. ENS74	24/100	1.43
ENS73,ENS74 vs. Total	12/247	1.86**
E73,E74 vs. East 73 + 74	11/69	1.96**
N73,N74 vs. North 73 + 74	10/67	.85
S73,S74 vs. South 73 + 74	12/67	.93

* Significant at the 1% level.

** Significant at the 5% level.

Table 6

Tests for Differences Between Predicted and Actual Means

Control: South 73

y_p	4619
$d = \bar{n}_e - \bar{y}_p$	97
t	.17

Control: Combined Nonexperimental Sections

$\bar{y}_p$	4708
$d = \bar{y}_e - \bar{y}_p$	8
t	.03

Appendix

DERIVATION OF THE TEST FOR DIFFERENCES BETWEEN MEANS

The purpose of the test developed below is to compare mean weekly output between the experimental and control sections while controlling for differences in the values of all independent variables. The goal is to place as few restrictions as possible on the form and properties of the production function in the experimental section. Operationally the test involves substituting observed values of the independent variables from the experimental section into the estimated production function for the control section. The test then compares mean weekly production predicted from the function for the control sections to mean actual production from the experimental section.

We observe the values of the dependent variable generated in the experimental section. Call these $\underset{\sim}{y}_e$, and let the mean of these be

$$(1) \qquad \bar{y}_e = \sum_{t=1}^{T} \frac{y_{et}}{T} \quad .$$

We assume that y_{et} is normally distributed with unknown mean $\mu_{e,t}$ and variance σ_e^2. In general, $\mu_{e,t}$ will be functionally dependent on values assumed by the vector of exogenous variables ($\underset{\sim}{X}_t$) in the experimental section at time t, but it is not necessary to specify the form of that function for the test described below. Mean output in the experimental section is then normally distributed

$$(2) \qquad \bar{y}_e \sim N(\mu_e, \frac{\sigma_e}{T})$$

where

$$\mu_e = \frac{\sum_{t=1}^{T} \mu_{e,t}}{T} .$$

The vector of values ($\underset{\sim}{y}_c$) of the dependent variable in the control group is observed with a different matrix of exogenous variables $\underset{\sim}{Z}$. Let $\underset{\sim}{Z}$ have dimension N x P; there are N weekly observations on P variables in the control sections. Let $\underset{\sim}{X}$ have dimension T x P where there are T weekly observations on the vector of P independent variables, and the ordering of variables is the same as in $\underset{\sim}{Z}$. The assumed model for the control group is linear:

$$(3) \qquad \underset{\sim}{y}_c = \underset{\sim}{Z}\,\underset{\sim}{\beta} + \underset{\sim}{\epsilon}$$

where $\epsilon \sim N(0, \sigma_c^2 \underset{\sim}{I}_N)$ and $\underset{\sim}{Z}$ and $\underset{\sim}{\epsilon}$ are independent.

If the matrix $\underset{\sim}{X}$ were to occur in the control section, the model in (3) implies

$$(4) \qquad \underset{\sim}{y}_p = \underset{\sim}{X}\,\underset{\sim}{\beta} + \underset{\sim}{u}$$

where

$$\underset{\sim}{u} \sim N(0, \sigma_c^2 \underset{\sim}{I}_T) .$$

That is, $\underset{\sim}{y}_p$ is the vector of observations on the dependent variable which would have occurred if the set of independent variables observed in the experimental section had also been observed in the control sections. The test procedure will be to predict $\underset{\sim}{y}_p$ and to compare the mean of the prediction to $\bar{y}_e$. the mean of the observed values in the experimental section.

By taking the mean of the observations in (4) it follows that

$$(5) \qquad \bar{y}_p = \frac{\sum_{t=1}^{T} y_{pt}}{T} = \bar{\underset{\sim}{X}}\,\underset{\sim}{\beta} + \bar{\underset{\sim}{u}}$$

where $\bar{u} \sim N(0, \frac{\sigma_c^2}{T})$ and $\bar{\underset{\sim}{X}}$ is the vector of sample means of the variables in $\underset{\sim}{X}$ (i.e., $\bar{X}_i = \frac{\sum_{t=1}^{T} X_{it}}{T}$).

Then

$$(6) \qquad \tilde{y}_p \sim N(\mu_p, \frac{\sigma_c^2}{T})$$

where $\mu_p = \bar{\underset{\sim}{X}}'\underset{\sim}{\beta}$.

Since $\underset{\sim}{\beta}$ is unobservable, ordinary least squares estimators are obtained from (3).

$$(7) \qquad \hat{\underset{\sim}{\beta}} = (\underset{\sim}{Z}'\,\underset{\sim}{Z})^{-1}\,\underset{\sim}{Z}'\,\underset{\sim}{y}_c$$

The mean of the predicted values from (4) is then

$$(8) \qquad \hat{\bar{y}}_p = \bar{\underset{\sim}{X}}'\,\hat{\underset{\sim}{\beta}} .$$

Since ordinary least squares is unbiased, it follows that

$$E\,(\hat{\bar{y}}_p) = \bar{\underset{\sim}{X}}'\,\underset{\sim}{\beta} = \mu_p.$$

The variance of the predicted mean is

$$\text{Var}\,(\hat{\bar{y}}_p) = E[(\hat{\bar{y}}_p - \mu_p)'\,(\hat{\bar{y}}_p - \mu_p)]$$

$$= E[(\bar{\underset{\sim}{X}}'\,\hat{\underset{\sim}{\beta}} - \bar{\underset{\sim}{X}}'\,\underset{\sim}{\beta})'(\underset{\sim}{X}'\,\hat{\underset{\sim}{\beta}} - \bar{\underset{\sim}{X}}'\,\underset{\sim}{\beta})]$$

$$= \sigma_c^2\,\bar{\underset{\sim}{X}}'\,(\underset{\sim}{Z}'\,\underset{\sim}{Z})^{-1}\,\bar{\underset{\sim}{X}} .$$

Then

(9) $$\hat{y}_p \sim N(\mu_p, \sigma_c^2 K)$$

where $K = \bar{\underset{\sim}{X}}' (\underset{\sim}{Z}' \underset{\sim}{Z})^{-1} \bar{\underset{\sim}{X}}$.

The objective is to test for the difference in means

(10) $$d = \mu_p - \mu_e ,$$

and the proposed test statistic is

(11) $$\hat{d} = \hat{y}_p - \bar{y}_e .$$

The test statistic is unbiased.

$$E(\hat{d}) = E(\hat{y}_p - \bar{y}_e) = \mu_p - \mu_e = d$$

The variance of the test statistic is

$$\text{Var}(\hat{d}) = \text{Var}(\hat{y}_p) + \text{Var}(\bar{y}_e) = K\sigma_c^2 + \frac{\sigma_e^2}{T}$$

where the assumption that $\underset{\sim}{u}$ and $\underset{\sim}{\epsilon}$ are independent has been utilized.

Thus

(12) $$\hat{d} \sim N\left(\mu_p - \mu_e , K\sigma_c^2 + \frac{\sigma_e^2}{T}\right)$$

The goal is to make a minimal set of assumptions about the experimental section. To avoid estimating the $\mu_{e,t}$ which are functions of $\underset{\sim}{X}_t$, we will assume that $\sigma^2 = \sigma_e^2 = \sigma_c^2$. Then the variance can be estimated using the data from the control sections. The standard error of the regression in (7) is

(13) $$S_c^2 = \frac{\sum_{t=1}^{T} (y_{c_t} - \hat{y}_{c_t})^2}{N-P} .$$

From the normality of $\underset{\sim}{\varepsilon}$ it follows that

$$(14) \qquad \frac{(N-P)S_c^2}{\sigma^2} \sim \chi^2_{N-P} \; .$$

The ratio of a unit normal and the square root of an independent chi-square divided by its degrees of freedom is distributed as the t. Thus

$$\frac{\dfrac{d - d}{\sigma\sqrt{K+\frac{1}{T}}}}{\sqrt{\dfrac{(N - P)S_c^2}{\sigma^2} \Big/ (N - P}} \sim t_{N-P} \; .$$

This reduces to the following

$$(15) \qquad \frac{d - d}{S_c\sqrt{K+\frac{1}{T}}} \sim t_{N-P}$$

This is the basis of the test results reported in the economic analysis of mean weekly production.

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