T-1505

SENSITIVITIES OF A VENTILATION NETWORK FOR A ROOM AND PILLAR MINE

By

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T-1505

A Thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

Ventilation is an integral part of any mine and is especially important for a coal mine. Sensitivities of a ventilation network are tested to determine what parameters are most critical. Of the physical and economic parameters examined, the most critical were size of entries, number of entries, thickness of seam, friction factor and number of working sections.

The ventilation network used was also discovered to be sensitive to intake air introduced into the system to supplement air supplied by the main shaft. For the fans used in the networks, the best supplementary air was supplied by a 12-foot diameter shaft intercepting the main entries.

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ACKNOWLEDGEMENTS

Consolidation Coal Company contributed the original idea for this thesis and much of the shaft cost information. Their contribution is much appreciated. Thanks are also extended to salesmen at Joy Manufacturing, Harrison-Western and Teton Exploration who contributed cost data used for this thesis.

Special appreciation is due Dr. Donald Gentry and Dr. Fun-Den Wang for their valuable advice during the writing of this thesis.

INTRODUCTION

Much attention is currently being focused on the proper ventilation of mines. In this age of rapid communication, recent mine disasters have been publicized throughout the country and have caused passage of a law to improve working conditions in mines and create a better environment for the miners.

The Federal Coal Mine Health and Safety Act of 1969 was enacted to improve working conditions in mines. Part of the law is concerned with effective ventilation of mines. Many accidents in coal mines are a result of explosions. Proper ventilation can help eliminate the conditions which allow explosive mixtures of gases to accumulate.

The law designates minimum air quantities which must be provided to working faces:

> The minimum quantity of air reaching the last open crosscut in any pair or set of developing entries and the last open crosscut in any pair or set of rooms shall be nine thousand cubic feet a minute, and the minimum quantity of air reaching the intake end of a pillar line shall be nine thousand cubic feet a minute. The minimum quantity of air in any coal mine reaching each working face shall be three thousand cubic feet a minute.(1)

The new law necessitates closer monitoring of mine ventilation systems to determine whether the proper amount of air is available to the working faces at all times. Mines have the problem of meeting the requirements of the law and minimizing the costs of improving ventilation.

There are many ways to improve ventilation in a mine. Airways can be made smoother. Leakages of air from intake to return entries due to poor stoppings can be decreased by more effective sealing methods or nearly eliminated by driving two sets of entries with a pillar separating intake entries from return entries.

This thesis investigates the contribution of air intakes in addition to the main shaft as a possible aid to better mine ventilation. Improvement of ventilation is necessary to meet requirements of the Federal regulations. Sensitivities of other parameters in a ventilation network are examined to provide a guideline for improving a ventilation system by altering the critical parameters wherever possible.

STATEMENT OF THE PROBLEM

The major objective of this study is to test the sensitivities of physical and economic parameters of a mine ventilation system for a room and pillar mine. Another goal is to test the sensitivity of the ventilation system to the use of more than one shaft for intake air.

Sensitivities are examined for physical and economic parameters: depth of shaft, size of shaft, thickness of seam, type of fan, number of entries, size of entries, friction factor, number of working sections, interest rate, percent recovery, power cost, rate of production and profit per recoverable ton of coal.

One objective of this study is to determine which combination of air shafts will ventilate as large an area as possible with the lowest capital investment in shaft construction, fans and working sections. Selected combinations of a large ventilation shaft and smaller bored shafts ventilating an area are compared to a single large shaft ventilating the area.

The study is oriented toward coal mines and mines classified as gassy by the United States Bureau of Mines,

but the comparisons would apply to any room and pillar mine. For a room and pillar mine not in coal or not classified as gassy, it would not be necessary to plan for permissible equipment. Thus, the costs are lower if non-permissible equipment is used, but relative costs remain unchanged.

SETTING UP THE NETWORKS

Physical Conditions

A simplified ventilation network was formulated for testing the parameters. Some simplifying assumptions were made but the network was set up as realistically as possible. The results of several ventilation surveys of operating mines were studied and the networks used for this study were modeled after these surveys.

Figure 1 is a schematic drawing of the basic network used for all the cases and is representative of the maximum mining condition for a given area. Each branch represents a set of entries. For example, in the main entries there are four intake entries, four return entries and one escapeway entry. In some non-gassy room and pillar mines the escapeway entry would not be required. The ventilation is not affected since the escapeway entry is not an airway, but the life of the area changes slightly when the number of entries to be developed changes.

More than one butt may be ventilated from one submain, but since the airways are in parallel it is only necessary to require the accumulated amount of air for one butt. Regulators control the amount of air

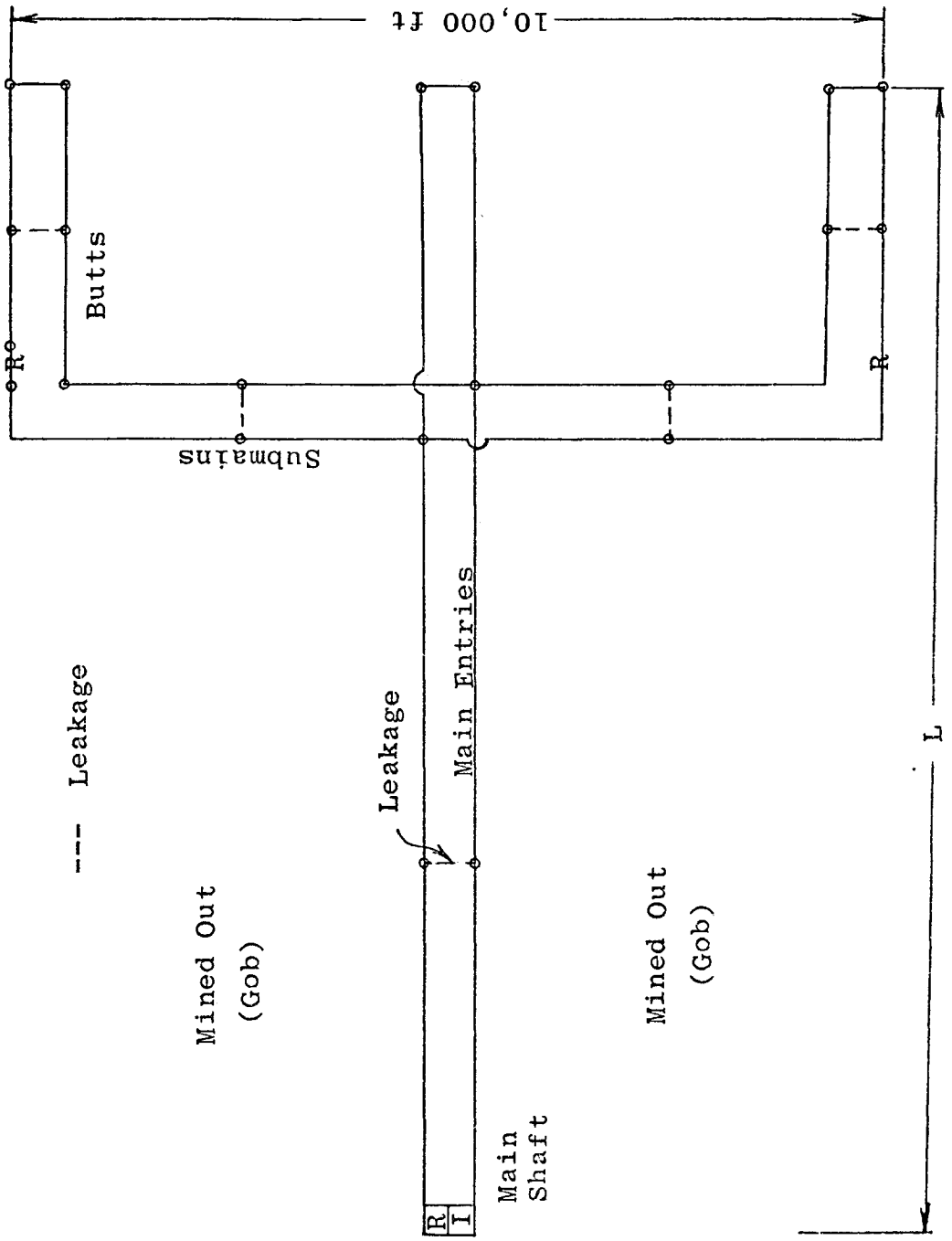


Fig. 1. Schematic of basic ventilation network

supplied to each butt. Air requirements are the same for a submain when butts are analyzed in parallel as when they are combined into one representative butt. The combined network is easier to work with.

In an actual mine, it may not be possible to combine the butts if there are different conditions in each. If there is a problem with ventilating the mine, each butt would need to be analyzed separately to find the source of the problem. If a mine is in the planning stages, combining air requirements for one submain would be reasonable. For this study, it is sufficient to combine the butts into one butt.

Leakages are handled by inserting a branch from a set of intakes to a set of returns. Leakage resistance for a set of entries is calculated based on the total length of the entries. The factor used in this study, 150 per 1000 feet, is one that was determined during ventilation surveys of operating mines.

Leakage in the main entries includes air lost in the mined-out areas. Resistance of the leakage branch is low enough to allow a loss of air from intake to return of 25,000 cfm (cubic feet per minute) to 50,000 cfm. This figure is probably low in relation to actual

losses in an operating mine, but is considered adequate for comparing the alternatives examined in this study. For this study, leakage is assumed to be highly controlled.

The network represents the area of a mine ventilated by a shaft or combination of shafts. The shafts provide the only air taken into the area. The shafts included in the network service the area during its life and when the area is mined out, the shafts contribute air to ventilate the main entries of the area.

Width of the area is 10,000 feet for all the networks tested. The length (L shown on Fig. 1) is varied until the optimum is reached for each set of conditions. The length is a maximum when the amount of air supplied to each butt approaches the amount of air regulated for each butt. At the maximum length, leakage in the submains is at a minimum so the amount of air supplied to the submain is nearly the amount regulated for the butt.

Some physical conditions are kept constant to allow comparison of Case 1 to Case 2 and Case 4. Case 3 is explained in a later section and is not used for comparison of the cases.

The constant physical conditions are:

1. Friction factor (K-factor) is 60 x 10^{-10} for all entries. This factor is obtained from Kingery (4) and is the factor for an airway in coal with an average surface irregularity and slightly obstructed, straight airways. Friction factor for the 17-foot x 30-foot elliptical shaft is 80 x 10^{-10} and is higher because there are generally more obstructions in the shaft such as artificial support, cage and skip guides, electric cables, etc.

2. The cross-section of all airways (exclusive of the shaft) was assumed to be 5 feet by 20 feet because many coal mine entries range between 15 feet and 20 feet in width.

3. Four intakes and four returns are used in the main entries, three intakes and three returns in the submains and two intakes and two returns in the butts. This combination of entries is abbreviated 4I,4R throughout this thesis.

4. The mine is at a depth of 500 feet from the surface and all shafts are 500 feet deep.

5. The quantity of air supplied to each butt is 80,000 cfm or a total of 160,000 cfm is supplied to 16 working sections.

6. Three different fans are used for all cases.

The fans used are a Buffalo Forge 84-D9-1170, a Joy Manufacturing 84-30-1170 and a Joy 72-30-1170, all operating at 1170 rpm.

Economic Conditions

The shaft arrangements considered are mutually exclusive alternatives, so to compare the alternatives a net present value per recoverable ton is calculated. The net present value per ton is a relative number for use in comparison of alternatives and should not be considered an absolute value for the project.

The networks are assumed to be the initial stage of a mine with a life of 20 years. The area specified has a particular life dependent on its individual size. When that particular area is mined out the mains are kept open to provide haulage and ventilation for the rest of the mine. The cost of ventilating the mains after an area is mined out is continued through the 20-year life of the mine. Using a 20-year life for all networks eliminates the problem of comparing unequal-life alternatives.

The present values of costs per ton, present values of benefits per ton and net present values per ton are calculated and plotted against interest rate. The costs included in the analysis are cost to sink the

shaft(s), cost of the fan and the cost of starting each working section. Variable costs include operating cost of the fan (annual power cost), and a maintenance cost for the fan.

A profit of $0.50 per ton recovered is used in calculating present value of benefits per recoverable ton. Present value of benefits per ton is determined by calculating present value of the total return of each year's production. Production for a year is assumed to be a discrete yearly tonnage. That is, the year's production is accrued at the end of the year.

The power cost at maximum production and distance is assumed to be the average cost over the life of the area. At 5 cents per kilowatt hour, cost for power increases by only $6900 per 100,000 cfm per year. An increase in length of 3000 feet only changes the air requirements by 10,000 cfm. At the beginning of the mining operation, the fan supplies much more air than is actually needed, so the volume of air may not change by more than 100,000 cfm over the life of the area. Thus, the assumption of average power cost does not result in a significant error.

Capital costs for sinking the shafts are assumed to be constant for the life of the area. That is, the

costs are 1972 costs and are not escalated over the life of the area.

Normal maintenance cost is 5% of the initial fan cost per year. Maintenance cost includes replacing blades every 3 to 4 years and rewinding the motor after 10 years to carry the fan through the 20-year life of the mine.

TABLE I

CONSTANT CONDITIONS USED IN

COMPARING ALL CASES

Physical Conditions	
Air supplied to each submain	80,000 cfm
Number of intakes and returns on main entries	4I,4R
Number of intakes and returns on submains	3I,3R
Number of intakes and returns on butts	2I,2R
Size of entries	5 ft x 20 ft
Friction factor of entries	60×10^{-10}
Friction factor of shafts	80×10^{-10}
Depth of shafts	500 ft
Width of area	10,000 ft
Economic Conditions	
Interest rates	12%,15%,16%,20%
Power cost	$0.05 per kwh
Maintenance of fans	5% of original fan cost per year
Cost to start a section	$250,000

TABLE I (cont.)

Economic Conditions (cont.)

Fan Costs -	
Buffalo Forge 84-D9-1170	$6180
Joy 84-30-1170	$7551
Joy 72-30-1170	$7360
Production rate	800 tpd
Tonnage factor	1800 tons per acre-ft
Percent recovery	40%
Working days per year	220
Number of shifts per day	1
Profit per ton	$0.50

ANALYZING THE NETWORKS

Ventilation Calculations

A mine ventilation program developed at Pennsylvania State University by Wang and Saperstein (7) was used to analyze all the networks for this study. The program was run on the Colorado School of Mines PDP-10 computer and used via teletype. The ventilation program is listed in Appendix A.

A change was made to allow any number of entries to be included in the resistance calculation. Other changes were made to shorten the output to numbers essential to this study. A sample of the shortened output is shown in Fig. 2.

When running the ventilation network program, it was discovered that there was a linear relationship between the extra air supplied to the butts and the total length of the area. This was a valuable tool for narrowing down the choice of length for each test of the network. Unfortunately, the slopes of the lines were not the same for each set of conditions (See Fig. 3), and the slopes were not the same for one fan when other conditions were different. The main advantage to using the graph was that it shortened the trial

```
SINGLE MINE, ONE SHAFT 17X30 EL

   NB   NJ  MAXJ  NM  NF MAXIT NVP FIXB      E
   34   27   68    8   1  100   0    2   0.0500


FAN    J1     J2    KEY      POINT        X        FX
     1     17     1     0
 1  160.0000  7.0000
 2  200.0000  5.3000
 3  220.0000  3.9500
 4  240.0000  2.2500

      7 ITERATIONS          SUMD = 0.4913841E-01


BRANCH    J1   J2       R        Q        H

     1    55   56  0000.000   70.0000    0.000
     2    65   66  0000.000   70.0000    0.000
     3    17    1     0.012  210.3288    0.052
     4     1   10     0.012  210.3288    0.052
    13    12   50     0.148   72.8317    0.078
    24    12   60     0.136   72.8318    0.072


FAN    J1    J2       Q        FQ

1      17     1  210.3288  4.6433969
```

Fig. 2. Sample output from ventilation program (shortened version).

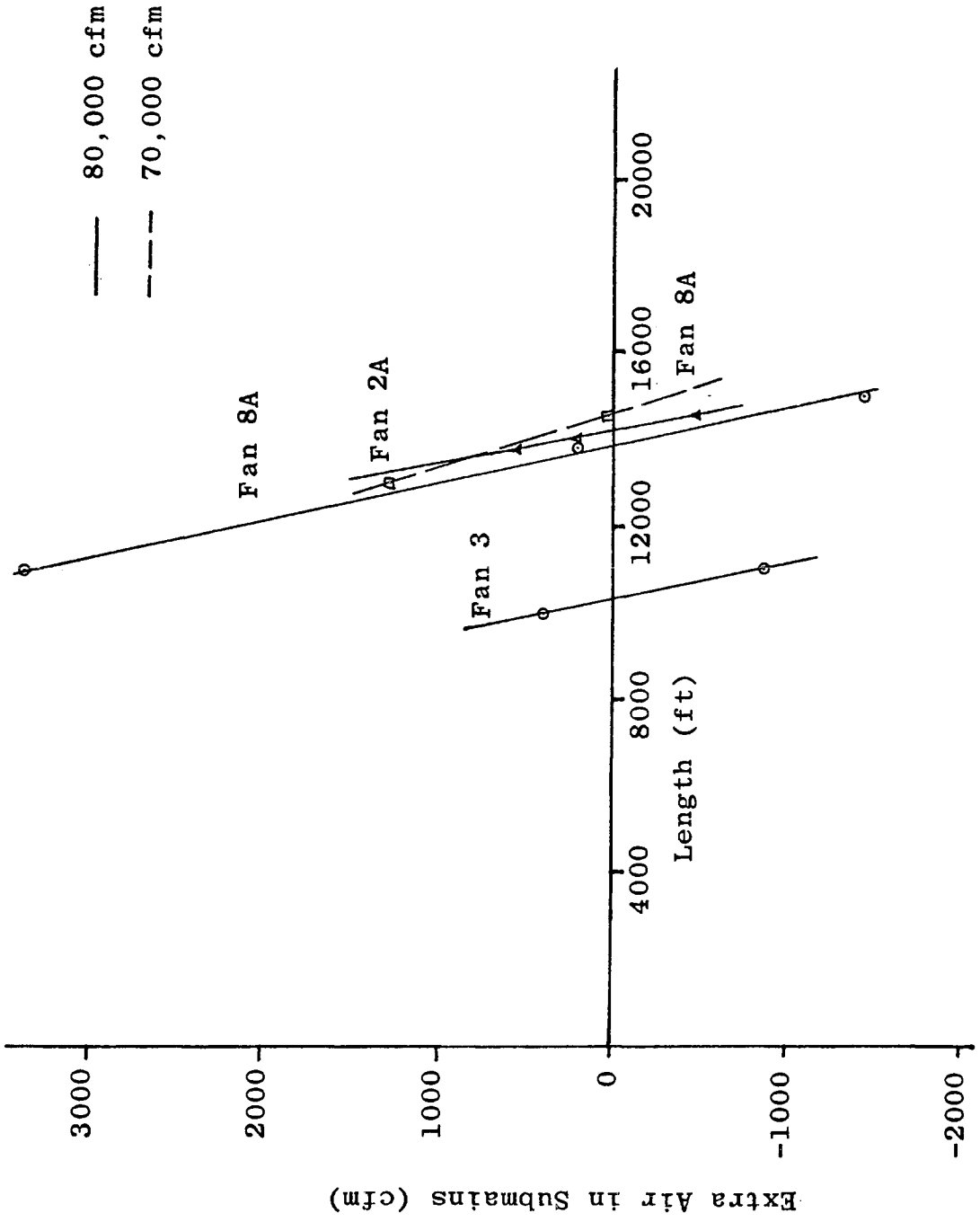


Fig. 3. Relationship of Length to Extra Air in Submains.

and error process of finding the maximum length of the area. An optimum length for the network could not be determined from one point and an established slope of line.

Present Value Calculations

The quantity of air, water gage at the fan, length of the area, fan cost, number of sections, size and number of entries and shaft costs are used as input data to the present value program, PV.F4 (See Appendix B). This program calculates total present value of costs, recoverable tons, present value of costs per recoverable ton and present value of benefits per recoverable ton.

Present value of the cost to start sections is calculated by assuming a limited number of sections can be started at any one time. Thus, two sections begin developing the mains from the bottom of the shaft. When the main entries have been developed to a distance of 1000 feet from the shaft, four more sections are added and two sections develop the submain entries on each side of the main entries. The process is repeated until all the sections have been assigned.

This staggered method of assigning a cost to sections is more accurate and more realistic than assuming all the sections start at the beginning of

development of the area.

Next the program calculates the operating cost for the fan over the life of the mine, the total recoverable tons for the area, a present value of fan maintenance and present value of shaft costs. Present value of all the costs is summed and present value per ton is calculated.

Economics of the alternatives cannot be compared by costs alone, so a profit per ton of ore is assumed and present value of benefits is calculated. The costs used in this study do not include all the costs of mining an area so a return is determined to indicate relative desireability of the alternatives.

It is assumed that the benefits are accrued at the end of each year. The benefits, return from sale of the material, are discrete cash flows at a discrete interest rate. All payments are considered to be made at the end of the year in which they occur and interest is paid at that time. The factor for a series of uniform payments is used to calculate the present value of benefits. The benefits are uniform payments because the assumption of constant rate of production results in the same tonnage per year for each year of life.

In reality, benefits may be accumulated

continuously at a continuous interest instead of by discrete payments at the end of a year. Present values of benefits calculated as discrete payments at a discrete interest rate are less than present values of benefits calculated at a continuous return and continuous interest rate.

The present value program is also used for sensitivity analysis of percent interest, power cost, percent recovery and production rate. When a sensitivity analysis is not wanted, the loops involving the sensitivities can be made into comment statements and will not be calculated in the program.

Two equations are used to find present value of costs for discrete cash flows. The equation used to find present value of a single payment is

$$\text{Present Value} = S \times \frac{1}{(1 + i)^n}$$

where

S = a single payment at a future time

i = interest (or discount) rate

n = years from present at which time payment is made.

This equation is used in calculating present value of costs of the sections and present value of costs of shafts subsequent to the main shaft. Both costs are

single payments made at a specific future time.

The other equation is that which determines the present value of a series of uniform payments (an annuity).

$$\text{Present Value} = R \times \frac{(1 + i)^n - 1}{i(1 + i)^n}$$

where

R = a uniform payment at the end of each period.

This equation is used to calculate present value of fan operating costs, fan maintenance costs and benefits.

SENSITIVITIES OF CASE 1

Case 1 is a room and pillar mine layout (See Fig. 1) with a single large ventilation shaft. Parameters are varied and net present values per ton are calculated to determine which parameters are the most critical. Parameters being varied fall into two classes: 1) those which primarily affect the physical aspects of the area and 2) those which primarily affect the present values of capital and operating costs and present values of benefits.

The physical parameters examined are:

1. Depth of shaft
2. Size of shaft
3. Type and performance of fan
4. Number of entries
5. Size of entries
6. Friction factor (K-factor)
7. Number of working sections
8. Thickness of seam.

Those parameters primarily affecting present value of capital and operating costs are:

1. Interest rate
2. Power cost

3. Percent recovery

4. Rate of production

5. Profit per recoverable ton.

For many real situations, some of the parameters considered in this study are not variable. Thickness of the seam is one parameter which may or may not be variable. Frequently the thickness varies due to geological factors, but often the coal seam will be of uniform thickness over an extensive area.

The effects on ventilation and power costs of mining a different thickness of seam could affect a decision as to what thickness of seam to mine.

Explanation and Results of Sensitivity Tests -

Physical Parameters

1. Depth of shaft - Figure 4 is a plot of actual bids for a series of shallow shafts in soft rock. The line drawn between the points is not meant to show an overall trend but to indicate the relationship between the costs for a specific set of conditions.

The total amount of air needed did not change significantly when the depth of the shaft was changed by 100 feet (See Table II). When the depth was changed to 1000 feet and compared to the 500-foot shaft, the main change was in the cost of the shaft, so the change in net present value is directly related to the

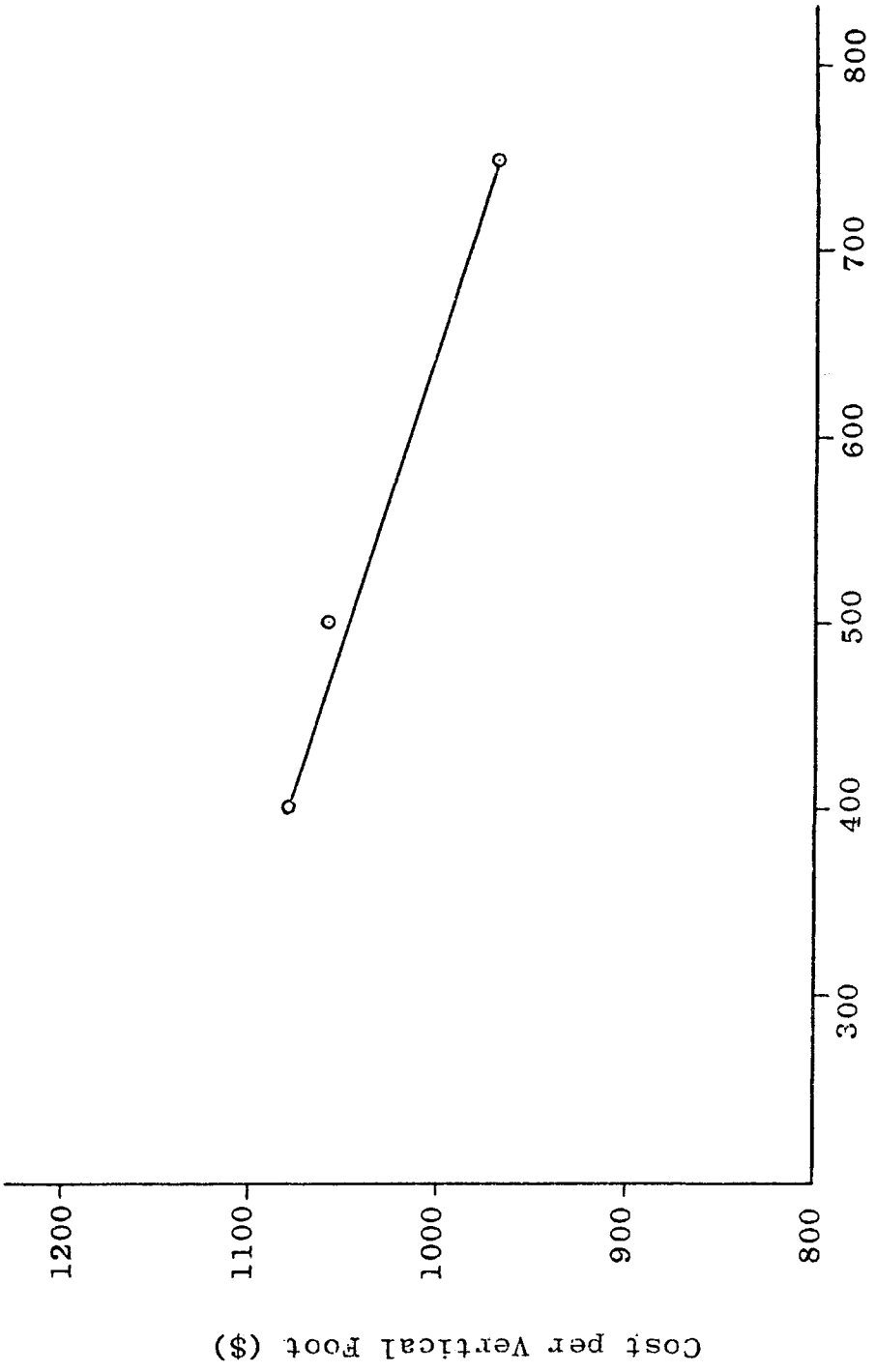


Fig. 4. 1969 Costs for a 17-ft x 30-ft elliptical shaft.

TABLE II

SENSITIVITY OF DEPTH OF SHAFT

70,000 cfm per submain

4I,4R

Fan 3

Depth (ft)	Length (ft)	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
500	18,400	205,560	4.96	15.207
600	18,400	205,383	4.97	15.207
700	18,400	205,266	4.98	15.207
1000	18,400	204,677	5.02	15.207

TABLE II (cont.)

Depth (ft)	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest			
500	0.2670	0.3397	0.0727
600	0.2747	0.3397	0.0650
700	0.2811	0.3397	0.0586
1000	0.3068	0.3397	0.0319
15% interest			
500	0.2582	0.3121	0.0539
600	0.2659	0.3121	0.0462
700	0.2723	0.3121	0.0398
1000	0.3979	0.3121	0.0142
16% interest			
500	0.2557	0.3038	0.0481
600	0.2634	0.3038	0.0404
700	0.2698	0.3038	0.0340
1000	0.2954	0.3038	0.0084
20% interest			
500	0.2475	0.2736	0.0261
600	0.2552	0.2736	0.0184
700	0.2616	0.2736	0.0120
1000	0.2872	0.2736	-0.0136

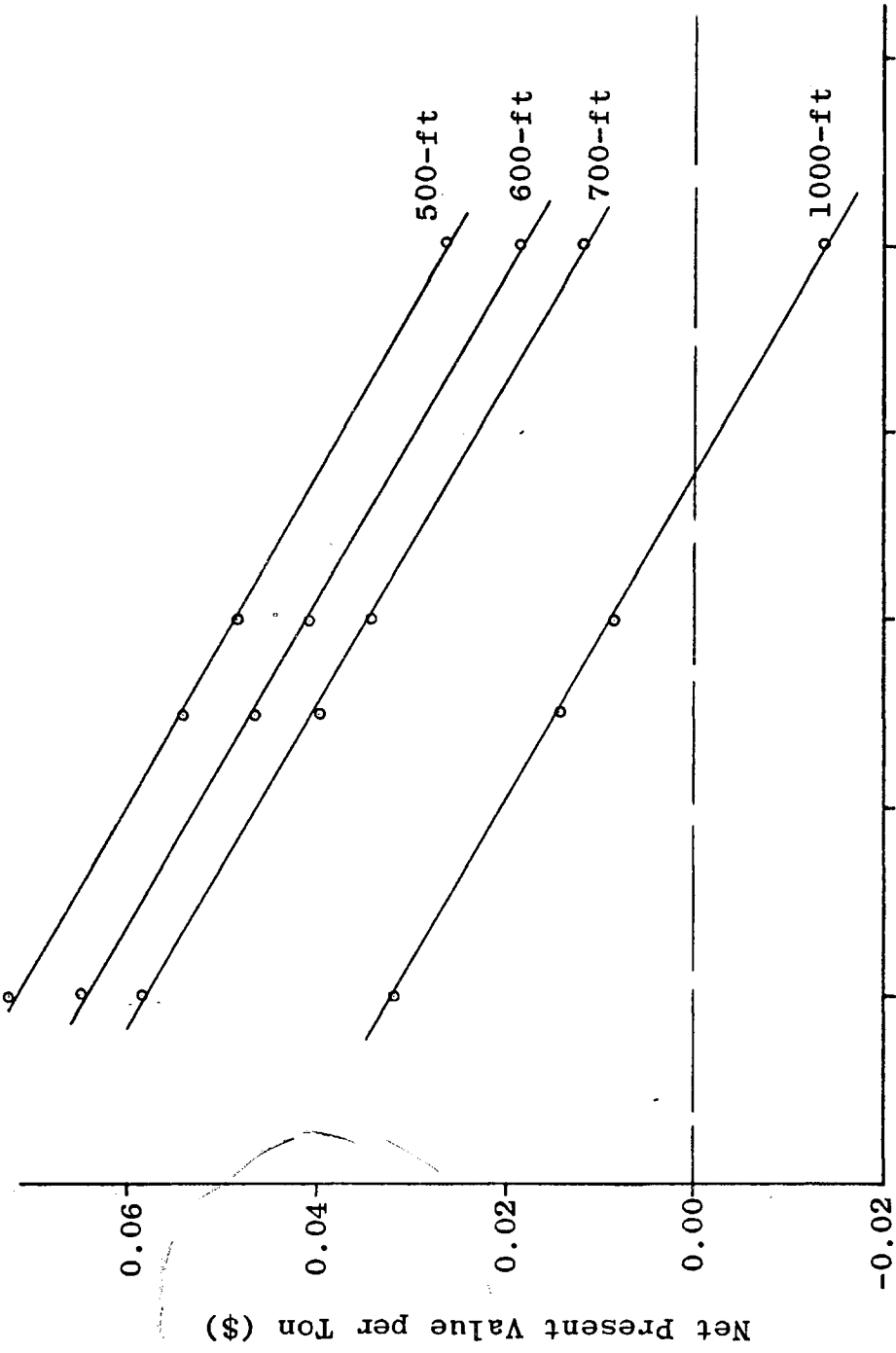


Fig. 5. Effect of Depth of Shaft on Net Present Value per Ton.

difference in cost of the shafts. The area mined remains the same size so present value of benefits does not change.

A problem that is not considered in this study is that the density of the air increases with the depth of the mine, which increases the resistance of the air to movement. Increased air resistance puts more load on the fan and increases the annual power cost. The mine ventilation program is not at the present time able to handle a change of density in the network calculations.

Figure 5 shows a decrease of net present values with depth of the shaft. The difference between the curves is directly related to cost of the shafts. The shaft cost is assumed to be incurred during the first year, so the present value of the shaft cost is the same as the shaft cost. For the 1000-foot shaft, the net present value is negative at 20% interest. Thus, under the given conditions, a 1000-foot shaft does not give a return large enough to balance the costs considered in the calculation.

2. Size of shaft - Three types of shafts were tested for the main shaft in the network. The base condition is the 17-foot x 30-foot elliptical shaft described previously. The elliptical shaft was compared to two 12-foot down-drilled shafts (one for intake air,

one for return air) and a 20-foot conventionally sunk shaft divided in the center and used for intake and return air (See Fig. 6).

Costs to sink the shafts vary with type and size. Shaft costs used in this study are shown in Table III. The 17-foot x 30-foot elliptical shaft costs are from a set of 1969 bids and the costs are taken directly from the bids (See Fig. 4). The 1969 costs are escalated by 30% as suggested by a shaft construction company in Denver, thus bringing the costs to 1972 equivalents.

The shaft costs also take into consideration the type of ground being excavated to sink or drill the shaft. For this study, the ground is assumed to be sedimentary material consisting of shales, clays, limestones and sandstones.

Figure 7 shows a decrease in net present values when using shafts other than the 17-foot x 30-foot elliptical shaft. The difference in net present value per ton recovered is almost $0.02 more for the 17-foot x 30-foot elliptical than for the 20-foot diameter shaft. According to Fig. 7, the most desireable shaft to use under the given conditions is the 17-foot x 30-foot elliptical shaft, because it has the highest net present value per ton for interest rates up to 20%.

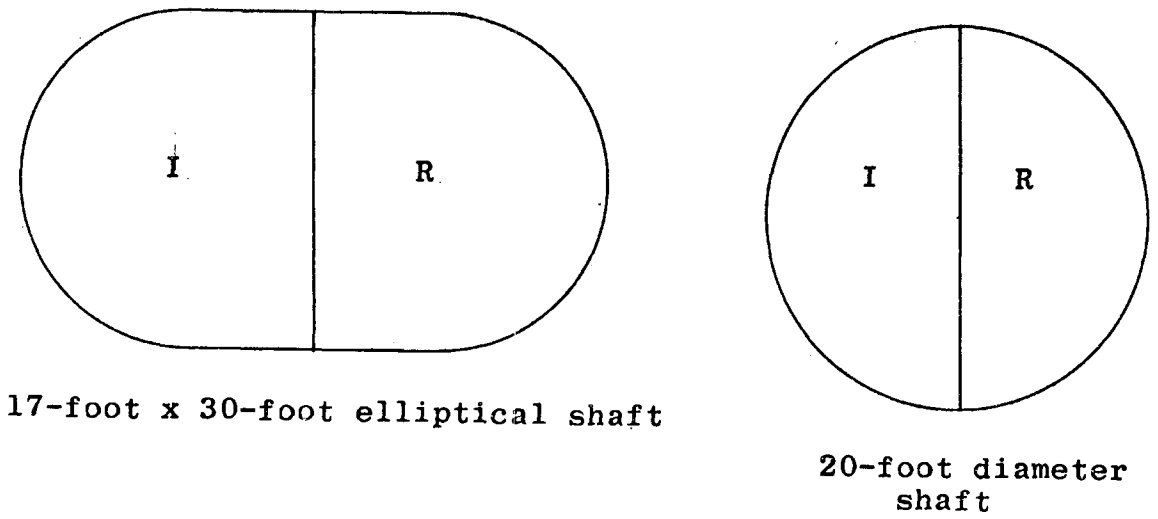


Fig. 6. Shafts used for main shaft sensitivity.

TABLE III

SHAFT COSTS

17-ft x 30-ft elliptical shaft - conventionally-sunk			
1969 cost -	$1057 per vertical foot (includes lining)		
30% escalation	317		
500 ft at	$1374 =		$687,000
20-ft diam conventionally-sunk shaft			
1969 cost -	$785.40 per vertical foot (includes lining)		
30% escalation	235.60		
500 ft at	$1021.00 =		$510,500
two 12-ft diam down-drilled shafts			
1972 cost -			
Drilling	$375 per ft		
Mobilization	36 per ft		
500 ft at	$411 per ft =	$205,500	
Lining - $3.25 per sq ft			
18,849.5 sq ft x 3.25		61,261	
Cost for one 12-ft shaft		$266,761	
Cost for two 12-ft shafts			$533,522

TABLE IV

EFFECT OF DIFFERENT SHAFT SIZES

70,000 cfm per submain

4I,4R

Fan 3

Shaft	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
17x30	19,000	204,216	5.10	15.702
2 12-ft	17,200	192,848	5.70	14.215
20-ft	16,000	202,571	5.15	13.223

TABLE IV (cont.)

Shaft	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest			
17x30	0.2595	0.3363	0.0768
2 12-ft	0.2786	0.3466	0.0680
20-ft	0.2949	0.3538	0.0589
15% interest			
17x30	0.2508	0.3084	0.0576
2 12-ft	0.2686	0.3198	0.0512
20-ft	0.2846	0.3277	0.0431
16% interest			
17x30	0.2484	0.2999	0.0515
2 12-ft	0.2658	0.3116	0.0458
20-ft	0.2817	0.3197	0.0380
20% interest			
17x30	0.2403	0.2695	0.0292
2 12-ft	0.2564	0.2820	0.0256
20-ft	0.2720	0.2907	0.0187

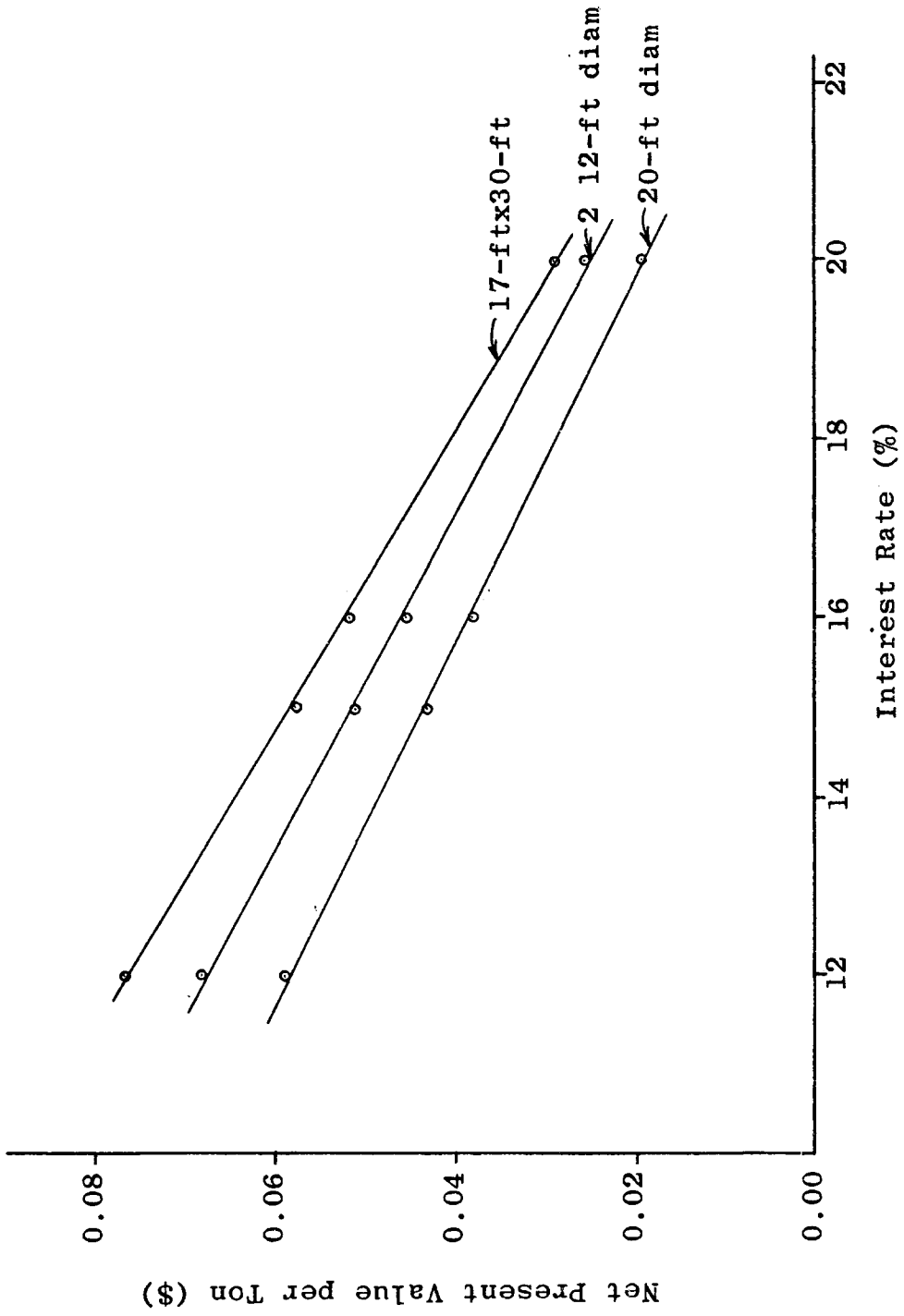


Fig. 7. Effect of size of Main Shaft on Net Present Value per Ton.

3. Type and performance of fans - Fans manufactured by two companies were used in this study (See Table V).

The maximum change in net present value per ton when comparing performances of the different fans was $0.08 (See Table VI). The blade settings for the three fans compared produced nearly the same range of quantities. There was more difference in net present value per ton between fan 2A and fan 3 than between fan 2A and fan 8A (See Fig. 8). Fan 3 results in a negative net present value per ton and could not be considered a possibility for use in the given network.

Changes in blade settings produced a change in net present value per ton recovered of $0.085 at 12% interest. The differences between alternatives are less at 20% interest (See Table VII and Fig. 9) and are converging at higher interest rates. The lines are nearly parallel and would cross eventually, but at interest rates higher than used for this study. Each fan and blade setting is mutually exclusive for interest rates of 12% to 20% and for the given network conditions, fan 2 with blade setting at 40 is the fan which will give the highest profit per ton.

4. Number of Entries - Changing the number of

TABLE V

FAN CURVES AND COSTS

Fan	Blade Setting	Cost	Quantity (cfm)	Water Gage (in.)
Buffalo Forge - 84-D9-1170				
2	30	$6180	130,000	5.80
			150,000	5.40
			180,000	4.40
			200,000	3.60
2A	40	$6180	180,000	6.40
			200,000	5.85
			220,000	5.20
			240,000	4.40
Joy 84-30-1170				
3	#2	$7551	160,000	7.00
			200,000	5.30
			220,000	3.95
			240,000	2.25
Joy 72-30-1170				
8A	#0	$7360	180,000	7.20
			200,000	6.35
			220,000	5.30
			240,000	4.00

TABLE V (cont.)

Fan	Blade Setting	Cost	Quantity (cfm)	Water Gage (in.)
Joy	72-30-1170			
8	#1	$7360	140,000	7.30
			160,000	6.60
			180,000	5.50
			200,000	3.90

TABLE VI

COMPARISON OF THREE FANS

80,000 cfm per submain

4I,4R

Fan	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
2A	14,000	230,213	4.80	11.570
3	10,000	226,968	3.39	8.264
8A	13,800	229,476	4.71	11.405

TABLE VI (cont.)

Fan	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest			
2A	0.3354	0.3775	0.0421
3	0.4419	0.4017	-0.0402
8A	0.3390	0.3787	0.0397
15% interest			
2A	0.3233	0.3544	0.0311
3	0.4295	0.3822	-0.0473
8A	0.3269	0.3577	0.0288
16% interest			
2A	0.3199	0.3472	0.0273
3	0.4260	0.3760	-0.0500
8A	0.3236	0.3486	0.0250
20% interest			
2A	0.3088	0.3208	0.0120
3	0.4143	0.3530	-0.0613
8A	0.3124	0.3223	0.0099

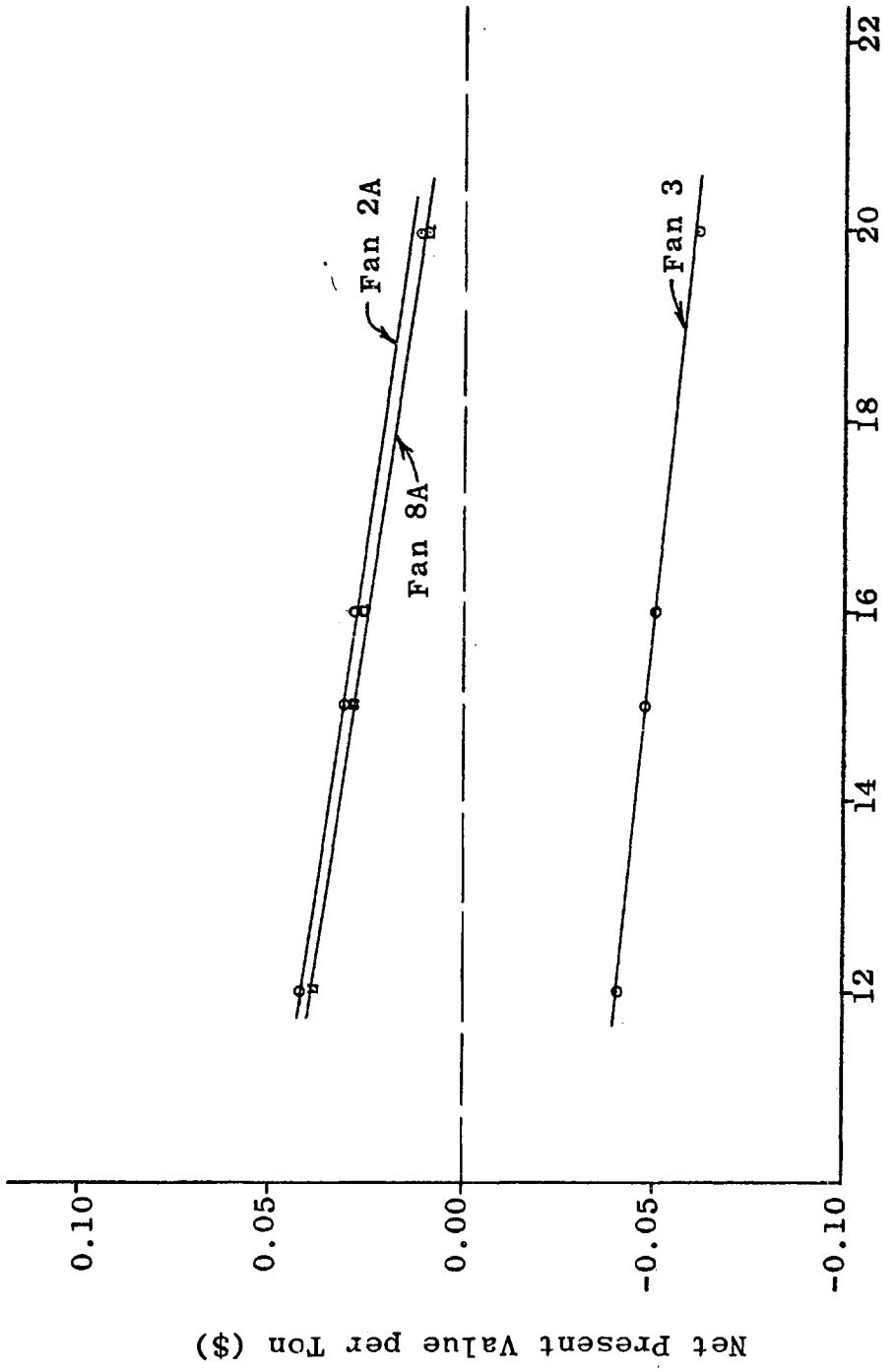


Fig. 8. Effect of Different Fans on Net Present Value per Ton.

TABLE VII

EFFECT OF BLADE SETTINGS

70,000 cfm per submain

4I,4R

Fan	Blade Setting	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
2	30	13,000	202,000	3.47	10.744
2(A)	40	22,000	206,384	5.66	18.182
8	#1	14,500	201,216	3.79	11.983
8(A)	#0	22,500	206,390	6.08	18.595

TABLE VII (cont.)

Fan	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest			
2	0.3573	0.3726	0.0153
2A	0.2276	0.3200	0.0924
8	0.3240	0.3630	0.0390
8A	0.2270	0.3174	0.0904
15% interest			
2	0.3482	0.3488	0.0006
2A	0.2196	0.2907	0.0711
8	0.3152	0.3381	0.0229
8A	0.2184	0.2878	0.0694
16% interest			
2	0.3456	0.3415	-0.0041
2A	0.2173	0.2818	0.0645
8	0.3127	0.3304	0.0187
8A	0.2160	0.2790	0.0630
20% interest			
2	0.3368	0.3144	-0.0224
2A	0.2098	0.2506	0.0408
8	0.3044	0.3023	-0.0021
8A	0.2080	0.2476	0.0396

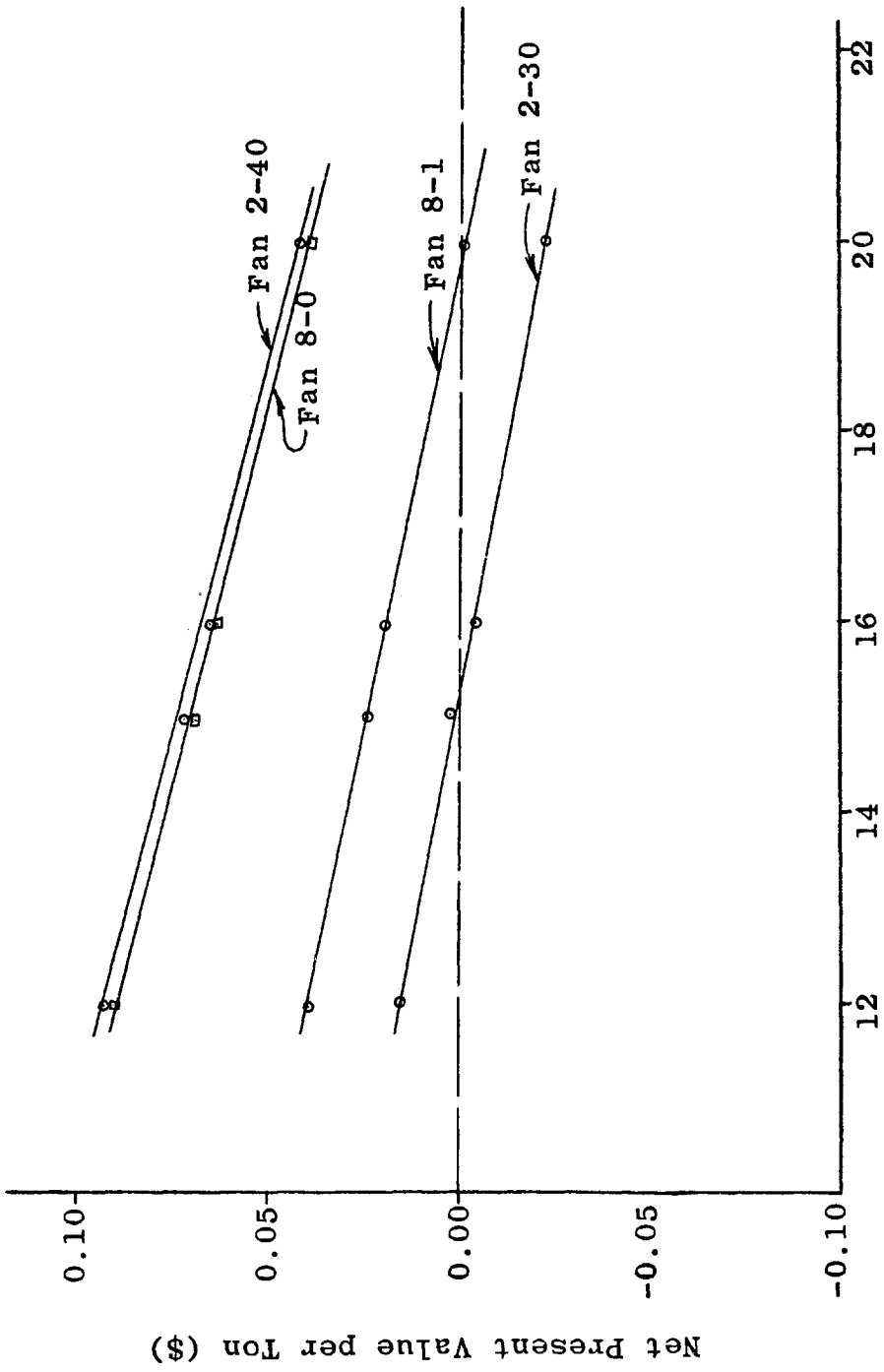


Fig. 9. Effect of Blade Settings on Net Present Value per Ton.

entries directly affects the mine resistance, thus changing the optimum length considerably (See Table VIII). The optimal length is increased more than twice for each set of conditions investigated.

Whatever directly affects the mine resistance has a significant effect on the optimum size of the area. If more entries are used, a lower mine resistance occurs, thus lowering the number of shafts required through the life of the entire mine. Each shaft can service a larger area before another main shaft is needed when more entries are driven.

Figures 10 and 11 show the effect of changing the number of entries for two fans. Both curves for three intakes and three returns for main entries have a negative net present value per ton. For each fan considered, it is more desirable to drive more entries for each set of mains, submains and butts.

5. Size of entries - Size of entries also directly affects the mine resistance and differences in size of the area are very apparent. In planning a mine, if the structure and strength of the materials permit, it is preferable to use the larger size openings. The shaft and fan will have a longer effective life and will

TABLE VIII

EFFECT OF CHANGING NUMBER

OF ENTRIES

70,000 cfm per submain (Fan 3)

60,000 cfm per submain (Fan 2)

Fan	Number of Entries	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
3	3I,3R	7,000	220,794	3.88	5.785
3	4I,4R	19,000	204,216	5.10	16.330
2	3I,3R	9,000	194,468	3.84	7.438
2	4I,4R	21,850	177,628	4.51	18.058

TABLE VIII (cont.)

Fan	Number of Entries	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest				
3	3I,3R	0.6857	0.4146	-0.2711
3	4I,4R	0.2549	0.3363	0.0814
2	3I,3R	0.3916	0.3830	-0.0086
2	4I,4R	0.1763	0.3024	0.1261
15% interest				
3	3I,3R	0.6664	0.3972	-0.2692
3	4I,4R	0.2478	0.3084	0.0606
2	3I,3R	0.3802	0.3606	-0.0196
2	4I,4R	0.1709	0.2718	0.1009
16% interest				
3	3I,3R	0.6610	0.3916	-0.2694
3	4I,4R	0.2458	0.2999	0.0541
2	3I,3R	0.3771	0.3537	-0.0234
2	4I,4R	0.1694	0.2627	0.0933
20% interest				
3	3I,3R	0.6431	0.3708	-0.2723
3	4I,4R	0.2396	0.2695	0.0299
2	3I,3R	0.3667	0.3279	-0.0388
2	4I,4R	0.1644	0.2309	0.0665

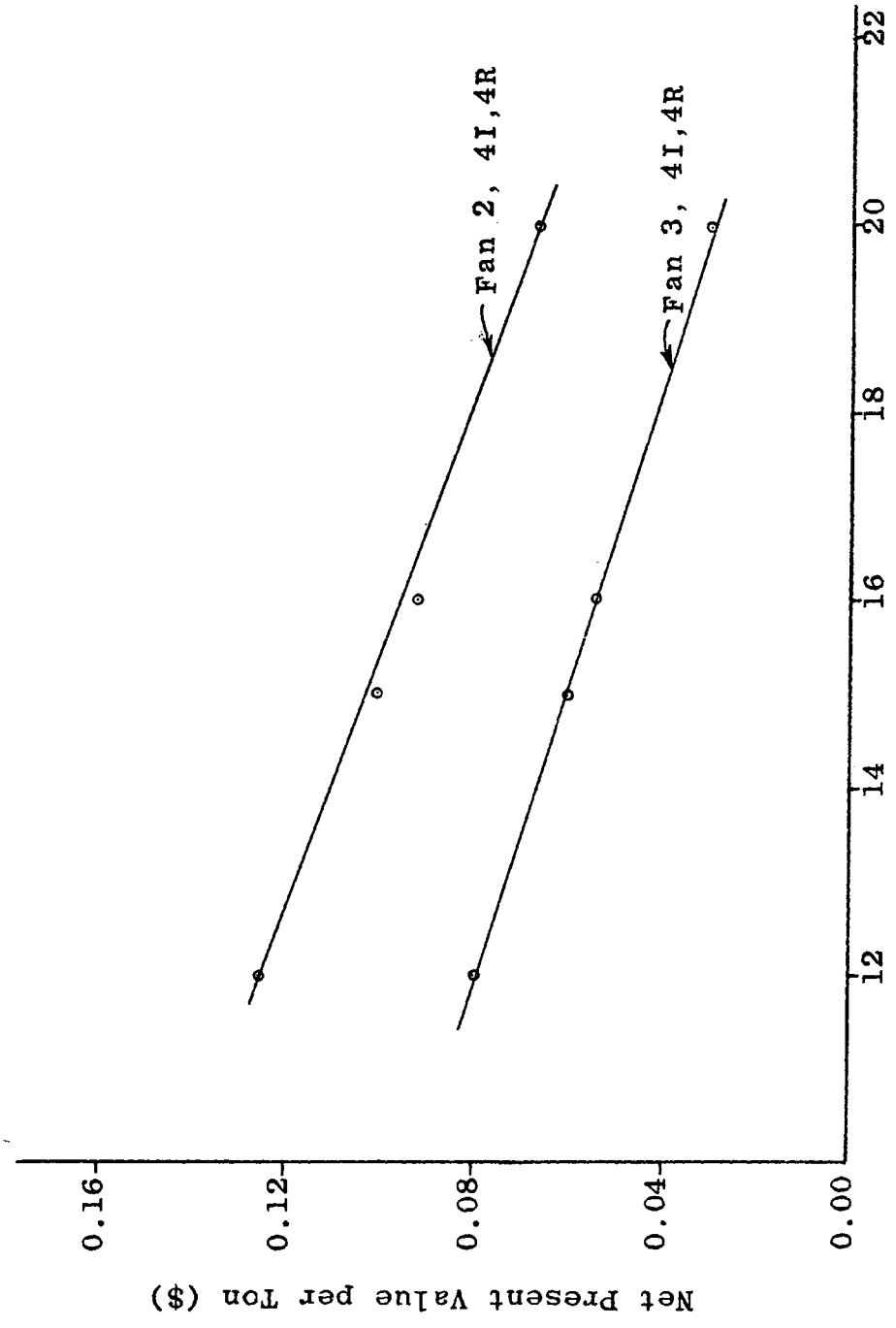


Fig. 10. Effect of Changing Entries on Net Present Value per Ton.

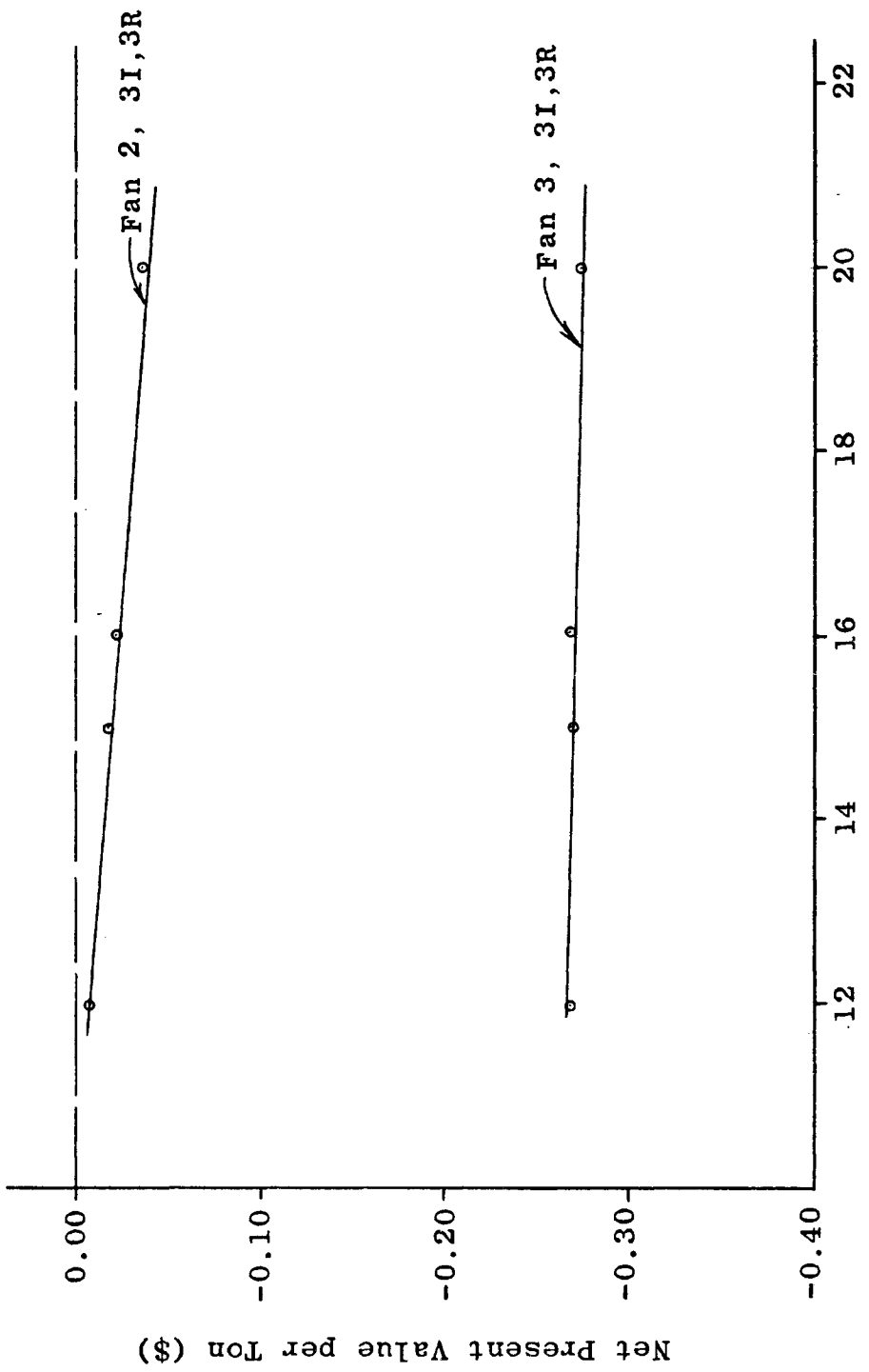


Fig. 11. Effect of Changing Entries on Net Present Value per Ton.

service a larger area before another main shaft is needed.

Figure 12 illustrates that the more desirable ventilation condition is to use a larger size entry. For the given conditions the smaller size entries have a negative net present value except fan 2 at 12% interest. The smaller size entry could be used if the conditions were changed, such as changing the amount of air supplied to each submain by decreasing the number of working sections, or by using a higher capacity fan.

6. Friction Factor - Friction factor directly affects mine resistance, thus if it is lowered, the passage of air is less restricted and more area can be ventilated. The friction factors for these tests were obtained from D. S. Kingery (4). Two different factors were used, and both were those tabulated for coal.

A friction factor of 60×10^{-10} was used throughout the study for all entries. For sensitivity analysis, a friction factor of 85×10^{-10} was substituted in all the entries. The friction factor 85×10^{-10} is the factor for maximum irregularities of surface, areas and alignment and a straight, moderately obstructed passage.

According to Bureau of Mines personnel, friction factors given for a particular type of airway do not correlate with friction factors calculated as a result of

TABLE IX

EFFECT OF SIZE OF ENTRIES

70,000 cfm per submain (Fan 2A)

60,000 cfm per submain (Fan 2)

4I,4R

Fan	Size of Entries	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
2	5x15	9,800	188,236	4.10	8.099
2	5x20	21,850	177,628	4.51	18.058
2A	5x15	9,300	218,474	5.25	7.686
2A	5x20	22,000	206,348	5.66	18.182

TABLE IX (cont.)

Fan	Size of Entries	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest				
2	5x15	0.3673	0.3830	0.0157
2	5x20	0.1644	0.3024	0.1380
2A	5x15	0.4995	0.3978	-0.1017
2A	5x20	0.2098	0.3200	0.1102
15% interest				
2	5x15	0.3776	0.3606	-0.0170
2	5x20	0.1694	0.2718	0.1024
2A	5x15	0.5162	0.3776	-0.1386
2A	5x20	0.2173	0.2907	0.0734
16% interest				
2	5x15	0.3808	0.3537	0.0271
2	5x20	0.1709	0.2627	0.0918
2A	5x15	0.5213	0.3713	-0.1500
2A	5x20	0.2196	0.2818	0.0622
20% interest				
2	5x15	0.3922	0.3279	-0.0643
2	5x20	0.1763	0.2309	0.0546
2A	5x15	0.5395	0.3476	-0.1919
2A	5x20	0.2276	0.2506	0.0230

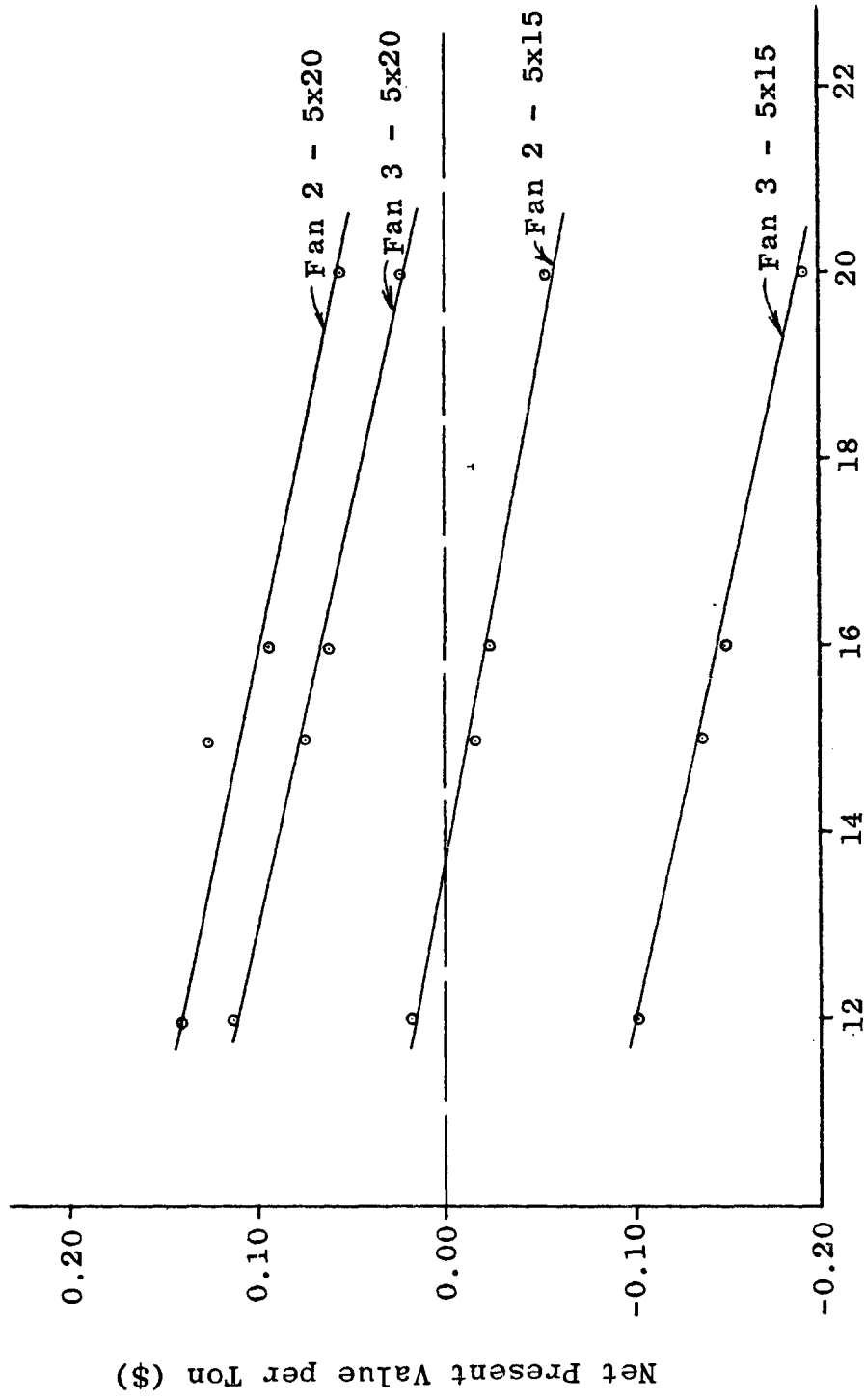


Fig. 12. Effect of Size of Entries on Net Present Value per Ton.

actual ventilation surveys of mines. For this report, however, comparisons are the main interest and the error introduced by using friction factors from Kingery (4) can be considered cancelled.

Figure 13 illustrates effect of the friction factor on net present value per ton. For the lower air requirement, friction factor changes the net present value per ton recovered by $0.048 and for the higher air requirement friction factor changes the net present value per ton by $0.130.

The amount of air determines the sensitivity of the system to friction factor. If the overall mine resistance is low, more resistance in the system is not critical. When the overall mine resistance is high, an added resistance can make a difference between positive and negative net present values per ton for the area.

7. Number of working sections - The number of working sections affects the total amount of capital invested and the amount of air needed for the area. The Federal Coal Mine Health and Safety Act of 1969 (1) requires a minimum of 3000 cfm at each working face. It is assumed there are three working faces per section, thus the air requirement is 9000 cfm per section or 10,000 cfm allowing for losses. Thus, when 60,000 cfm

TABLE X

EFFECT OF FRICTION FACTOR

4I,4R

Fan 2

Air per Submain	Friction Factor	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
60,000	85×10^{-10}	15,000	180,000	4.42	12.397
60,000	60×10^{-10}	21,850	177 628	4.51	18.058
70,000	85×10^{-10}	9,000	203,000	3.44	7.438
70,000	60×10^{-10}	13,000	202,000	3.47	10.744

TABLE X (cont.)

Air per Submain	Friction Factor	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest				
60,000	85×10^{-10}	0.2566	0.3449	0.0883
60,000	60×10^{-10}	0.1763	0.3024	0.1361
70,000	85×10^{-10}	0.5142	0.3999	-0.1143
70,000	60×10^{-10}	0.3561	0.3726	0.0165
15% interest				
60,000	85×10^{-10}	0.2487	0.3179	0.0692
60,000	60×10^{-10}	0.1709	0.2718	0.1009
70,000	85×10^{-10}	0.5013	0.3801	-0.1212
70,000	60×10^{-10}	0.3472	0.3488	0.0016
16% interest				
60,000	85×10^{-10}	0.2465	0.3096	0.0631
60,000	60×10^{-10}	0.1644	0.2627	0.0983
70,000	85×10^{-10}	0.4976	0.3738	-0.1238
70,000	60×10^{-10}	0.3446	0.3415	-0.0031
20% interest				
60,000	85×10^{-10}	0.2393	0.2798	0.0405
60,000	60×10^{-10}	0.1644	0.2309	0.0665
70,000	85×10^{-10}	0.4853	0.3505	-0.1348
70,000	60×10^{-10}	0.3361	0.3144	-0.0217

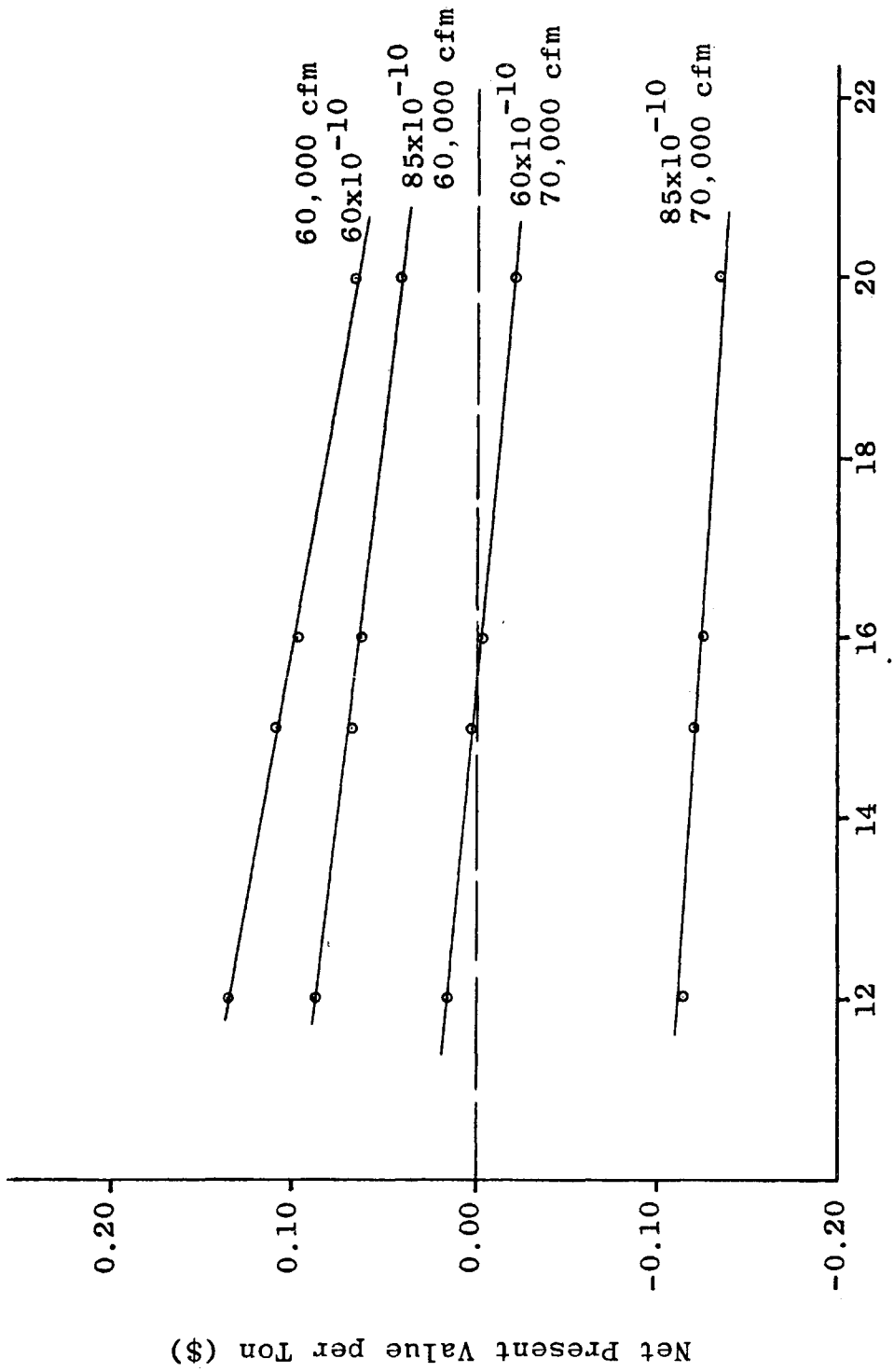


Fig. 13. Effect of Friction Factor on Net Present Value per Ton.

is allowed per submain, the assumption is that 6 sections are working from that submain.

In practice, there are limited numbers of sections operating from one shaft. Assumption of an ideal mine with rather limited leakage has allowed up to 16 working sections to be ventilated from one shaft.

Figure 14 shows the effect of two different fans on net present value per ton recovered. As would be expected, the system is very sensitive to a change in the number of sections, because the number of sections directly affects the amount of air needed.

For fan 2, the net present value per ton changes by $0.307 when the number of sections is changed from 12 to 16. Fourteen and 16 sections have negative net present values per ton except for the lower interest portion of the curve for 14 sections.

For fan 3, the curve for net present value per ton for 14 sections is all in the positive region and for 16 sections is all in the negative region.

It can be concluded that it is better to have fewer working sections than to place more load on the system. However, there may be factors other than ventilation which affect the number of working sections used.

TABLE XI

EFFECT OF NUMBER OF WORKING SECTIONS

4I,4R

Fan	Number of Sections	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
2	12	21,850	177,628	4.51	18.058
2	14	13,000	202,000	3.47	10.744
2	16	7,000	224,285	2.36	5.785
3	14	19,000	204,216	5.10	15.702
3	16	10,000	226,968	3.39	8.264

TABLE XI (cont.)

Fan	Number of Sections	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest				
2	12	0.1763	0.3024	0.1261
2	14	0.3573	0.3726	0.0153
2	16	0.6025	0.4213	-0.1812
3	14	0.2595	0.3363	0.0828
3	16	0.4419	0.4017	-0.0402
15% interest				
2	12	0.1709	0.2718	0.1009
2	14	0.3482	0.3488	0.0006
2	16	0.5894	0.4050	-0.1844
3	14	0.2508	0.3084	0.0576
3	16	0.4295	0.3822	-0.0473
16% interest				
2	12	0.1694	0.2627	0.0933
2	14	0.3456	0.3415	-0.0041
2	16	0.5856	0.3998	-0.1858
3	14	0.2484	0.2999	0.0515
3	16	0.4260	0.3760	-0.0500

TABLE XI (cont.)

Fan	Number of Sections	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
20% interest				
2	12	0.1644	0.2309	0.0465
2	14	0.3368	0.3144	-0.0224
2	16	0.5730	0.3802	-0.1928
3	14	0.2403	0.2695	0.0292
3	16	0.4143	0.3530	-0.0613

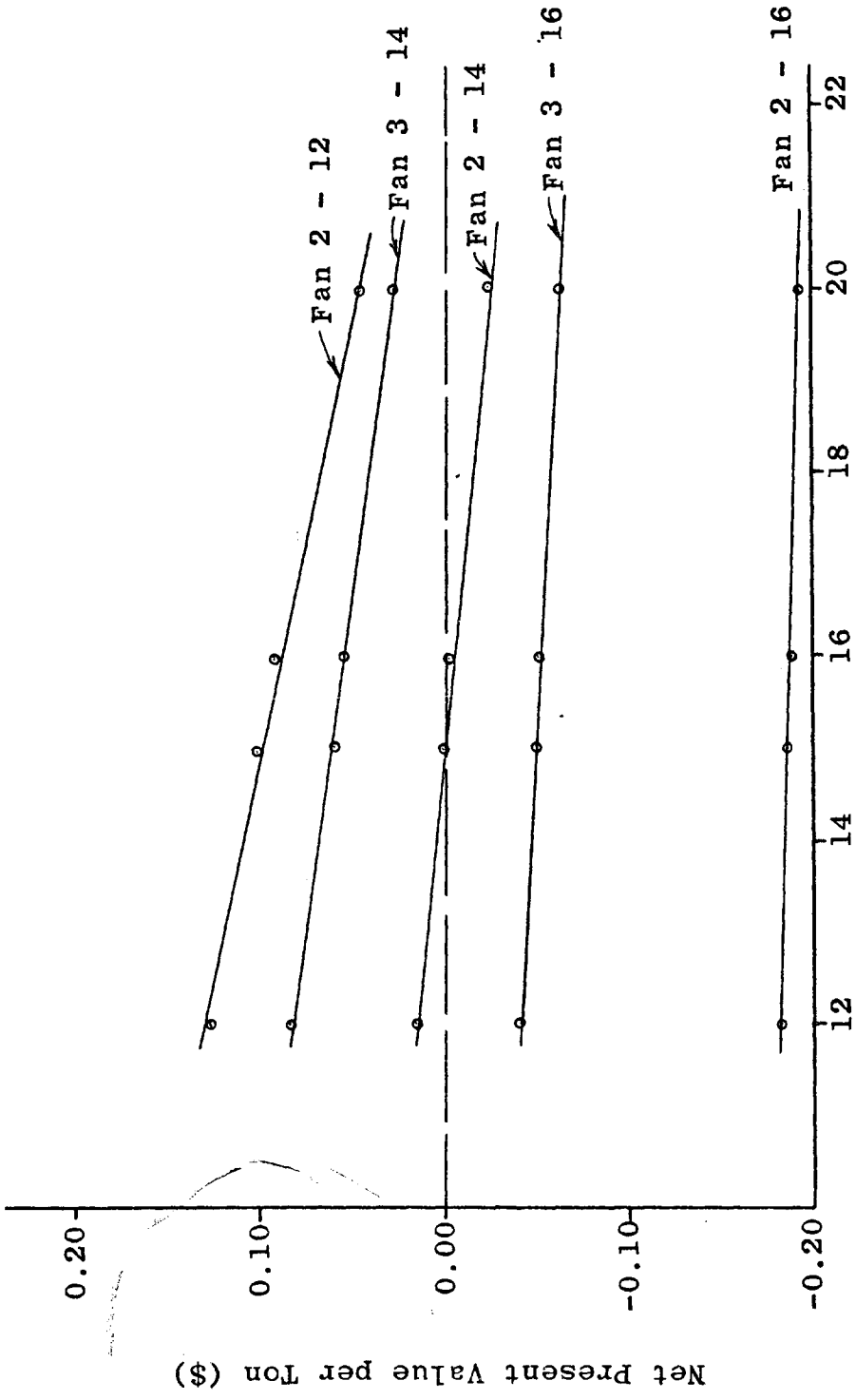


Fig. 14. Effect of Number of Sections on Net Present Value per Ton.

8. Thickness of seam - Thickness of the seam being mined has a strong effect on the overall mine resistance and the optimal lengths of areas. As the seam gets thicker, resistance of the passages decreases. Thicknesses of 5 and 6 feet were tested for an area having 3 intake and 3 return entries and supplying 70,000 cfm to each of two submains.

Figure 15 shows that thickness of the seam is a highly sensitive factor in the given network. There is a difference in net present value per ton recovered of $0.342 at 12% interest. For the given conditions, a 5-foot seam has negative net present values. Thus, if it is necessary to mine a 5-foot seam, other variables in the network would have to be changed.

Economic Parameters

Some parameters affect primarily the economics of the networks. Rate of return is not used for comparing alternatives because the area tested is only a part of the mine and the total investment and return for the life of the mine is not included in the calculations.

Economic parameter sensitivities for a single main shaft were run and five parameters were changed.

1. Interest rate - Interest rates used for

TABLE XII

EFFECT OF THICKNESS

70,000 cfm per submain

3I,3R

Fan 3

Seam Thickness	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
5 ft	7,000	220,790	3.88	5.785
6 ft	15,000	210,850	4.61	14.876

TABLE XII (cont.)

Seam Thickness	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest			
5 ft	0.6857	0.4146	-0.2711
6 ft	0.2711	0.3420	0.0709
15% interest			
5 ft	0.6664	0.3972	-0.2692
6 ft	0.2625	0.3147	0.0522
16% interest			
5 ft	0.6610	0.3916	-0.2694
6 ft	0.2601	0.3060	0.0462
20% interest			
5 ft	0.6431	0.3708	-0.2723
6 ft	0.2521	0.2764	0.0243

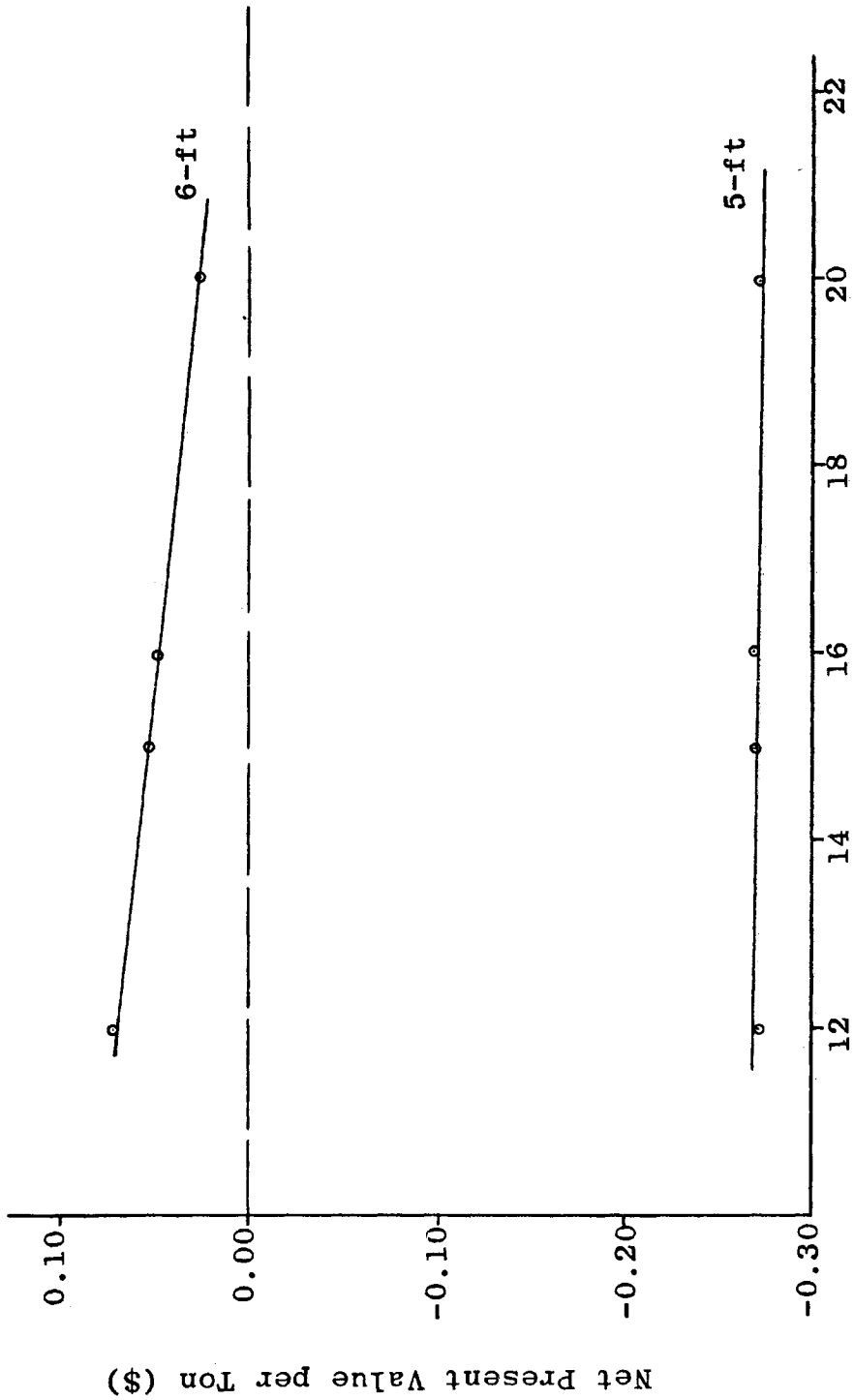


Fig. 15. Effect of Thickness of Seam on Net Present Value per Ton.

comparing each alternative were 12%, 15%, 16%, and 20%. For the test shown in Table XIII, there is a change in net present value per ton recovered of $0.030 between 12% and 20% interest. Figure 16 shows the effect of interest rate on net present value per ton.

2. Power Cost - Power costs were varied to determine whether $0.01 per kwh causes a significant change in present value of costs. The power costs used were $0.05, $0.06 and $0.07 per kwh. For a difference of 2 cents per kwh, there is a difference of $0.026 between the net present values per ton at 12% interest.

Figure 17 shows the sensitivity of power costs to net present value per ton recovered. Present value of benefits per ton does not change for increased power cost because the tonnage stays the same. The sensitivity is due to the change in present value of costs per ton.

3. Percent Recovery - Percent of total tons recovered was tested at 40%,50% and 60%. These are recoveries obtained by most underground coal mines.

Figure 18 shows the sensitivity to percent recovery of net present value per ton. For a change of 20% recovery, the net present value per ton changes by $0.084 at 12% interest. Net present value per ton is very

TABLE XIII

EFFECT OF INTEREST RATE

80,000 cfm per submain

Length - 14,000 ft

4I,4R

Fan 2A

Air Quantity - 230,213 cfm

Water Gage - 4.80 in.

Interest (%)	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12	0.3354	0.3775	0.0421
15	0.3233	0.3544	0.0322
16	0.3199	0.3472	0.0273
20	0.3088	0.3208	0.0120

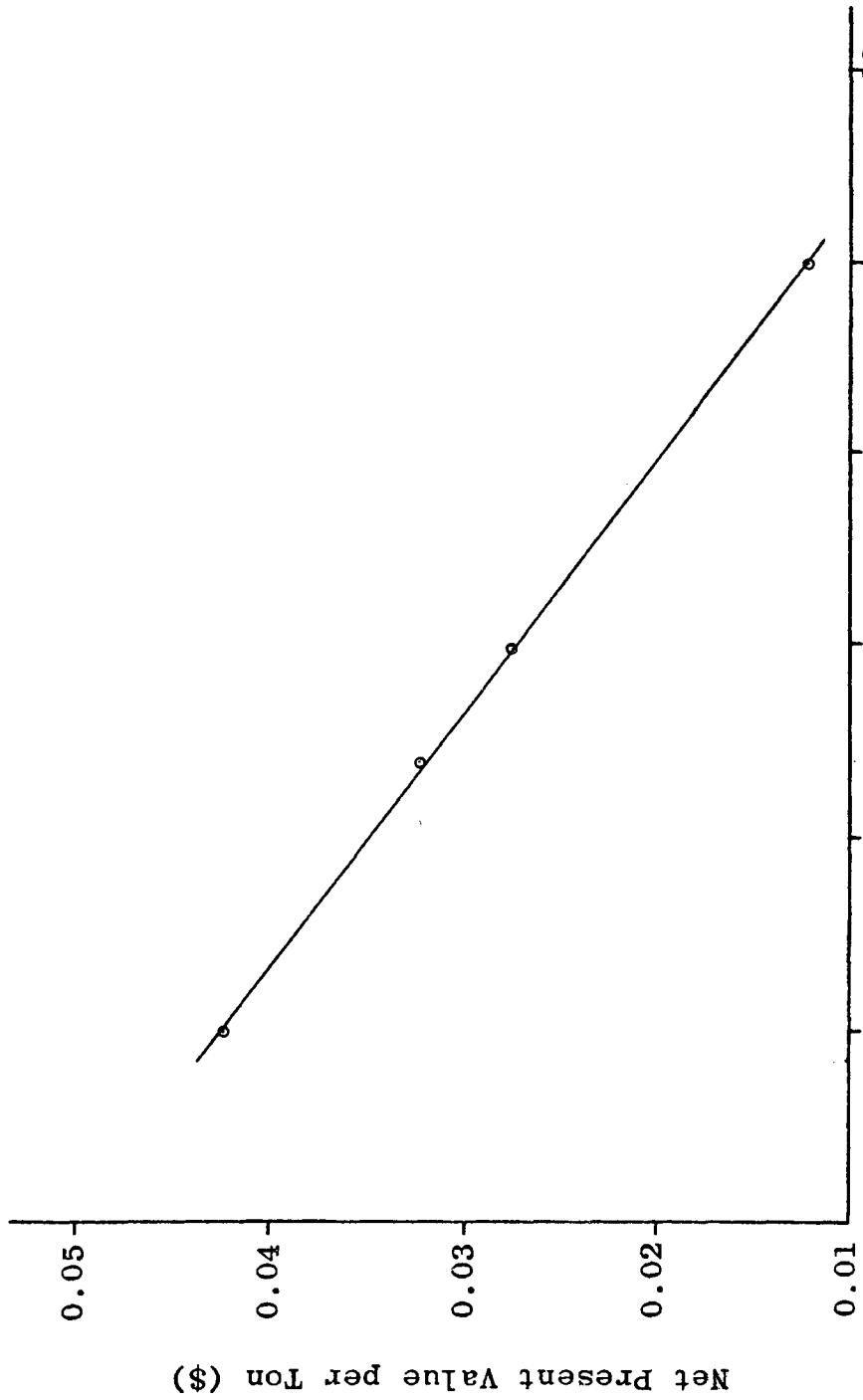


Fig. 16. Effect of Interest Rate on Net Present Value per Ton.

TABLE XIV

EFFECT OF POWER COST

80,000 cfm per submain — Fan 2A

Length - 14,000 ft — Air Quantity - 230,213 cfm

4I,4R — Water Gage - 4.80 in.

Power Cost ($ per kwh)	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest			
0.05	0.3354	0.3775	0.0421
0.06	0.3486	0.3775	0.0289
0.07	0.3617	0.3775	0.0158
15% interest			
0.05	0.3233	0.3544	0.0311
0.06	0.3343	0.3544	0.0201
0.07	0.3453	0.3544	0.0091
16% interest			
0.05	0.3199	0.3472	0.0273
0.06	0.3304	0.3472	0.0168
0.07	0.3408	0.3472	0.0064
20% interest			
0.05	0.3088	0.3208	0.0120
0.06	0.3173	0.3208	0.0035
0.07	0.3259	0.3208	0.0051

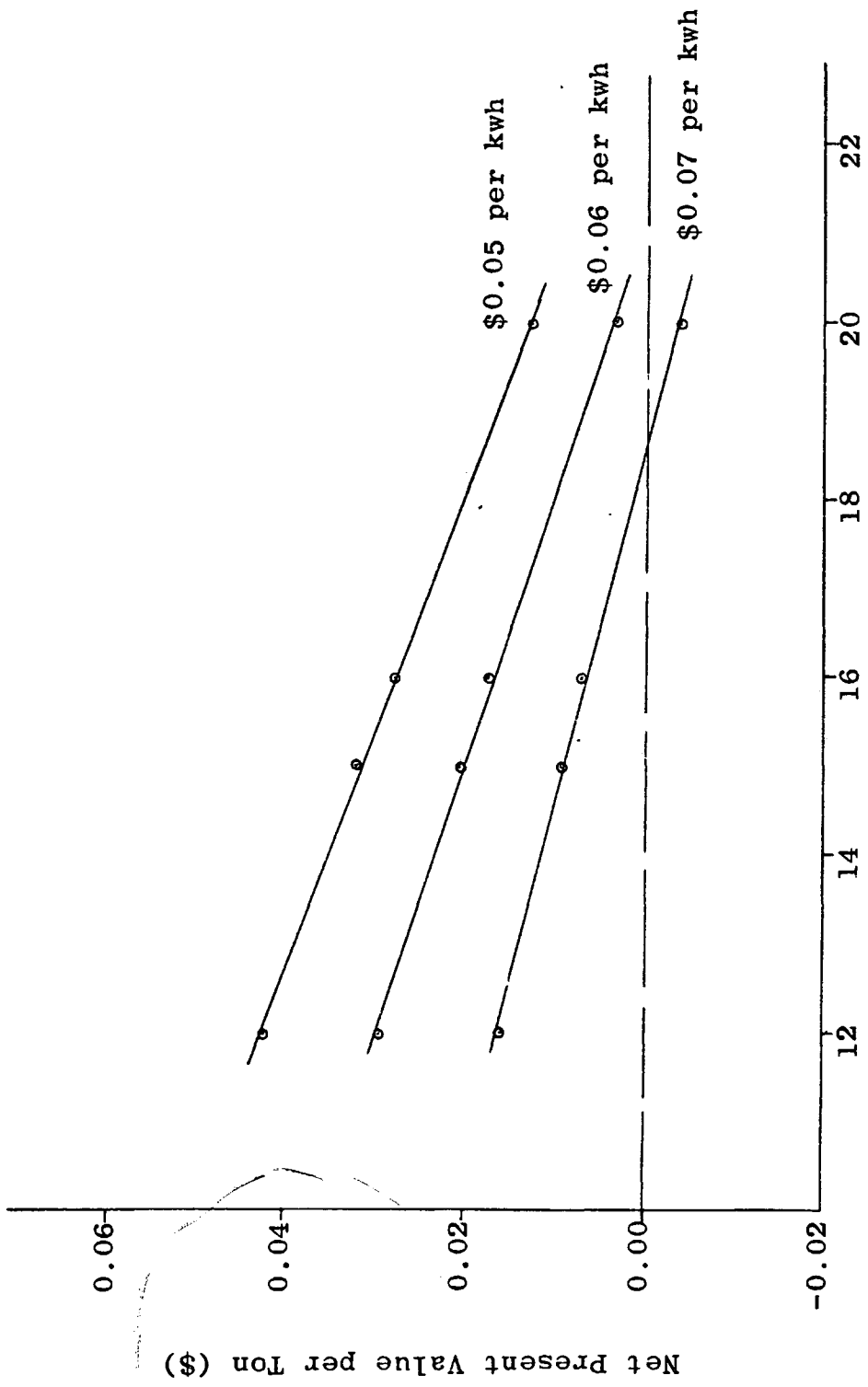


Fig. 17. Effect of power cost on net present value per ton.

TABLE XV

EFFECT OF PERCENT RECOVERY

80,000 cfm per submain — Fan 2A

Length - 14,000 ft — Air Quantity - 230,213 cfm

4I,4R — Water Gage - 4.80 in.

Percent Recovery	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest			
40	0.3354	0.3775	0.0421
50	0.2683	0.3580	0.0897
60	0.2236	0.3398	0.1162
15% interest			
40	0.3233	0.3544	0.0311
50	0.2587	0.3324	0.0737
60	0.2155	0.3123	0.0968
16% interest			
40	0.3199	0.3472	0.0273
50	0.2560	0.3245	0.0685
60	0.2133	0.3039	0.0906
20% interest			
40	0.3088	0.3208	0.0120
50	0.2470	0.2959	0.0489
60	0.2059	0.2738	0.0679

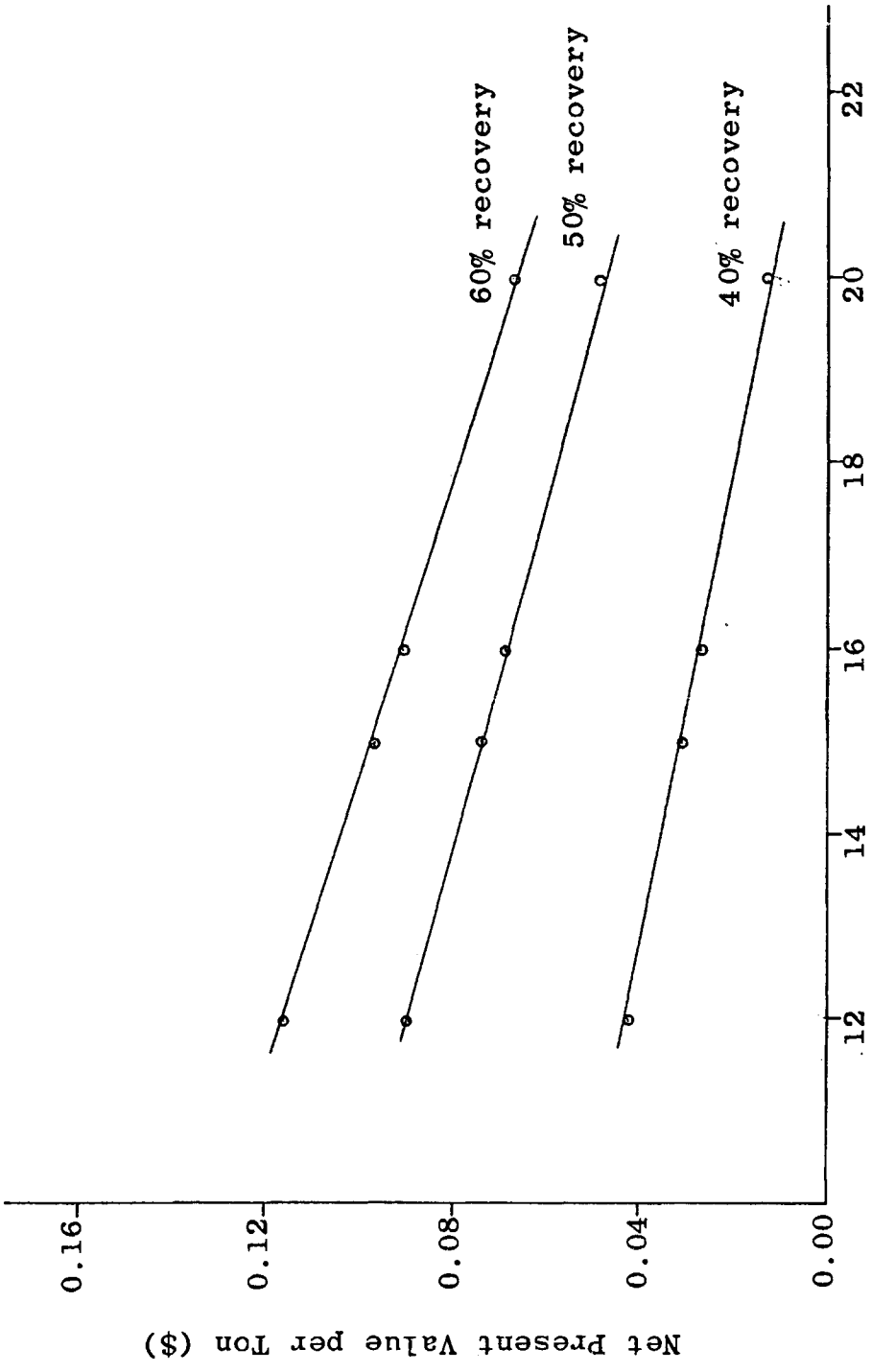


Fig. 18. Effect of percent recovery on net present value per ton.

sensitive to change in the number of tons recovered. Present value of costs per ton decreases drastically as recoverable tons increases. The decrease in present value of costs per ton more than compensates for the moderate decrease in present value of benefits per ton recovered.

4. Rate of Production - The production rate is assumed to be constant throughout the life of the area. The number of tons per day produced directly affects the life of an area.

Figure 19 shows the sensitivity of net present value per recoverable ton to production rate. As the tonnage per day increases, the net present value per ton increases because the life of the area is shortened and the payments are made sooner. Production rate has a low sensitivity. The net present value per ton only changes by $0.015 at 12% interest when production rate is changed from 800 tpd to 1000 tpd. Thus, a higher production rate is desireable, but not critical when analyzing a ventilation system.

5. Profit per recoverable ton - Figure 20 shows that net present value per ton is very sensitive to profit per ton. A difference of only $0.20 in profit per ton makes a difference of approximately $0.15 per ton at 12%

TABLE XVI

EFFECT OF PRODUCTION RATE

80,000 cfm — Fan 2A

Length - 14,000 ft — Air Quantity - 230,213 cfm

4I,4R — Water Gage - 4.80 in.

Production (tpd per section)	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest			
800	0.3354	0.3775	0.0421
900	0.3361	0.3867	0.0506
1000	0.3367	0.3942	0.0575
15% interest			
800	0.3233	0.3544	0.0311
900	0.3242	0.3649	0.0407
1000	0.3249	0.3735	0.0486
16% interest			
800	0.3199	0.3472	0.0273
900	0.3208	0.3580	0.0372
1000	0.3216	0.3670	0.0454
20% interest			
800	0.3088	0.3208	0.0120
900	0.3099	0.3328	0.0229
1000	0.3107	0.3429	0.0322

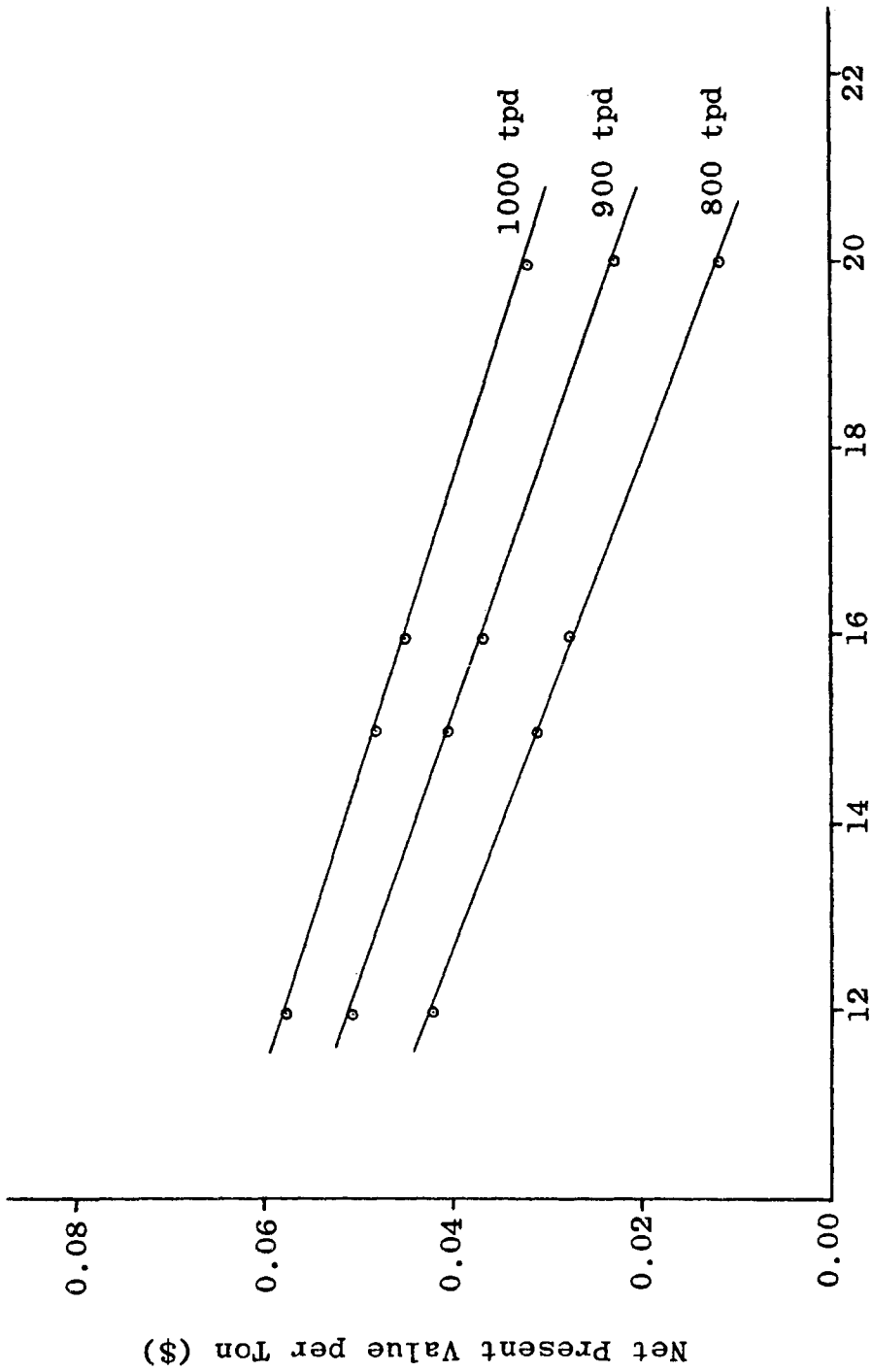


Fig. 19. Effect of Production Rate on Net Present Value per Ton.

TABLE XVII

EFFECT OF PROFIT PER RECOVERABLE TON

80,000 cfm per submain — Fan 2A

Length - 14,000 ft — Air Quantity - 230,213 cfm

4I,4R — Water Gage - 4.80 in.

Profit per ton ($)	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Net Present Value per ton ($)
12% interest			
0.50	0.3354	0.3775	0.0421
0.60	0.3354	0.4820	0.1466
0.70	0.3354	0.5285	0.1931
15% interest			
0.50	0.3233	0.3544	0.0311
0.60	0.3233	0.4586	0.1353
0.70	0.3233	0.4962	0.1729
16% interest			
0.50	0.3199	0.3472	0.0273
0.60	0.3199	0.4512	0.1313
0.70	0.3199	0.4861	0.1662
20% interest			
0.50	0.3088	0.3208	0.0120
0.60	0.3088	0.4236	0.1148
0.70	0.3088	0.4491	0.1403

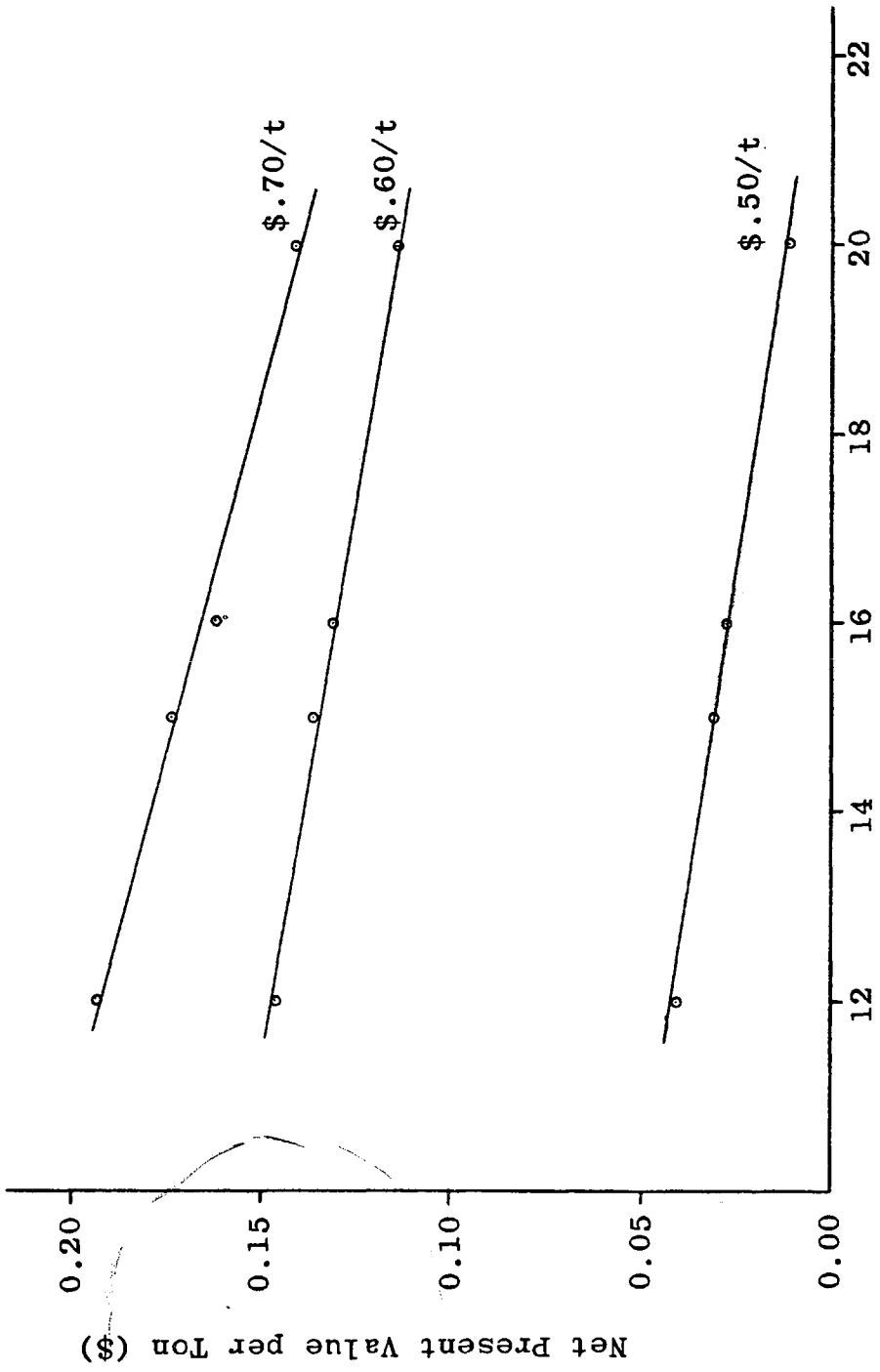


Fig. 20. Effect of Profit per Ton on Net Present Value per Ton.

interest. The difference is very significant when compared to the difference of net present value per ton when production rate is changed ($0.015).

For the given conditions $0.50 profit per ton is a minimum profit which could be expected for the net present value per ton to remain positive for all interest rates up to 20%.

SUMMARY OF SENSITIVITIES

The purpose of testing sensitivities is to determine which parameters are most critical to change. When the differences due to changing one parameter are small, the effects of the parameter are not critical to decisions affecting the project.

Sensitivities are compared by noting the differences in net present value per ton (See Table XVIII). The ventilation network is least sensitive to production rate, power cost and size of shaft. The network is most sensitive to thickness of the seam and size and number of entries when the air requirements per submain are 70,000 cfm.

In the ventilation system tested in this study, the next highest sensitivities are effects of size of entries at 60,000 cfm, number of sections for both fans tested, friction factor at 70,000 cfm per submain, number of entries at 60,000 cfm per submain and profit per ton.

For the parameters listed in Table XVIII, any parameter which shows a change in net present value per ton greater than $0.10 can be considered critical to ventilation. In the range of $0.05 to $0.10, the effects

TABLE XVIII

SUMMARY OF SENSITIVITIES

Parameter		Change in Net Present Value per ton ($)
Depth of shaft		0.041
Size of shaft		0.018
Type of fan		0.082
Blade Settings -	Fan 2	0.077
	Fan 8	0.051
Number of entries -	70,000 cfm, Fan 3	0.352
	60,000 cfm, Fan 2	0.134
Size of entries -	70,000 cfm, Fan 2A	0.211
	60,000 cfm, Fan 2	0.119
Friction factor -	70,000 cfm, Fan 2	0.130
	60,000 cfm, Fan 2	0.048
Number of sections -	Fan 2	0.196
	Fan 3	0.123
Thickness of seam		0.342
Interest Rate		0.030
Power Cost		0.016
Percent Recovery		0.074
Production Rate		0.015
Profit per ton		0.151

TABLE XVIII (cont.)

Range of changes in Net Present Value per ton ($)	Parameter
0 - 0.020	Production rate
	Power cost
	Size of shaft
0.021 - 0.050	Interest rate
	Depth of shaft
	Friction factor at 60,000 cfm
0.051 - 0.100	Blade settings for fans 2 and 8
	Percent recovery
	Different fans
0.101 - 0.200	Size of entries at 60,000 cfm
	Number of sections for fan 3
	Friction factor at 70,000 cfm
	Number of entries at 60,000 cfm
	Profit per ton
	Number of sections for fan 2
Greater than 0.201	Size of entries at 70,000 cfm
	Thickness of seam
	Number of entries at 70,000 cfm

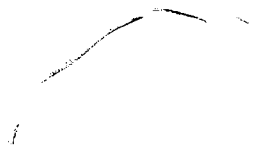
of the parameters are not critical but could be important under a different set of conditions than used in this study. Of the three parameters listed in the $0.05 to $0.10 range, percent recovery is the most difficult to change favorably.

Sensitivities for number of entries and size of entries do not have the same trend. Number of entries and size of entries were examined for two air requirements and each had a wide range of sensitivities. The sensitivities were lower but still significant in both sets when only 60,000 cfm was supplied to each submain. The sensitivity at 60,000 cfm is less because the overall mine resistance is low for that amount of air, and lowering it still further has only a small effect on net present values per ton. When the mine resistance is higher, the effect is much more critical.

Friction factor is another parameter which is sensitive to overall mine resistance. The change in net present value per ton is only $0.048 at 60,000 cfm per submain, while the change is $0.130 per ton at 70,000 cfm per submain.

The difference in sensitivities for number and size of entries and for friction factor suggests that for

low resistance mines changing the number of entries or size of entries will have only a limited effect on net present value per ton. However, in high resistance mines more and larger entries will produce a more favorable net present value per ton.



CASE 1

Case 1 is a room and pillar mine ventilated by a single shaft (See Fig. 21). The results of this network are used to compare with the cases including additional intake shafts.

The physical conditions for Case 1 are:

1. 80,000 cfm supplied to each submain
2. 4 intake and 4 return entries in mains
3. A 17-foot x 30-foot elliptical shaft is used as the main shaft
4. Depth of the shaft is 500 feet
5. Friction factor is 60×10^{-10} for all entries
6. Friction factor is 80×10^{-10} for the shaft
7. All entries are 5 feet x 20 feet in cross-section.

Economic conditions are the same as those listed in Table I. The results of Case 1 are in Table XIX.

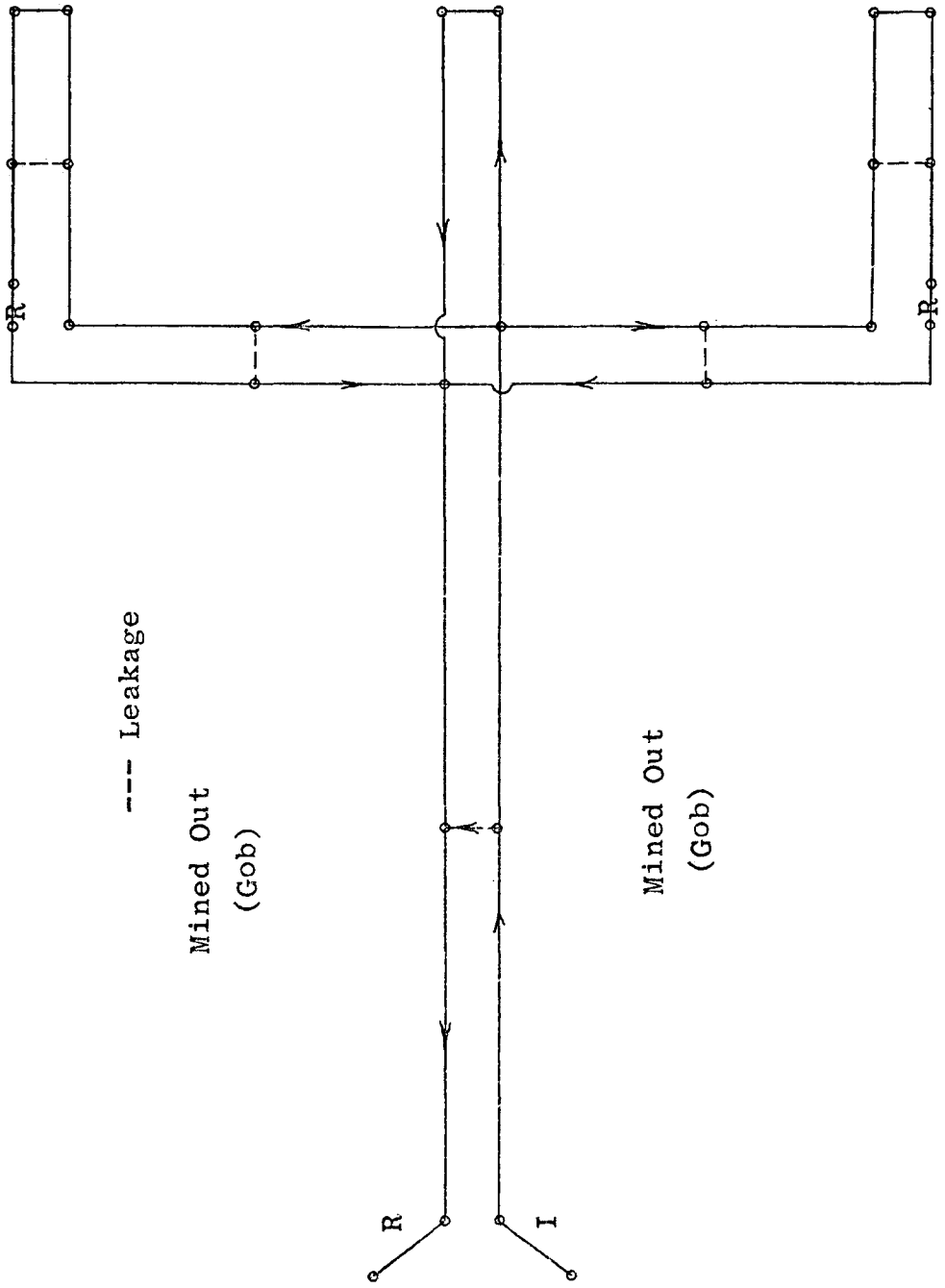


Fig. 21. Case 1 Ventilation Network

TABLE XIX

RESULTS OF CASE 1

80,000 cfm per submain

4I,4R

40% recovery

800 tpd per section

$0.05 per kwh power cost

Fan	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
2A	14,000	230,213	4.80	11.570
3	10,000	226,968	3.39	8.264
8A	13,800	229,476	4.71	11.405

TABLE XIX (cont.)

Fan	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Profit-ability Index	Net Present Value per ton ($)
12% interest				
2A	0.3354	0.3775	1.125	0.0421
3	0.4419	0.4017	0.909	-0.0402
8A	0.3390	0.3787	1.117	0.0397
15% interest				
2A	0.3233	0.3544	1.110	0.0311
3	0.4295	0.3822	0.890	-0.0473
8A	0.3269	0.3557	1.088	0.0288
16% interest				
2A	0.3199	0.3472	1.085	0.0273
3	0.4260	0.3760	0.883	-0.0500
8A	0.3236	0.3486	1.077	0.0250
20% interest				
2A	0.3088	0.3208	1.039	0.0120
3	0.4143	0.3530	0.852	-0.0613
8A	0.3124	0.3223	1.032	0.0099

CASE 2

An intake is added to the network of Case 1 and the new network is called Case 2 (See Fig. 22). The additional intake is located in the main entries 500 feet from the point where the air splits into the submains. All other physical and economic conditions are the same as for Case 1.

Three sizes of raise-drilled shafts are used for the additional intake:

1. A 6-foot diameter shaft
2. A 9-foot diameter shaft
3. A 12-foot diameter shaft.

Each shaft is 500 feet deep and the friction factor is 80×10^{-10}. The costs for the drilled shafts are shown in Table XX. The costs are current 1972 costs for up-reamed (or raise-drilled) shafts and were obtained from Teton Exploration Company in Casper, Wyoming.

The results of Case 2 are listed in Table XXI.

TABLE XX

DRILLED SHAFT COSTS FOR

CASES 2 AND 4

			Total Cost
6-ft diam			
Drilling -	$65 per ft		
Mobilization -	20 per ft		
500 ft at	$85 per ft	$42,500	
Lining - $3.25 per sq ft			
9424.77 x $3.25		30,630	
			$73,130
9-ft diam			
Drilling -	$115 per ft		
Mobilization -	30 per ft		
500 ft at	$145 per fr	$72,500	
Lining - $3.25 per sq ft			
14,137 x $3.25		49,945	
			$121,445
12-ft diam			
Drilling -	$180 per ft		
Mobilization -	30 per ft		
500 ft at	$210 per ft	$105,000	
Lining - $3.25 per sq ft			
18,849.5 x $3.25		61,261	
			$166,261

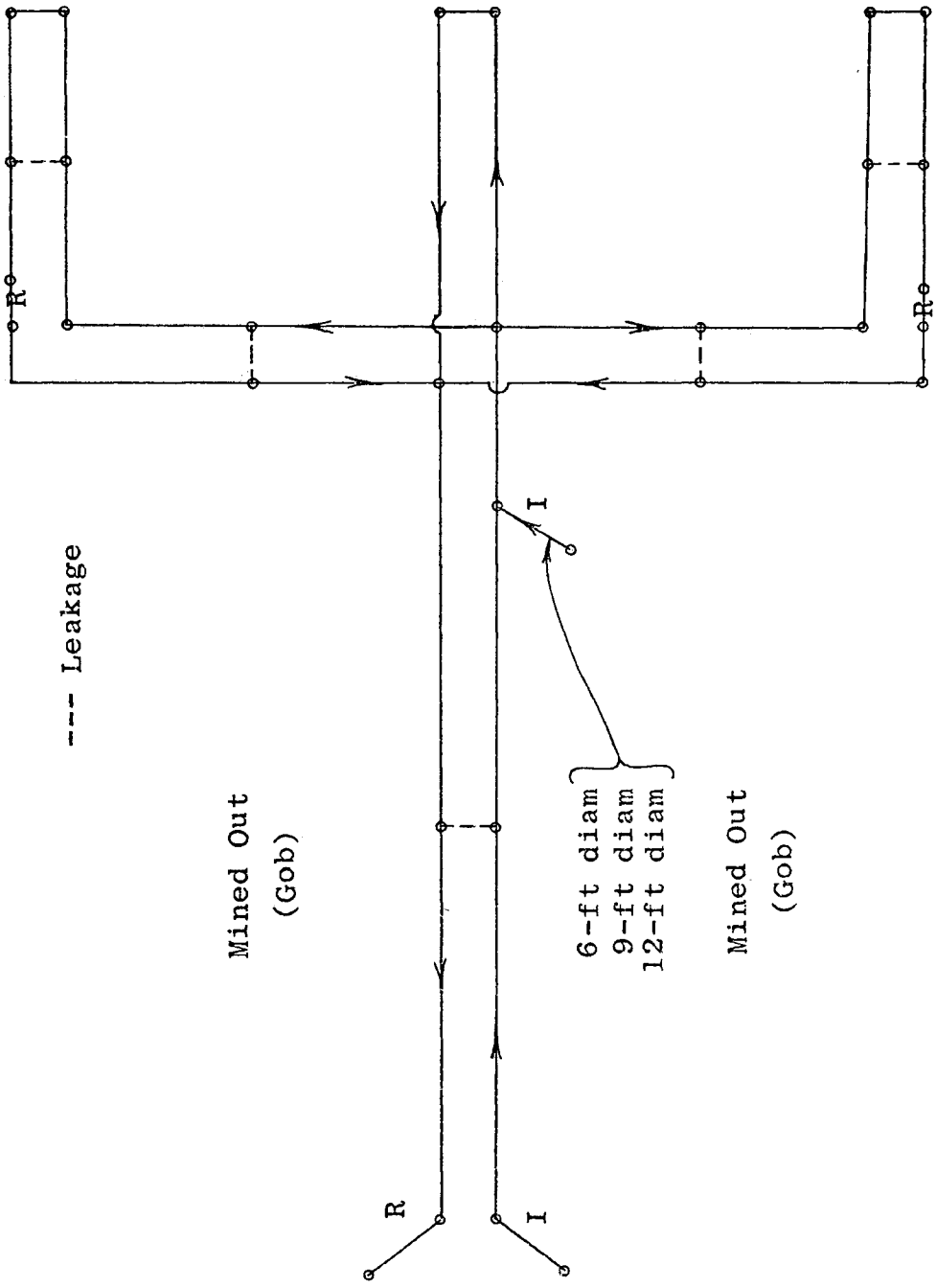


Fig. 22. Ventilation network for Case 2.

TABLE XXI

RESULTS OF CASE 2

80,000 cfm per submain

4I,4R

40% recovery

800 tpd per section

$0.05 per kwh power cost

Fan	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
6-ft diam intake				
2A	17,500	229,885	4.82	14.463
3	12,500	225,861	3.48	10.330
8A	17,500	229,456	4.71	14.463
9-ft diam intake				
2A	22,000	229,243	4.84	18.182
3	15,000	226,409	3.44	12.397
8A	21,000	229,861	4.68	17.355
12-ft diam intake				
2A	24,600	230,119	4.81	20.330
3	17,400	226,196	3.46	14.380
8A	24,300	229,267	4.72	20.083

TABLE XXI (cont.)

6-ft diam intake

Fan	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Profit-ability Index	Net Present Value per ton ($)
12% interest				
2A	0.2715	0.3580	1.319	0.0865
3	0.3596	0.3863	1.073	0.0267
8A	0.2703	0.3580	1.324	0.0877
15% interest				
2A	0.2614	0.3324	1.272	0.0710
3	0.3490	0.3645	1.044	0.0155
8A	0.2600	0.3324	1.278	0.0724
16% interest				
2A	0.2586	0.3245	1.255	0.0659
3	0.3461	0.3577	1.034	0.0116
8A	0.2577	0.3245	1.259	0.0668
20% interest				
2A	0.2493	0.2959	1.187	0.0466
3	0.3361	0.3324	0.989	-0.0037
8A	0.2485	0.2959	1.191	0.0474

TABLE XXI (cont.)

9-ft diam intake

Fan	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Profit-ability Index	Net Present Value per ton ($)
12% interest				
2A	0.2170	0.3349	1.543	0.1179
3	0.3014	0.3718	1.234	0.0704
8A	0.2262	0.3398	1.502	0.1136
15% interest				
2A	0.2088	0.3069	1.470	0.0981
3	0.2924	0.3479	1.190	0.0555
8A	0.2178	0.3123	1.434	0.0945
16% interest				
2A	0.2065	0.2984	1.445	0.0919
3	0.2898	0.3405	1.175	0.0507
8A	0.2155	0.3039	1.410	0.0884
20% interest				
2A	0.1988	0.2679	1.348	0.0691
3	0.2813	0.3134	1.114	0.0321
8A	0.2076	0.2738	1.319	0.0662

TABLE XXI (cont.)

12-ft diam intake

Fan	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Profit-ability Index	Net Present Value per ton ($)
12% interest				
2A	0.1948	0.3225	1.656	0.1277
3	0.2614	0.3585	1.371	0.0971
8A	0.1964	0.3239	1.649	0.1275
15% interest				
2A	0.1870	0.2934	1.569	0.1064
3	0.2530	0.3330	1.316	0.0800
8A	0.1889	0.2949	1.561	0.1060
16% interest				
2A	0.1850	0.2846	1.538	0.0996
3	0.2511	0.3252	1.295	0.0741
8A	0.1868	0.2861	1.531	0.0993
20% interest				
2A	0.1781	0.2534	1.423	0.0753
3	0.2435	0.2966	1.218	0.0531
8A	0.1799	0.2550	1.417	0.0751

CASE 3

Case 3 adds another return to the network of Case 1 (See Fig. 23). For the conditions assumed in the network, this case did not give any reasonable results. When there is no fan on the extra return shaft, fresh air is pulled into the returns instead of used air being returned to the surface.

If a fan is put in the extra return shaft, the fan on the small shaft is under-loaded and that on the large, main shaft is over-loaded. The situation could be made to work with two fans if the mine resistance is increased. If the mine resistance is changed for this case, comparison with the other cases would not be valid. Thus, Case 3 is not used in the comparison.

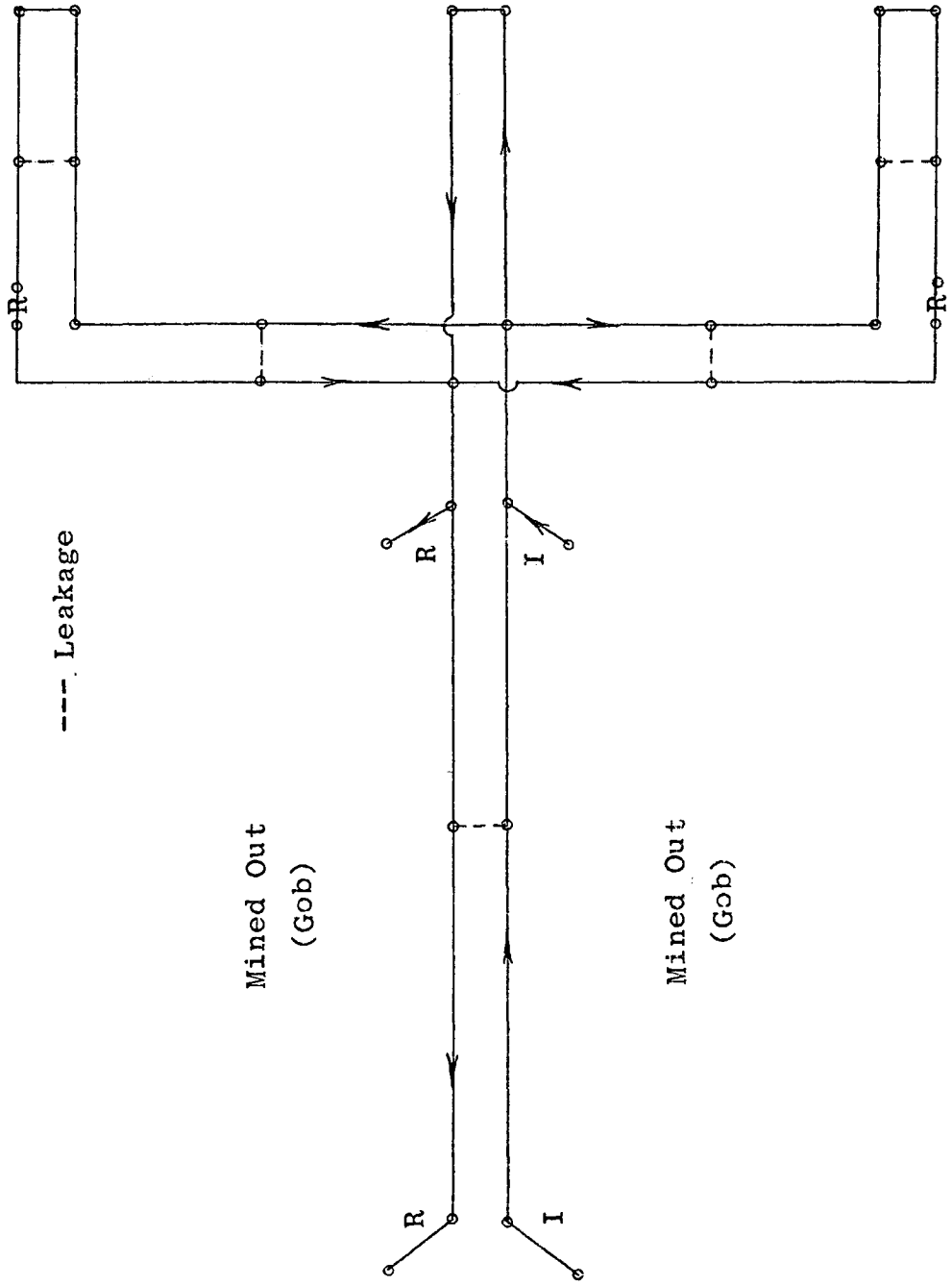


Fig. 23. Ventilation network for Case 3.

CASE 4

Two intake shafts are added to the network of Case 1 and called Case 4 (See Fig. 24). Four arrangements of intakes are used:

1. A 6-foot diameter shaft for both intakes
2. A 6-foot diameter shaft at the first intake and a 12-foot diameter shaft at the second intake
3. A 12-foot diameter shaft at the first intake and a 6-foot diameter shaft at the second intake
4. A 12-foot diameter shaft at both intakes.

Each shaft is 500 feet deep and has a friction factor of 80×10^{-10}. All other parameters are the same as those listed in Table I.

The intakes are located in the main entries 500 feet and 1000 feet, respectively, from the point where air splits at the entrance to the submains.

The results of Case 4 are listed in Table XXII.

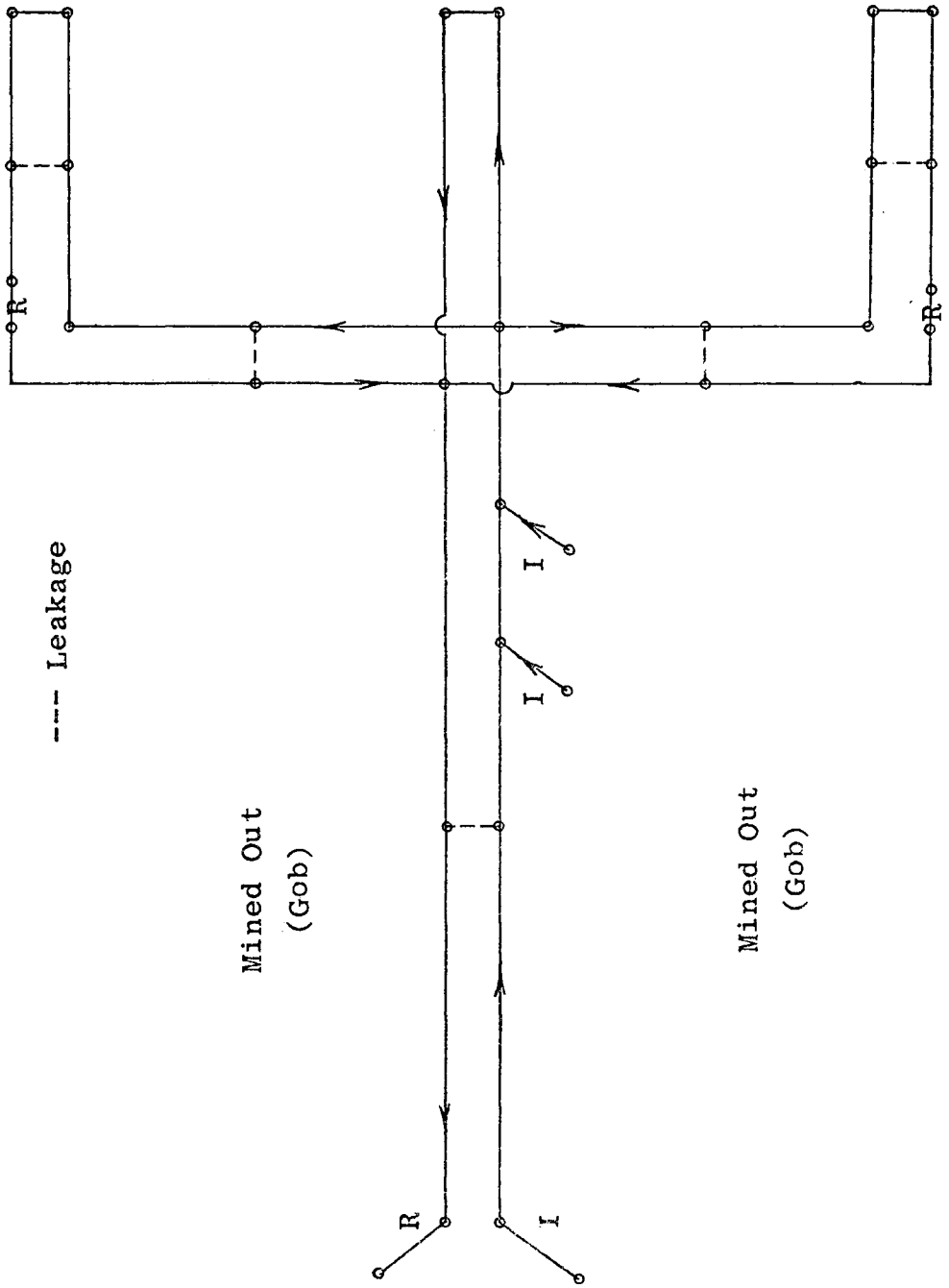


Fig. 24. Ventilation network for Case 4.

TABLE XXII

RESULTS OF CASE 4

80,000 cfm per submain 800 tpd per section

4I,4R $0.05 per kwh power cost

40% recovery

Fan	Length	Quantity (cfm)	Water Gage (in.)	Recoverable tons (Mill. tons)
two 6-ft diam intakes				
2A	19,900	229,839	4.82	16.446
3	13,800	226,140	3.46	11.405
8A	19,300	229,700	4.69	15.950
one 6-ft and one 12-ft diam intake				
2A	25,200	229,541	4.83	20.826
3	17,700	226,080	3.47	14.628
8A	24,600	229,287	4.72	20.330
one 12-ft and one 6-ft diam intake				
2A	24,500	229,934	4.82	20.248
3	17,000	226,353	3.44	14.049
8A	23,800	229,747	4.69	19.699
two 12-ft diam intakes				
2A	26,000	229,991	4.81	21.488
3	18,300	226,446	3.44	15.124
8A	25,400	229,626	4.70	20.992

TABLE XXII (cont.)

two 6-ft diam intakes

Fan	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Profit-ability Index	Net Present Value per ton ($)
12% interest				
2A	0.2358	0.3454	1.465	0.1096
3	0.3297	0.3787	1.149	0.0490
8A	0.2474	0.3485	1.409	0.1011
15% interest				
2A	0.2275	0.3184	1.400	0.0909
3	0.3198	0.3557	1.112	0.0359
8A	0.2381	0.3218	1.352	0.0837
16% interest				
2A	0.2251	0.3102	1.378	0.0851
3	0.3170	0.3486	1.100	0.0316
8A	0.2355	0.3137	1.332	0.0782
20% interest				
2A	0.2173	0.2805	1.291	0.0632
3	0.3076	0.3223	1.048	0.0147
8A	0.2269	0.2842	1.254	0.0573

TABLE XXII (cont.)

one 6-ft and one 12-ft diam intake

Fan	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Profit-ability Index	Net Present Value per ton ($)
12% interest				
2A	0.1918	0.3197	1.667	0.1279
3	0.2600	0.3569	1.373	0.0969
8A	0.1957	0.3225	1.648	0.1268
15% interest				
2A	0.1841	0.2904	1.577	0.1063
3	0.2518	0.3312	1.315	0.0794
8A	0.1881	0.2934	1.560	0.1053
16% interest				
2A	0.1820	0.2816	1.547	0.0996
3	0.2494	0.3233	1.296	0.0739
8A	0.1859	0.2846	1.531	0.0987
20% interest				
2A	0.1749	0.2503	1.431	0.0754
3	0.2415	0.2946	1.219	0.0531
8A	0.1788	0.2534	1.417	0.0746

TABLE XXII (cont.)

one 12-ft and one 6-ft diam intake

Fan	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Profit-ability Index	Net Present Value per ton ($)
12% interest				
2A	0.1985	0.3229	1.627	0.1244
3	0.2729	0.3607	1.322	0.0878
8A	0.2035	0.3262	1.603	0.1227
15% interest				
2A	0.1905	0.2939	1.543	0.1034
3	0.2641	0.3354	1.270	0.0713
8A	0.1955	0.2974	1.521	0.1019
16% interest				
2A	0.1883	0.2851	1.514	0.0968
3	0.2616	0.3277	1.253	0.0661
8A	0.1932	0.2887	1.494	0.0945
20% interest				
2A	0.1808	0.2540	1.405	0.0732
3	0.2532	0.2993	1.182	0.0461
8A	0.1857	0.2578	1.388	0.0721

TABLE XXII (cont.)

two 12-ft diam intakes

Fan	Present Value of costs per ton ($)	Present Value of benefits per ton ($)	Profit-ability Index	Net Present Value per ton ($)
12% interest				
2A	0.1876	0.3161	1.685	0.1285
3	0.2547	0.3537	1.389	0.0990
8A	0.1914	0.3188	1.666	0.1264
15% interest				
2A	0.1799	0.2865	1.592	0.1066
3	0.2463	0.3277	1.330	0.0814
8A	0.1836	0.2894	1.576	0.1058
16% interest				
2A	0.1777	0.2776	1.562	0.0999
3	0.2439	0.3197	1.311	0.0758
8A	0.1815	0.3806	1.546	0.0991
20% interest				
2A	0.1706	0.2461	1.442	0.0755
3	0.2359	0.2906	1.231	0.0547
8A	0.1742	0.2492	1.430	0.0750

COMPARISON OF CASES 1, 2 AND 4

Figure 25 shows the relationship of present value of costs per ton to cross-section area of the extra intake shafts. Point 8 (See Table XXIII) shows a slight upward trend from points 4, 6 and 7. It is expected that increasing the area of extra intakes beyond point 8 would cause an increase in present value of costs per ton. This has not been done in this thesis, but if a larger total cross-section of intakes does result in higher present value of costs, points 4, 6, 7 and 8 represent a minimum cost condition.

Table XXIV is a list of profitability indices for all cases with Fan 2A at 12% interest. Profitability index is the ratio of present value of benefits to present value of costs. A higher profitability index indicates a more profitable network. The indices for points 4, 6, 7 and 8 are highest with only a small difference between the indices.

Figures 26 through 28 are plots of present value of costs per ton versus present value of benefits per ton. These curves could also be called profitability index curves. The profitability index curves show that

TABLE XXIII

KEY TO COMPARISON GRAPHS

Number of Point	Explanation
1	Case 1 - a single main shaft
2	Case 2 - one main shaft and one 6-ft diam intake
3	Case 2 - one main shaft and one 9-ft diam intake
4	Case 2 - one main shaft and one 12-ft diam intake
5	Case 4 - one main shaft and two 6-ft diam intakes
6	Case 4 - one main shaft and one 6-ft and one 12-ft diam intake
7	Case 4 - one main shaft and one 12-ft and one 6-ft diam intake
8	Case 4 - one main shaft and two 12-ft diam intakes

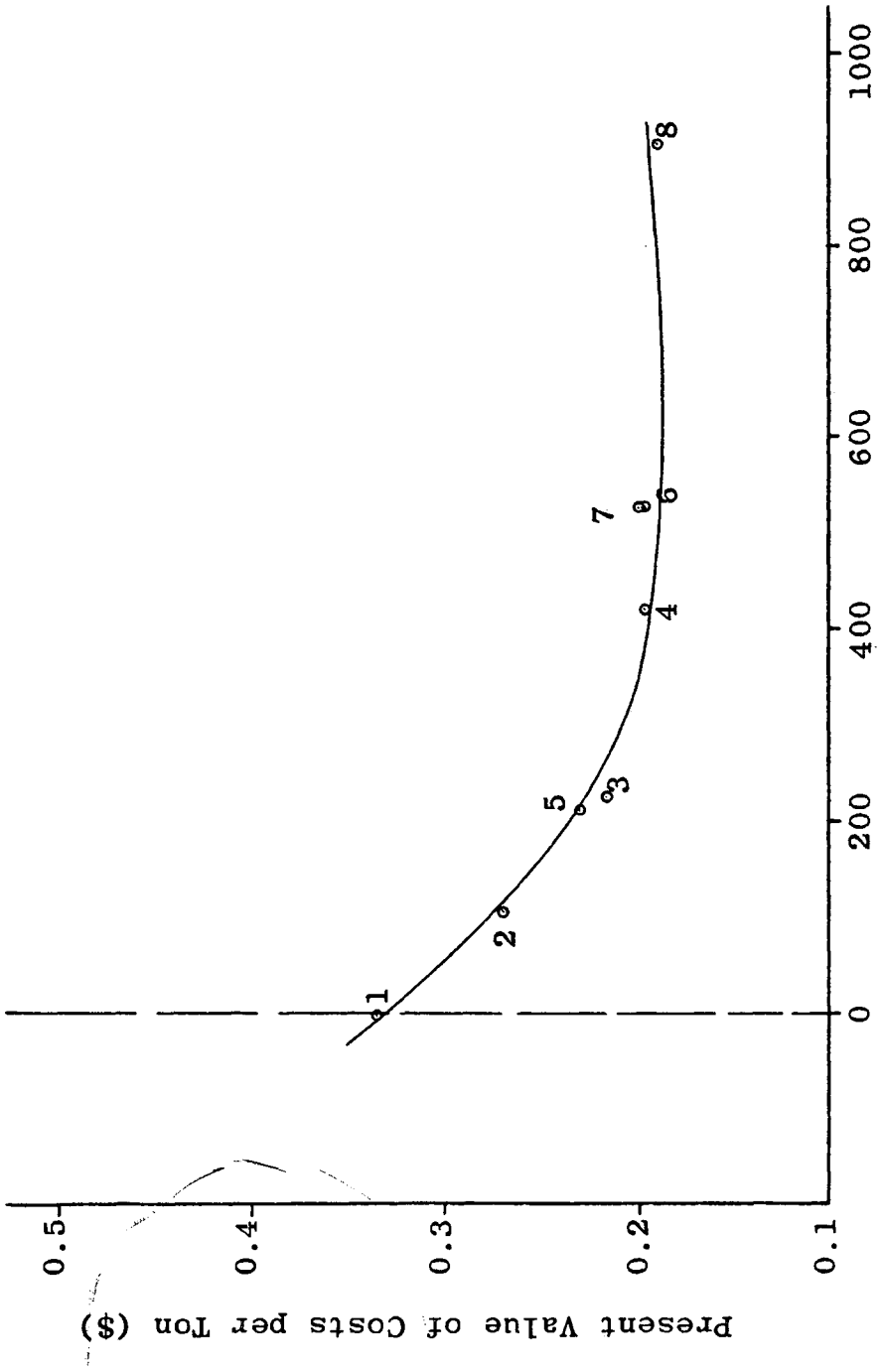


Fig. 25. Relationship of Area of Extra Intakes to Present Value of Costs per Ton.

TABLE XXIV

RANKING OF ALL CASES BY

PROFITABILITY INDEX

Fan 2A

12% interest

Point	Profitability Index
1	1.125
2	1.319
5	1.465
3	1.543
7	1.627
4	1.656
6	1.667
8	1.685

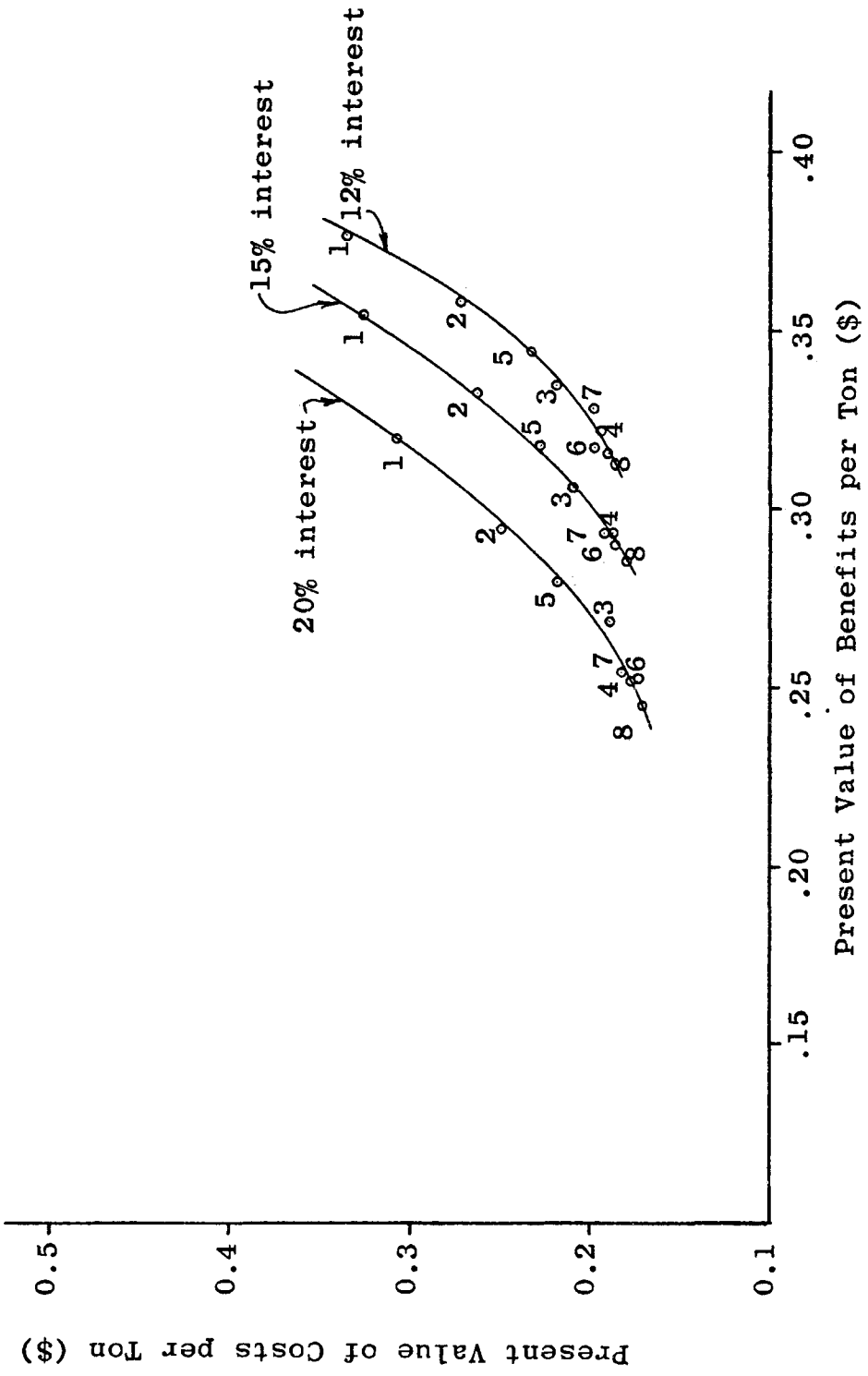


Fig. 26. Comparison of Cases 1, 2 and 4 for Fan 2A.

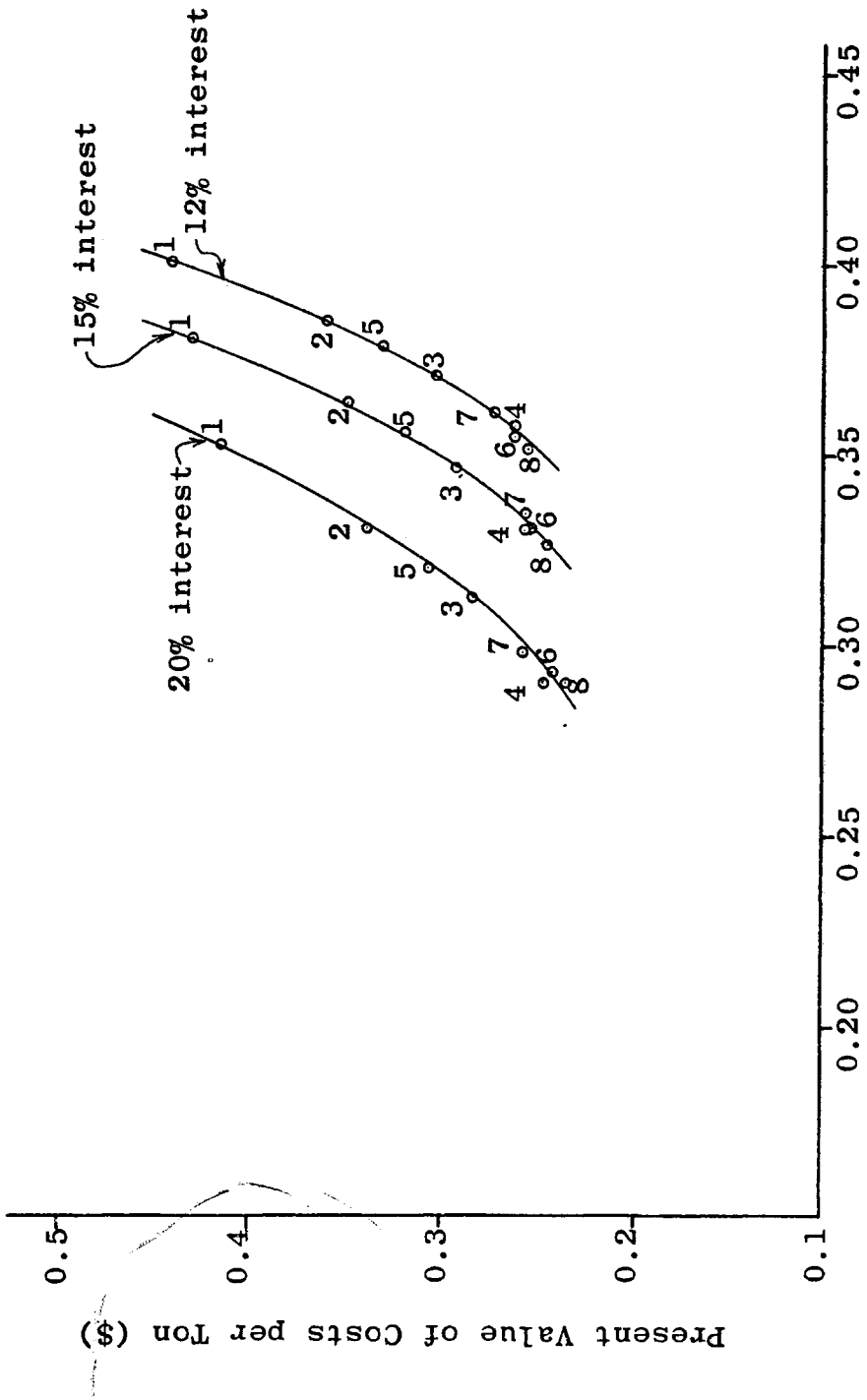


Fig. 27. Comparison of Cases 1, 2 and 4 for Fan 3.

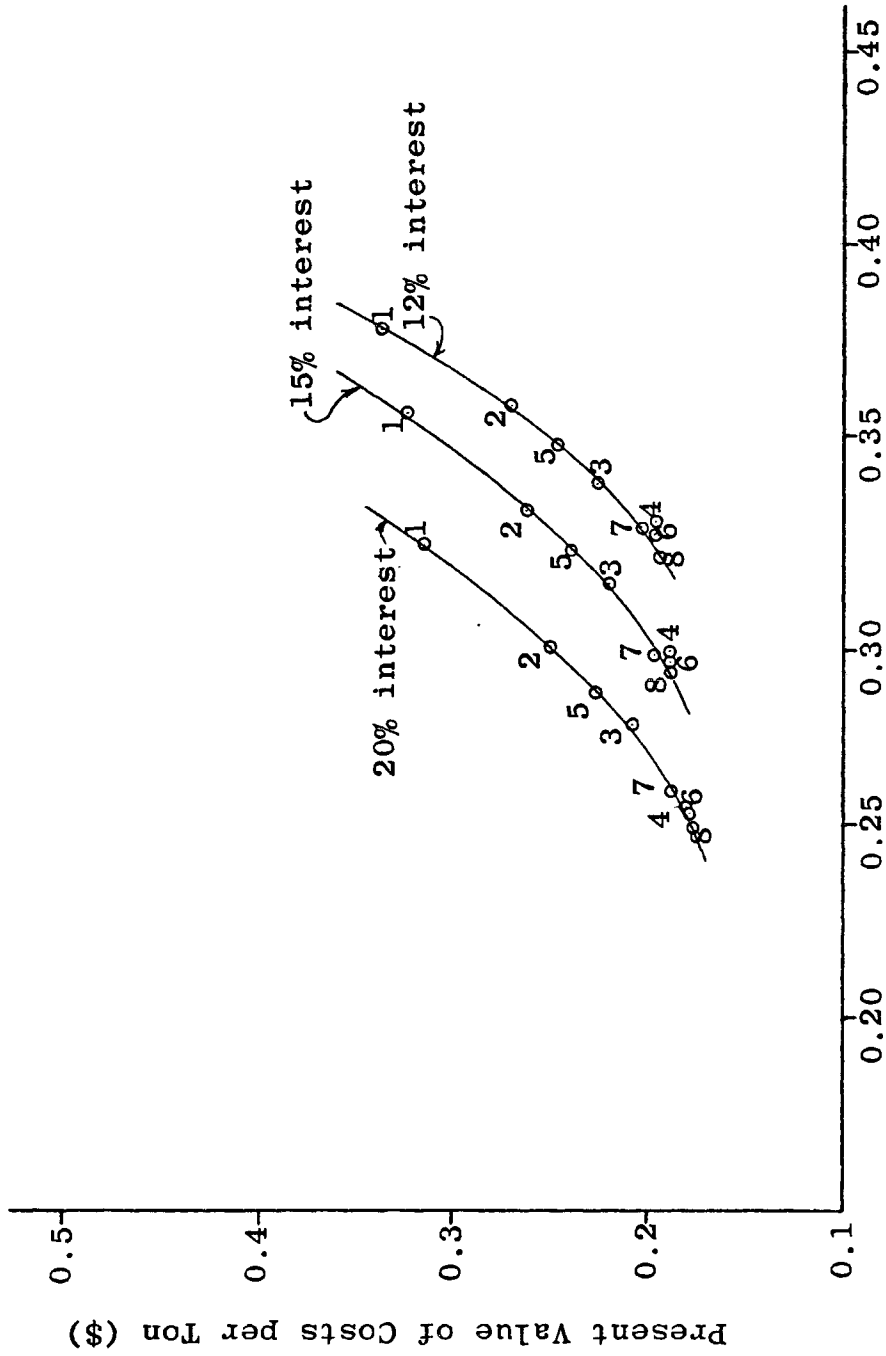


Fig. 28. Comparison of Cases 1, 2 and 4 for Fan 8A

points 4, 6, 7 and 8 are the better networks to use to ventilate an area with the conditions used in this study. The points 4, 6, 7 and 8 do not necessarily indicate a minimum condition, but they are the best choices of the shaft arrangements considered in this study.

Figures 29 through 31 show the relationships of each shaft arrangement by plots of net present value per ton to interest rate. The arrangements are shown to be mutually exclusive for all interest rates, though there is a slight convergence of the curves. Thus, for the interest rates used in this study, the shaft arrangement with the highest net present value at 12% interest is the choice for all interest rates to 20%.

For all three fans, the curves for points 4, 6 and 8 are very close in net present value per ton. The net present values per ton are so close that for all fans curves for points 4 and 8 coincide. For fans 2A and 3, the curves for point 6 also coincide with the curves for points 4 and 8.

The curve for point 7 nearly coincides with the curve for points 4 and 8, but has a lower net present value per ton and is eliminated as a final choice of intake shaft arrangements.

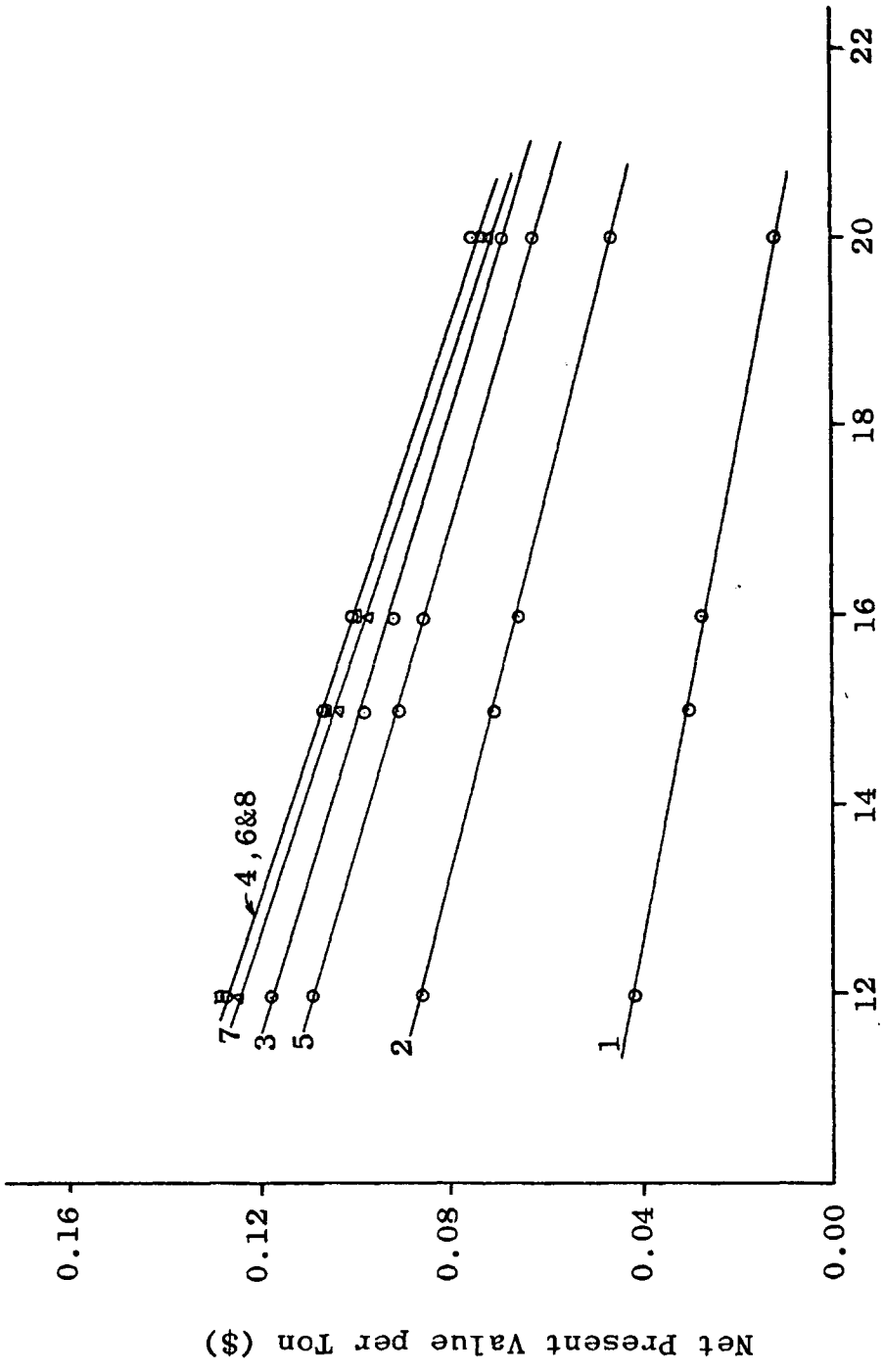


Fig. 29. Comparison of Net Present Values for Fan 2A.

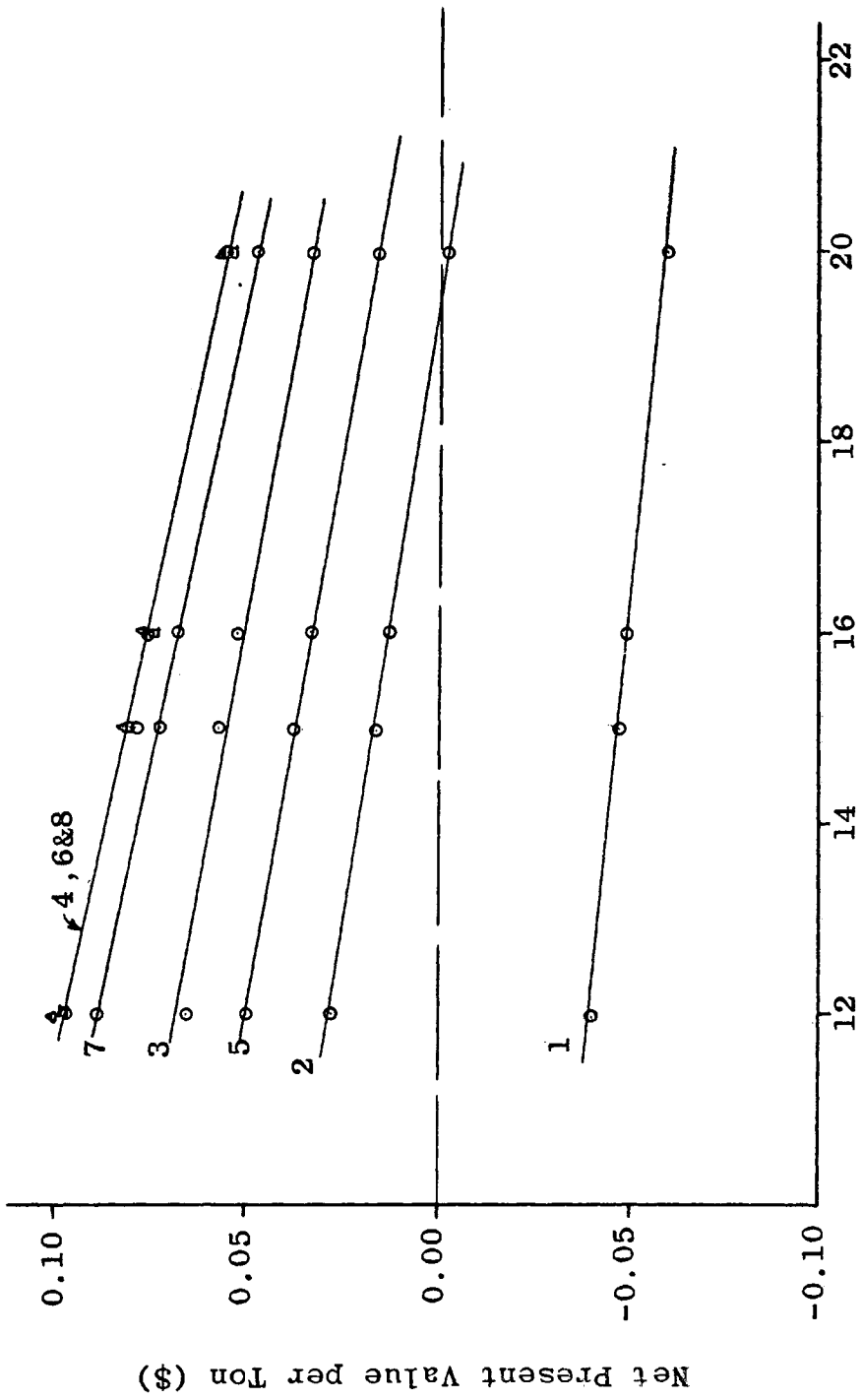


Fig. 30. Comparison of Net Present Values for Fan 3.

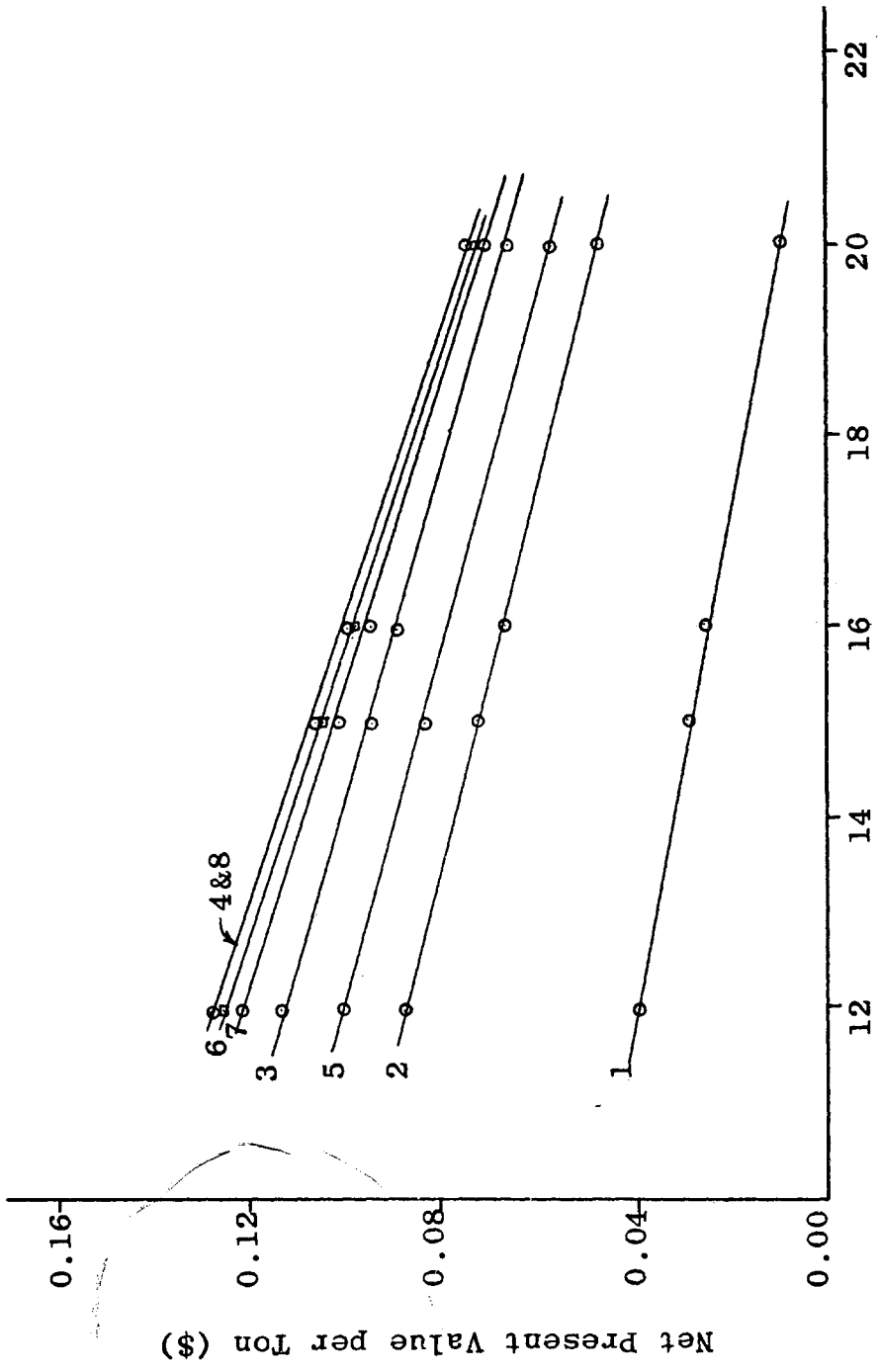


Fig. 31. Comparison of Net Present Values for Fan 8A

The net present values per ton for points 4, 6 and 8 determine which alternative to use for a given fan. Each fan has a different shaft arrangement with the highest net present value per ton. For fans 2A and 3, point 8 has the highest net present value per ton. For fan 8A, point 4 has the highest net present value per ton.

Point 4 is the arrangement with one 12-foot diameter intake added to Case 1, the base system. Point 8 is the arrangement with two 12-foot diameter intake shafts added to the main entries. When there is so little difference in net present values per ton at the given conditions, it is simpler to put in just one extra shaft (point 4) rather than two extra shafts (point 8).

Thus, even though point 8 has higher net present values per ton for fans 2A and 3, it may be preferable to use the single additional intake shaft as in the network for point 4.

CONCLUSIONS

Sensitivities of a mine ventilation network for a room and pillar mine have been tested in this thesis. The base condition includes the following physical and economic constraints:

1. Depth of mine and all shafts is 500 feet.
2. Friction factor for all entries is 60×10^{-10} and for all shafts is 80×10^{-10}.
3. Size of all entries is 5 feet by 20 feet in cross-section.
4. There are four intake and four return entries for the main entries, three intake and three return entries for submains and two intake and two return entries for butts.
5. Interest rates used are 12%, 15%, 16% and 20%.
6. Cost of power is $0.05 per kwh.
7. Cost to start a section is $250,000.
8. Production rate is 800 tons per day.
9. Percent recovery is 40%.
10. Profit is $0.50 per ton.

All the parameters listed above were varied except the cost to start a section. A net present value per ton

was calculated for each set of conditions and the differences in net present value per ton indicated the sensitivity of each parameter being tested. Present values of benefits were calculated as discrete cash flows at a discrete interest rate. Thus, all benefits were accrued annually and interest was charged annually.

The network was found to be most sensitive to number of entries, size of entries and friction factor when 70,000 cfm of air was supplied to each submain, thickness of seam, number of working sections and profit per ton. The network was least sensitive to size of the main shaft, depth of main shaft, production rate, power cost and interest rate. The other parameters tested had sensitivities between the parameters mentioned here.

The base case was also compared with the results of including additional intake air shafts in the network. When a 12-foot diameter intake shaft was added to the main entries, the net present value per ton was highest.

Thus, for the physical and economic conditions of the ventilation network used in this study, the best arrangement of shafts is to include a 12-ft diameter

intake shaft in the main entries. The type of fan is not critical to the network because the air supplied by the fan can be easily adjusted or a different fan can be substituted.

This thesis presents a guideline which could be used for evaluating a ventilation network during the planning stages of mine development. The procedure could also be used to evaluate the effects of adding extra intake shafts in the main entries.

SUGGESTIONS FOR FURTHER WORK

The two programs used for this thesis could be combined into one program which would do all the calculations in one step. The single program would combine the process of calculating length of an area, air supplied by the fan and economics of each system. The program would have one input and one output.

A ventilation program is a basic necessity of the system. The ventilation program used in this study could be altered to find the maximum condition of the branch or branches of the network which are necessary to determine the optimum length of the area. When the program determines the optimum, present values would be calculated and printed out. The ventilation program should also be able to handle changing air densities.

A study of an actual mine could be done to check the decision-making procedure described in this thesis. To be pertinent, however, a study of an operating mine would necessitate consideration of parameters other than those directly related to the mine ventilation system.

An examination of other factors involved in mine planning or revising a ventilation network is necessary

to the analysis. The benefits of small diameter intakes added to a ventilation system are only a part of any decision as to what shafts are needed for a given mine. To make and applicable decision about size and location of shafts, the ventilation system must be studied but other qualities of the proposed mine are needed to make the final decision.

Besides ventilation, some of the other conditions which should be considered when determining size and placement of shafts are haulage, transport of men, surface location of shafts and the economic alternatives.

APPENDIX A

VENTILATION PROGRAM

```
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 NVP(200),LENGTH
      DIMENSION NA(4200),JC(500),BRANCH(200),R(200),Q(200),RR(200),
     1 OUT(200),J1(100),J2(100),ME(100),SUMNVP(100),ND(40),DD(80),
     2 X(20),FX(20),W(6),Z(6),S(6),ALPHA(6),BETA(6),SIGMA2(6),C(40,6),
     3 P(7,20),FQ(40),HH(550),TITLE(10)
      EQUIVALENCE(NA,JC),(BRANCH,SUMNVP),(BRANCH(351),C),(Q,RR,OUT,
     1 NVP,X),(Q(21),FX),(Q(41),W),(Q(51),Z),(Q(61),S),(Q(71)
     2,SIGMA2),(Q(81),ALPHA),(Q(91),BETA),(Q(101),P)
      CALL IFILE(1,'VEN1')
10    READ(1,500) (TITLE(I),I=1,10)
      READ(1,501) NB,NJ,MAXJ,NF,MAXIT,NBWNVP,NFIXB,E
      IF(NB.GT.0) GO TO 12
      STOP
12    WRITE(5,610) (TITLE(I),I=1,10)
      NM=NB-NJ+1
      NFBPF=NFIXB+NF
      WRITE(5,502),NB,NJ,MAXJ,NM,NF,MAXIT,NBWNVP,NFIXB,E
      DO 15 I=1,NB
      READ(1,503) J1(I),J2(I),R(I),FF,HEIGHT,WIDTH,LENGTH, ENT
      BRANCH(I)=I
      IF(HEIGHT.LE.0.) GO TO 14
      T=HEIGHT*WIDTH*ENT
      R(I)=FF*(HEIGHT+WIDTH)*ENT*LENGTH/(2.6*T*T*T)
14    RR(I)=R(I)
15    CONTINUE
      IS=NFBPF+1
      IE=NB-1
      JE=IE
      L=0
      DO 18 I=IS,IE
      DO 17 J=IS,JE
      IF(RR(J+1)-RR(J)) 17,17,16
16    T=RR(J)
```

```
      RR(J)=RR(J+1)
      RR(J+1)=T
      T=BRANCH(J)
      BRANCH(J)=BRANCH(J+1)
      BRANCH(J+1)=T
      L=1
17    CONTINUE
      IF(L.LE.0) GO TO 19
18    JE=JE-1
19    CONTINUE
      DO 20 I=1,MAXJ
20    JC(I)=0
      I=NB+1
      L=0
      N=0
      DO 31 IJ=IS,NB
      I=I-1
      OUT(I)=0.
      K=BRANCH(I)
      JA=J1(K)
      JB=J2(K)
      IF(JC(JA)-JC(JB)) 26,28,21
21    IF(JC(JB)) 22,25,22
22    JJ=JC(JB)
      DO 24 J=1,MAXJ
      IF(JC(J).NE.JJ) GO TO 24
      JC(J)=JC(JA)
24    CONTINUE
      GO TO 31
25    JC(JB)=JC(JA)
      GO TO 31
26    IF(JC(JA).NE.0) GO TO 22
      JC(JA)=JC(JB)
```

```
      GO TO 31
28    IF(JC(JA).EQ.0) GO TO 30
      OUT(I)=1.
      N=N+1
      GO TO 31
30    L=L+1
      JC(JA)=L
      JC(JB)=L
31    CONTINUE
      IF(N+NFBPF-NM) 32,33,32
32    WRITE(5,505) N
      STOP
33    IF(NFBPF.LE.0) GO TO 36
      DO 35 I=1,NFBPF
35    OUT(I)=1.
36    JK=0
      JE=0
      L=0
      DO 54 I=1,NB
      IF(OUT(I).LE.0.) GO TO 54
      K=BRANCH(I)
      L=L+1
      JK=JK+1
      NA(JK)=K
      JA=J1(K)
      JB=J2(K)
      N=I+1
38    CONTINUE
      DO 45 J=N,NB
      IF(OUT(J).NE.0.) GO TO 45
      K=BRANCH(J)
      IF(JB.NE.J1(K)) GO TO 41
      JB=J2(K)
```

```
      JK=JK+1
      NA(JK)=K
      GO TO 43
41    IF(JB.NE.J2(K)) GO TO 45
      JB=J1(K)
      JK=JK+1
      NA(JK)=-K
43    IF(JB.EQ.JA) GO TO 51
      OUT(J)=-1
      GO TO 50
45    CONTINUE
      K=IABS(NA(JK))
      IF(NA(JK).LT.0) GO TO 47
      JB=J1(K)
      GO TO 48
47    JB=J2(K)
48    JK=JK-1
      IF(JK.GT.JE) GO TO 38
49    K=BRANCH(I)
      WRITE(5,525) K
      STOP
50    GO TO 38
51    CONTINUE
      DO 53 J=N,NB
      IF(OUT(J).GE.0.) GO TO 53
      OUT(J)=0.
53    CONTINUE
      ME(L)=JK
      JE=JK
54    CONTINUE
      DO 55 I=1,NB
55    NVP(I)=0.
      IF(NBWNVP)57,57,56
56    READ(1,506) (I,NVP(I),J=1,NBWNVP)
```

```
      WRITE(5,507)
57    CONTINUE
      JE=0
      DO 61 I=1,NM
      JS=JE+1
      JE=ME(I)
      SUMNVP(I)=0.
      DO 60 J=JS,JE
      K=IABS(NA(J))
      IF(NA(J).LT.0) GO TO 59
      SUMNVP(I)=SUMNVP(I)+NVP(K)
      GO TO 60
59    SUMNVP(I)=SUMNVP(I)-NVP(K)
60    CONTINUE
      L=JE-JS+1
61    CONTINUE
      IF(NFBPF.LE.0) GO TO 88
      IF(NF.LE.0) GO TO 287
      WRITE(5,513)
      DO 87 L=1,NF
      JJ=L+NFIXB
      READ(1,501) NP,KEY
      WRITE(5,514) L,J1(JJ),J2(JJ),KEY
      IF(KEY.GT.0) GO TO 85
      READ(1,515)(X(I),FX(I),I=1,NP)
      WRITE(5,516)(I,X(I),FX(I),I=1,NP)
      DD(JJ)=X(NP)
      IF(NP.GT.2) GO TO 970
      ND(L)=1
      N1=2
      IF(NP-1) 920,930,940
920   STOP
930   C(L,1)=FX(1)
      C(L,2)=0.
```

```
      GO TO 840
940   IF(X(1).NE.X(2)) GO TO 960
      STOP
960   C(L,1)=(FX(1)*X(2)-FX(2)*X(1))/(X(2)-X(1))
      C(L,2)=(FX(2)-FX(1))/(X(2)-X(1))
      GO TO 840
970   DSQ=0.
      DO 64 J=1,NP
      DSQ=DSQ+FX(J)*FX(J)
      P(1,J)=0.
64    P(2,J)=1.
      W(1)=NP
      BETA(1)=0.
      IF(NP.LT.7) GO TO 66
      N1=6
      GO TO 67
66    N1=NP-1
67    CONTINUE
      DO 73 I=1,N1
      K=I+1
      Z(I)=0.
      DO 68 J=1,NP
68    Z(I)=Z(I)+FX(J)*P(K,J)
      S(I)=Z(I)/W(I)
      DSQ=DSQ-S(I)*S(I)*W(I)
      FNP=NP-I
      SIGMA2(I)=DSQ/FNP
      IF(SIGMA2(I).LE.1.D-6) GO TO 78
      IF(I.GE.N1) GO TO 74
      ALPHA(I)=0.
      DO 71 J=1,NP
71    ALPHA(I)=ALPHA(I)+X(J)*P(K,J)*P(K,J)
      ALPHA(I)=ALPHA(I)/W(I)
      W(K)=0.
```

```
      DO 72 J=1,NP
      P(K+1,J)=(X(J)-ALPHA(I))*P(K,J)-BETA(I)*P(I,J)
72    W(K)=W(K)+P(K+1,J)*P(K+1,J)
73    BETA(K)=W(K)/W(I)
74    SMALL=SIGMA2(1)
      I=1
      DO 77 J=2,N1
      IF(SMALL.LE.SIGMA2(J)) GO TO 77
      I=J
      SMALL=SIGMA2(J)
77    CONTINUE
78    WRITE(5,517) SIGMA2(I)
      N1=I
      N=N1-1
      IF(N.GT.0) GO TO 79
      ND(L)=1
      C(L,1)=S(1)
      C(L,2)=0.
      GO TO 840
79    ND(L)=N
      DO 81 I=1,N1
      DO 80 J=1,I
80    P(I,J)=0.
81    P(I,I+1)=1.
      DO 82 J=1,N
82    P(1,J+2)=-P(1,J+1)*ALPHA(J)-P(1,J)*BETA(J)
      DO 83 I=2,N
      DO 83 J=I,N
83    P(I,J+2)=P(I-1,J+1)-P(I,J+1)*ALPHA(J)-P(I,J)*BETA(J)
      DO 84 I=1,N1
      C(L,I)=0.
      DO 84 J=I,N1
84    C(L,I)=C(L,I)+P(I,J+1)*S(J)
840   WRITE(5,518)(C(L,I),I=1,N1)
```

```
      GO TO 87
85    ND(L)=ND(KEY)
      N1=ND(KEY)+1
      DD(JJ)=DD(KEY+NFIXB)
      DO 86 J=1,N1
86    C(L,J)=C(KEY,J)
87    CONTINUE
287   IE=NFBPF
      IF(NFIXB.LE.0) GO TO 891
      READ(1,515)(DD(I),I=1,NFIXB)
      GO TO 891
88    DD(1)=100.
      IE=1
891   DO 90 I=1,NB
      Q(I)=0.
90    R(I)=R(I)*1.D-4
      JE=0
      DO 93 I=1,IE
      JS=JE+1
      JE=ME(I)
      DO 93 J=JS,JE
      K=IABS(NA(J))
      IF(NA(J).LT.0) GO TO 92
      Q(K)=Q(K)+DD(I)
      GO TO 93
92    Q(K)=Q(K)-DD(I)
93    CONTINUE
      IB=NFIXB+1
      DO 108 IT=1,MAXIT
      IF(NFIXB.LE.0) GO TO 820
      JE=ME(NFIXB)
      GO TO 830
820   JE=0
830   L=0
```

```
      SUMD=0.
      DO 107 I=IB,NM
      IM=I-NFIXB
      JS=JE+1
      JE=ME(I)
      SUMH=-SUMNVP(I)
      SUMDH=0.
      DHF=0.
      IF(NFBPF.LT.I) GO TO 98
94    N=ND(IM)
      FQ(IM)=C(IM,N+1)*Q(I)
      IF(N.LE.1) GO TO 97
      J=N
      DO 96 IJ=2,N
      FQ(IM)=(FQ(IM)+C(IM,J))*Q(I)
      FJ=J
      DHF=(DHF+FJ*C(IM,J+1))*Q(I)
96    J=J-1
97    FQ(IM)=FQ(IM)+C(IM,1)
      SUMH=SUMH-FQ(IM)
      DHF=DHF+C(IM,2)
98    DO 101 J=JS,JE
      K=IABS(NA(J))
      DH=R(K)*DABS(Q(K))
      H=DH*Q(K)
      SUMDH=SUMDH+DH
      IF(NA(J).LT.0) GO TO 100
      SUMH=SUMH+H
      GO TO 101
100   SUMH=SUMH-H
101   CONTINUE
      SUMDH=SUMDH+SUMDH-DHF
      IF(DABS(SUMDH).LE.1.D-20) GO TO 106
```

```
      D=-SUMH/SUMDH
      DO 105 J=JS,JE
      K=IABS(NA(J))
      IF(NA(J).LT.0) GO TO 104
      Q(K)=Q(K)+D
      GO TO 105
104   Q(K)=Q(K)-D
105   CONTINUE
      SUMD=SUMD+DABS(D)
      IF(DABS(D).LE.E) GO TO 107
106   L=1
107   CONTINUE
      IF(L.LE.0) GO TO 109
108   CONTINUE
      WRITE(5,519) IT,SUMD
      WRITE(5,520)
      GO TO 110
109   WRITE(5,519) IT,SUMD
110   WRITE(5,521)
      DO 111 I=1,NB
      HH(I)=R(I)*DABS(Q(I))*Q(I)
111   WRITE(5,522) I,J1(I),J2(I),R(I),Q(I),HH(I)
      IF(NFIXB.LE.0) GO TO 880
      WRITE(5,600)
      JE=0
      DO 870 I=1,NFIXB
      JS=JE+1
      JE=ME(I)
      SUMH=-SUMNVP(I)
      DO 860 J=JS,JE
      K=IABS(NA(J))
      IF(NA(J).LT.0) GO TO 856
      SUMH=SUMH+HH(K)
```

```
      GO TO 860
856   SUMH=SUMH-HH(K)
860   CONTINUE
870   WRITE(5,522) I,J1(I),J2(I),R(I),Q(I),SUMH
880   IF(NF.LE.0) GO TO 10
890   WRITE(5,523)
      WRITE(5,524)(I,J1(I+NFIXB),J2(I+NFIXB),Q(I+NFIXB),FQ(I),
     1 I=1,NF)
      GO TO 10
500   FORMAT(10A4)
501   FORMAT(7I,F)
502   FORMAT(//1H0,5X,2HNB,3X,2HNJ,2X,4HMAXJ,2X,2HNM,3X,2HNF,1X,
     1 5HMAXIT,1X,3HNVP,1X,4HFIXB,6X,1HE/2X,8I5,F9.4//1H0,2X,
     2 6HBRANCH,4X,2HJ1,2X,2HJ2,6X,2HR,7X,2HFF,5X,6HHEIGHT,2X,5HWIDTH,
     3 2X,6HLENGTH/)
503   FORMAT(2I,6F)
504   FORMAT(1X,I7,3X,2I4,F8.4,1X,5F8.1)
505   FORMAT(//27H*** NO. OF BASIC BRANCHES =,I4,5H + NF)
506   FORMAT(I,F)
507   FORMAT(1H1,4X,6HBRANCH,11X,4HNVP /)
508   FORMAT(I11,F14.7)
509   FORMAT(1H1,2X,4HMESH,5X,6HNO. OF,5X,6HSUMNVP/10X,8HBRANCHES/)
510   FORMAT(1I9,F15.7)
511   FORMAT(1X,10I6)
512   FORMAT(/5X,7HTOTAL =,I5)
513   FORMAT(1H1)
514   FORMAT(//2X,3HFAN,4X,2HJ1,4X,2HJ2,4X,3HKEY,5X,5HPOINT,6X,1HX,
     1 6X,2HFX//I7,3I6)
515   FORMAT(8F)
516   FORMAT(I35,2X,2F8.4)
517   FORMAT(/8X,8HSIGMA2= ,E14.7)
518   FORMAT(1H0,7X,'COEFFICIENTS'//2X,6F10.5)
```

```
519      FORMAT(1H1,I8,11H ITERATIONS,9X,6HSUMD =,E14.7)
520      FORMAT(10X,25H** D STILL GREATER THAN E)
521      FORMAT(///2X,6HBRANCH,4X,2HJ1,2X,2HJ2,6X,1HR,6X,1HQ,7X,1HH/)
522      FORMAT(I8,3X,2I4,4PF10.3,0PF10.4,0PF10.3)
523      FORMAT(1H1,3X,3HFAN,4X,2HJ1,3X,2HJ2,6X,1HQ,6X,2HFQ/)
524      FORMAT(I5,2X,2I5,F9.4,F10.7)
525      FORMAT(//27H*** NO MESH FOUND AT BRANCH,I4)
600      FORMAT(1H1,3X,'HEAD LOSS TO BE ADJ IN F-Q BRANCH'///4X,
     1 6HBRANCH,5X,2HJ1,2X,2HJ2,2X,1H5,6X,1HQ,5X,4HSUMH/)
610      FORMAT(1H1,4X,10A4)
         END
```

SAMPLE DATA FOR VENTILATION PROGRAM

```
 CASE_2
36,28,68,1,100,0,2,.05
55,56,0,0,0,0,0,0
65,66,0,0,0,0,0,0
17,1,0,80,20,18.42,500,1
1,10,0,80,20,18.42,500,1
10,11,0,60,5,20,11000,4
11,18,0,60,5,20,10700,4
18,12,0,60,5,20,500,4
1,18,1,6895,0,0,0,0,0,0
12,13,0,60,5,20,800,4
13,14,1,0,0,0,0,0
14,15,0,60,5,20,1000,4
15,16,0,60,5,20,11000,4
16,17,0,60,5,20,11000,4
11,16,33,0,0,0,0,0
12,50,0,60,5,20,2600,3
50,51,0,60,5,20,2300,3
51,52,0,60,5,20,400,2
52,53,0,60,5,20,400,2
53,54,1,0,0,0,0,0
54,58,0,60,5,20,400,2
58,55,0,60,5,20,400,2
56,57,0,60,5,20,2600,3
57,15,0,60,5,20,2400,3
50,57,16,0,0,0,0,0
52,58,7,0,0,0,0,0
12,62,0,60,5,20,2400,3
60,61,0,60,5,20,2400,3
61,62,0,60,5,20,400,2
62,63,0,60,5,20,400,2
63,64,1,0,0,0,0,0
64,68,0,60,5,20,400,2
68,65,0,60,5,20,400,2
66,67,0,60,5,20,2600,3
67,15,0,60,5,20,2600,3
60,67,16,0,0,0,0,0
62,68,7,0,0,0,0,0
4,0
180,7,2,200,6.35,220,5,3,240,4
80,80
```

SAMPLE OUTPUT FROM VENTILATION PROGRAM

CASE 2

NB	NJ	MAXJ	NM	NF	MAXIT	NVP	FIXB	E
36	28	68	9	1	100	0	2	0.0500

FAN	J1	J2	KEY	POINT	X	FX
	1	17	1	0		
1	180.0000	7.2000				
2	200.0000	6.3500				
3	220.0000	5.3000				
4	240.0000	4.0000				

9 ITERATIONS SUMD = 0.4529483E-01

BRANCH	J1	J2	R	Q	H
1	55	56	0000.000	80.0000	0.000
2	65	66	0000.000	80.0000	0.000
3	17	1	0.012	231.3521	0.063
4	1	10	0.012	84.7987	0.009
8	1	18	0.200	146.5534	0.430
14	11	16	33.000	25.2737	2.108
15	12	50	0.167	80.8241	0.109
26	12	60	0.154	80.8098	0.100

FAN	J1	J2	Q	FQ
1	17	1	231.3521	4.5876728

APPENDIX B

PRESENT VALUE PROGRAM

PRESENT VALUE PROGRAM

```
      DIMENSION TITLE(5),Q(35),H(35),L(4,35),FNCST(35),
     1SH(4,35),LIF(35),EFF(35),COST(35),CPV(35),XINT(4),
     2PV(4,35),SEC(35),PVT(35),TONS(35),SML(35),NS(35),
     3CSEC(4,35),HT(35),WID1(35),ENT(35),ATON(35),
     4ANCST(35)
      REAL L,LIF
5000  FORMAT(5A4)
6001  FORMAT(1H ,4X,'PRESENT VALUE',4X,' PV POWER',4X,
     1'PV/TON')
6002  FORMAT(1H1,I4,3F13.2)
6004  FORMAT(1H ,'INT =',F4.2)
6005  FORMAT(1H ,'POWER =',F4.2)
6007  FORMAT(1H ,'PROD =' ,F5.0)
6010  FORMAT(1H ,I4,2F15.2,F12.4)
6012  FORMAT(1H ,'PCREC =',F4.2)
6020  FORMAT(1H ,I3,F12.2)
6022  FORMAT(1H0,7X,'OPER COST',3X,'TOTAL TONS',6X,
     1'LIFE')
      DAYS = 220.
      PCREC = .4
      XINT(1) = .12
      XINT(2) = .15
```

```
      XINT(3) = .16
      XINT(4) = .20
      WID = 10000.
      POWER = .05
      PROD = 800.
      TFAC = 1800.
C READ DATA
      READ(1,5000)(TITLE(I),I=1,5)
      WRITE(6,5000)(TITLE(I),I=1,5)
      READ(1,) NF
      DO 10 I = 1,NF
      READ(1,) NS(I),SEC(I),Q(I),H(I),FNCST(I),EFF(I),
     1HT(I),WID1(I),ENT(I)
      SML(I) = 0.0
      IF(NS(I).EQ.1) GO TO 9
      NS1 = NS(I)
      DO 8 J = 1,NS1
      READ(1,) L(J,I),SH(J,I)
      SML(I) = SML(I) + L(J,K)
8     CONTINUE
      GO TO 10
9     READ(1,) L(1,I),SH(1,I)
      SML(I) = L(1,I)
10    CONTINUE
```

```
      WRITE(6,6007) PROD
C  DETERMINE PRESENT VALUE OF STARTING SECTIONS
      SCOS = 250000.
      DIST = 1000.
      XCUT = 200.
      PIL = .15
      DO 50 N = 1,4
      DO 40 I = 1,NF
      ARM = ENT(I)*HT(I)*WID1(I)*DIST
      ARX = (ENT(I) - 1.)*HT(I)*PIL*DIST/XCUT
      TAR = (ARM + ARX)*TFAC/43560.
      XL1 = TAR /(PROD*DAYS*2.)
      PS = SCOS*2.
      XL = XL1
      S = 2.
20    IF(S.GT.SEC(I)) GO TO 30
      PS = PS + (SCOS*SP)/((1. + XINT(N))**XL)
      CSEC(N,I) = PS
40    CONTINUE
50    CONTINUE
C  BEGIN SENSITIVITY LOOPS, CALCULATE PRESENT VALUE
C  OF COSTS
      DO 500 L = 1,3
      WRITE(6,6007) PROD
      DO 400 L1 = 1,3
```

```
      WRITE(6,6012) PCREC
      DO 300 M = 1,3
      WRITE(6,6005) POWER
      DO 200 N = 1,4
      WRITE(6,6004) XINT(N)
      WRITE(6,6022)
      DO 100 I = 1,NF
      TPD = SEC(I)*PROD*DAYS
      T = WID*HT(I)*PCREC*TFAC/43560.
      TONS(I) = SML(I)*T
      LIF(I) = TONS(I)/TPD
      RPF = ((1.+XINT(N))**20.-1.)/(XINT(N)*(1.+XINT(N))
     1**20.)
      RP1 = ((1.+XINT(N))**LIF(I)-1.)/(XINT(N)*(1.+XINT
     1(N))**LIF(I))
      ATON(I) = TONS(I)/LIF(I)
      PVM = FNCST(I)*0.05*RPF
      COST(I) = H(I)*Q(I)*365.*24.*POWER*1000./(6350.*
     1EFF(I))
      CPV(I) = COST(I)*RPF
      CP = SH(1,I)
      IF(NS(I).EQ.1) GO TO 95
      N1 = NS(I) - 1
```

```
      XLIF = 0.0
      DO 90 J = 1,N1
      TON = L(J,I)*T/TPD
      XLIF = TON + XLIF
      CP = CP + SH(J+1,I)/((1.+XINT(N))**XLIF)
90    CONTINUE
95    PV(N,I) = PVM+CP+CPV(I)+FNCST(I)+CSEC(N,I)
      PVT(I) = PV(N,I)/TONS(I)
      PB1 = TPD * 0.5 /TONS(I)
      PVB = PB1*RP1
      WRITE(6,8000( I,PB1,PVB
      AM = AM + 1.
8000  FORMAT(1H ,I5,2F8.4)
100   CONTINUE
      IF(N.EQ.1) WRITE(6,6002)(I,COST(I),TONS(I),LIF(I),
     1I = 1,NF)
      WRITE(6,6001)
      WRITE(6,6010) (I,PV(N,I),CPV(I),PVT(I),I =1,NF)
200   CONTINUE
      POWER = POWER + 0.01
300   CONTINUE
      POWER = 0.05
      PCREC = PCREC + 0.1
400   CONTINUE
```

```
      PCREC = 0.4
      PROD = PROD + 100.
500   CONTINUE
      END
```

SAMPLE DATA FOR PRESENT VALUE PROGRAM

```
CASE 2
9
2, 16, 229.885, 4.82, 6180, .75, 5, 20, 9
16000, 687 000
1500, 73130
2, 16, 225.861, 3.48, 7551, .75, 5, 20, 9
11000, 687 000
1500, 73130
2, 16, 229.456, 4.71, 7360, .75, 5, 20, 9
16000, 687 000
1500, 73130
2, 16, 229.243, 4.84, 6180, .75, 5, 20, 9
20500, 687 000
1500, 121445
2, 16, 226.409, 3.44, 7551, .75, 5, 20, 9
13500, 687 000
1500, 121445
2, 16, 229.861, 4.68, 7360, .75, 5, 20, 9
19500, 687 000
1500, 121445
2, 16, 230.119, 4.81, 6180, .75, 5, 20, 9
23100, 687 000
1500, 166261
2, 16, 226.196, 3.46, 7551, .75, 5, 20, 9
15900, 687 000
1500, 166261
2, 16, 229.267, 4.72, 7360, .75, 5, 20, 9
22800, 687 000
1500, 166261
```

SAMPLE OUTPUT FROM PRESENT VALUE PROGRAM

CASE 2

FRLD = 8[illegible]

FC REC = .43

POWER = .25

INT = .12

	OVER COST	TOTAL TONS	TONS/YR	LIFE		
1	1[illegible]5.31	14462679.22	2816200.00	5.14		
2	72[illegible]6.96	10[illegible]78.58	2816200.00	3.67		
3	99[illegible]3.93	14[illegible]89.96	2816200.00	5.14		
4	87[illegible]2.38	18[illegible]8.30	2816200.00	6.46		
5	71629.39	12396[illegible]4.30	2816200.00	4.40		
6	99[illegible]5.07	17[illegible]72.98	2816200.00	6.16		
7	131707.40	29[illegible]78.58	2816200.00	7.22		
8	71275.86	14[illegible]5.36	2816200.00	5.11		
9	99[illegible]2.82	20[illegible]4.88	2816200.00	7.13		
	PRESENT VAL	ANNUAL COST	PV POWER	PV/TON		
1	3926241.72	525613.68	761175.94	0.2715		
2	3718462.91	497267.73	539942.94	0.3596		
3	3[illegible]3.13	523319.16	742416.63	0.2703		
4	3[illegible]527.41	528222.43	762199.77	0.2170		
5	3753342.16	502[illegible]6.93	535031.69	0.3014		
6	3[illegible]515.22	525[illegible]0.13	736989.93	0.2262		
7	3[illegible]395.47	5[illegible]79.54	760369.92	0.1948		
8	3758[illegible]6.31	5[illegible]5.13	537636.87	0.2614		
9	3[illegible]799.59	5231[illegible]4.94	743381.87	0.1964		

REFERENCES

1. Federal Coal Mine Health and Safety Act of 1969 P.L. 91-173, U.S.Department of the Interior, Bureau of Mines, December 30, 1969, 101 p.

2. Hartman, Howard L., Mine Ventilation and air conditioning, The Ronald Press Company, New York, 1961, 398 p.

3. Kalasky, John D., Ventilation of deep coal mines, Mining Cong. Jour., v. 58, n. 9, September 1972.

4. Kingery, D.S., Introduction to mine ventilating principles and practices, Bureau of Mines Bulletin 589, 1960, 54 p.

5. Nair, Oscar B., The optimal location of mine shafts: an out-of-kilter technique for the solution of the fixed-charge problem, Colorado School of Mines Master's Thesis T-1468, 108 p.

6. Stermole, Franklin J., Engineering economy and investment decision methods, Colorado School of Mines, 1972, 331 p.

7. Wang, Y. J. and Saperstein, L. W., Computer-aided solution of complex ventilation networks, Society of Mining Engineers Transactions, v. 247, September 1970.